Language Series

# The BYTE Book Of Pascal

Blaise W. Liffick, Editor

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# INTRODUCTION

This book is part of the "Language Series" of BYTE Books. It is a collection of the best articles from past issues of BYTE magazine, the leading technical journal in the microcomputer field. The language under discussion is a relatively new computer programming language, Pascal. Until recently, Pascal has only enjoyed a large following in the academic community, and only more recently has it been practical to use this language with microcomputers. But the curious thing about Pascal is its ability to win nearly instant converts; so, while Pascal may be one of the newest computer languages, especially in the field of microcomputers, it is also one of the fastest growing in use and acceptance.

The purpose of this book is twofold. First, for those uninitiated, the articles contained in this book can serve as a general introduction to Pascal, providing the background information necessary for a potential user. The **Comments** section itself is a general discussion of the properties, merits, and applicability of Pascal. It includes reprints from the "Languages Forum" of BYTE magazine, an ongoing dialogue among the magazine's knowledgeable readers. The Forum is intended as an interactive dialogue about the design and implementation of languages for personal computing. In addition, an editorial by Carl Helmers, one of the industry's leading proponents of Pascal, rounds this section out as a beginning point for those unfamiliar with the language.

Second, for those requiring a more in depth study of the merits of the language and its possible implementation, there are two sections, **About the Language** and **Applications**.

**About the Language** provides insights into the usefulness of Pascal by comparing it to BASIC and COBOL. Also, a detailed look at some possible implementations of the language helps define the scope of the impact on the industry. This includes listings of a Pascal to p-code compiler written in both Pascal and BASIC, and two listings in the appendices: one a p-code to 8080 assembly language conversion program in BASIC; the second a "tiny" Pascal compiler and p-code interpreter written in 8080 assembly language.

The final section is **Applications** and, as the name implies, includes several application and system programs written in Pascal. For general applications there is an automatic metric conversion program, nontrivial implementation of a chess program, and an implementation of a print utility program. In the area of system software there is the choice of two language implementations: one is a minimum implementation of a language, written in less than 256 words (it has surprising usefulness); the other is an APL interpreter.

So, this book provides not only a general introduction to the Pascal language, but is also a tremendous resource for software: two versions of a Pascal compiler, one written in BASIC and the other in 8080 assembly language; a p-code interpreter written in both Pascal and 8080 asembly language; a chess playing program; and an APL interpreter.

Finally, a note about how the articles in this book were updated. We have been very careful to make corrections to articles where an error has been made in the original article. However, because many of these articles are reprinted from back issues of BYTE magazine, some of the information contained in them is out of date. This information is flagged in the form of footnotes within the article, and includes such items as page references and the availablity of UCSD Pascal. All footnotes throughout this book can be taken as current as of 1 July 1979.

*Blaise W. Liffick*
*Editor*

# Consistency — or a Lack Thereof . . .

**Notes by C Helmers**

*Readers will note a lack of consistency in the typography of various articles on Pascal.*

*One area of questionable typography is a bit nebulous and less subject to editorial fiat when "camera ready" type is received from authors: the style of representation of Pascal program listings. The ideal style is of course that used by Niklaus Wirth in his book* Algorithms + Data Structures = Programs, *published by Prentice-Hall in 1976. This style uses* **bold face type** *in lowercase for representation of the Pascal language keywords. It uses italics for the representation of specific variable names, procedure names and literal values which are part of the program. In articles by authors Ken Bowles (page 51), Charles Forsyth and Randall Howard (page 33), and Allan Schwartz (page 41) this notation was used. But in two of these cases, the authors supplied camera ready typeset copy along with the articles involved, in order to minimize potential errors due to keystroking. Since two of these were typeset at BYTE, and the other two were typeset with different type specifications on different machines, there is naturally a different aesthetic flavor to the listings in these articles. A close variant of this form is seen in the listings of David Mundie's article (page 7) where bold fact type and normal type are mixed in the listing.*

*There is yet another variation on the graphics used to represent Pascal programs, provided by the listings accompanying Stephen Alpert's article (page 27). Here, the camera ready listing was supplied by the author as printed on an uppercase line printer, so keywords are indistinguishable from program details on the basis of typography alone.*

*What can we conclude about this inconsistency? Our goal at BYTE is to asymptotically approach the notation of Pascal programs in the bold face and italic form whenever we do the actual typesetting of a listing. The italic and the bold face typography provides an excellent contrast to normal type when elements of a program are mentioned within text. But when a manuscript comes with a usable camera ready listing of a Pascal program, such details of aesthetics must take second place to the goal of minimizing errors of transcription: it is far better to use a camera ready image derived from a machine produced listing than to key in a program manually in order to create a typeset form of the listing. . . .* **CH**

# Comments

# UCSD PASCAL:

## A (Nearly) Machine Independent Software System (for Microcomputers and Minicomputers)

Kenneth L Bowles

### Overview

This article describes a complete interactive software system which can operate virtually without change on many different microcomputers and minicomputers. Because the semiconductor industry is evolving new equipment very fast, it is becoming a practical necessity to have machine independent software to prevent rapid obsolescence of large application programs. The software described here has been developed at the University of California San Diego (UCSD), and is available to anyone for a $200 subscription fee. This article presents an appeal to readers of BYTE for help to bring about a true community-wide software system for business, educational and other professional users of small computer systems. Help is needed from the user community, since the manufacturers have so far avoided standardizing software except as regards some aspects of programming languages. For single user microcomputers, it appears to be far more practical to *standardize the entire software system* than the language processor alone!

### The Software System

UCSD Pascal is a complete interactive software system for small computers, yet it offers many features normally found only on medium and large scale machines. It is designed to operate, with minimal adaptation, on most microcomputers or minicomputers based on 8 bit bytes or 16 bit words. Supported versions are now available for use on machines based on the Digital Equipment LSI-11 or other PDP-11 processors, and on the 8080 and Z-80 microprocessors. Having first been sent to users in August 1977, the system is in use on approximately 60 mainframes using these processors (as of mid February 1978), and the list of both users and processors has started to grow rapidly. Versions not yet supported by the Project are operating, or nearly operating, on four other processors (General Automation 440, Univac V75, Nanodata QM-1, National Semiconductor PACE). The UCSD Pascal Project is discussing arrangements with various manufacturers whereby supported versions can be released for most other popular microprocessors, and additional inquiries would be welcomed.

The system is written almost entirely in the Pascal programming language, extended for system programming and for disk based interactive applications. Far more than a simple *compiler* for Pascal, it should be viewed as a complete and fully integrated system which is self-maintaining, and generally independent of software from any other source. The system operates in a small pseudomachine (interpreter) which can be written in the native machine language of conventional processors, or can be microprogrammed on machines which provide that capability. The object code processed by the Pascal pseudomachine is compressed relative to conventional object code, and consumes roughly one third to one half as much space as the native object code of most present day processors. A feature to be implemented soon will allow mixing Pascal pseudocode routines, for efficient use of memory, with native code routines, for fast processing.

The system is the product of a growing project team, and is evolving rapidly in an upward compatible way. As of early 1978, the system represents the equivalent of about 15 full-time years of programming and design effort. Major components of the system currently being distributed include the following:

- *Single user operating system.*
- *Pascal Compiler.* Standard Pascal plus extensions for strings, disk files, graphics, system programming (business oriented extensions are planned).
- *Editors.* High performance screen oriented editor for program development and word processing, line oriented editor for hard copy devices.
- *File Manager.* General purpose utility for maintaining a library of disk files (usually floppy disks).
- *Debugger.* Single statement and breakpoint processing, access to program variables.
- *Utilities.* Programs for printing, communicating, accessing disks written under DEC's RT11 system, diagnosing disk faults, desk calculator, etc...
- *BASIC language compiler.* Implemented for those who insist on using BASIC, but may wish to write powerful subroutines in Pascal. (The compiler works, but subroutine binding is not yet ready.)

Major components now operating, but not quite ready for general distribution, include the following:

- *CAI Package.* Adaptation of the major Computer Assisted Instruction package developed at University of California Irvine; includes automated materials for an introductory Pascal programming course.
- *Assemblers.* For the PDP-11, 8080 and Z-80, these are written in Pascal for machine independence, but generate native code for those processors.
- *TREEMETA.* A metacompiler developed at UC Irvine.

## The UCSD Pascal Project

The Project is one of the principal activities of the Institute for Information Systems, an embryonic "organized research unit" concerned with interdisciplinary studies, and with related instructional and public service activities. The main objectives of the Project include the following:

- *Machine Independence.* To foster the widespread use of machine independent software systems, particularly for small computers, as a means to avoid software obsolescence. A major premise of the project is that applications software can best be made truly portable by making *the entire operating system and support software* portable to a new processor at the cost of only a small effort (eventually: one to three programmer months; currently: about six months).
- *Pascal.* To promote the widespread use of standard Pascal, and standardized extensions, as (the basis of) a general purpose programming language, both for writing system programs such as operating systems and compilers, and for applications software in education, research and business data processing.
- *Software Exchange.* To foster the development of a national or international marketplace within which authors of computer based course materials, and other applications software, may receive reasonable *royalties* to compensate them for their work. As an initial step, the Project will operate a Software/Courseware Exchange, using Tele-Mail techniques, for users of the UCSD Pascal Software System.
- *Mass Education.* To demonstrate that it is practical to improve the quality of mass education at the college level (and adult training in technical topics), while simultaneously reducing costs, through the use of microcomputer based course materials.
- *Research and Development.* To provide facilities, a team working environment above critical size, and salary support for students and faculty members who wish to conduct research or development projects in software engineering and many related fields of study.

## Hardware Configuration

The UCSD Pascal system has been designed to run as a single user interactive system with superior response characteristics when one or more floppy disks are used for secondary storage. Wherever possible, single character commands are used, and prompting messages remind the user of the significance of the various commands that are available in different contexts. While the system has proven that machine independence of a complex software system is practical, there are of course practical limits to the range of characteristics that can be accommodated on the host machine. The major characteristics of a typical system needed to run UCSD

Pascal include the following:

- *Main memory.* 56 K bytes (48 K will do, but only for compiling small programs).
- *Word Size.* 8 bit bytes, 16 bit words (hardware or simulated).
- *Secondary Storage.* Standard 8 inch floppy disk (the major system program files occupy roughly 70 K bytes).
- *Console Display.* 9600 bps ASCII terminal with x-y cursor addressing works best (slower CRTs or hard copy terminals can be handled, but less effectively).
- *Keyboard.* Uses ASCII keys for CR, ESC, ETX, BS, DEL and four positioning arrows (up, down, left, right).

In addition, the system is being used to drive a variety of printers such as the Diablo HYTYPE and Printronix 300, and for communicating via standard asynchronous lines.

### Compatibility with Other Software Systems

In Project discussions with manufacturers of computers, on which the UCSD Pascal System might potentially be run, the most frequently asked question is: "How much effort will it take to adapt Pascal to run under my software system?" This question is understandable in view of the approach generally taken by the computer industry when a new language is to be installed on a machine produced in quantity. Unfortunately, this question misses the main point the Project is trying to make regarding transportable software. The effort needed to convert the Pascal compiler to run under the operating system of manufacturer "X" will generally be far greater than the effort to make the entire UCSD Pascal system run on that manufacturer's hardware. In the interest of promoting software transportability, the Project will generally not agree to adapt just the compiler to run under another operating system.

### Pascal Language Extensions

Like many others who use Pascal as the basis for writing large system programs, the Project has found it necessary to extend the language. The most notable extensions have to do with strings of characters, for natural reading and writing from and to interactive files, and for tools needed in writing the software. A concerted effort has been made to implement all of the "standard" Pascal language as defined in *Pascal User Manual and Report*, by Kathleen Jensen and Niklaus Wirth (Springer Verlag, New York and Heidelberg, 1975). (However, UCSD Pascal still lacks the ability to allow procedure and function names to be passed as parameters.) The Project is making an effort to serve as coordinator among several large industrial firms which are preparing to use extended versions of Pascal for major programming projects. It is hoped that a consensus will emerge from this effort on extensions to the language for system programming. UCSD Pascal implements integers in two's complement form in 16 bit words, and real numbers in a 32 bit field. Since neither form is suitable for large integers or for business applications, it is planned to add the facility to handle fixed decimal numbers whose precision may be declared by the programmer.

### Speed of Execution

Although the system is entirely interpretive, as currently implemented, execution speed is fast enough to permit highly interactive programs to be run on microcomputers. For example, compilation speed ranges from 600 to 700 lines per minute on the DEC LSI-11, or on an 8085 with a 3 MHz clock.

### Availability

Copies of the system may be obtained by writing to UCSD Pascal Project, Maildrop C-021, La Jolla CA 92093. The system is available at a subscription fee of $200, made payable to "Regents of the University of California," which pays for materials, handling, and a limited amount of direct assistance to users. Those who wish to order the system should send details describing the system on which they wish it to run, or should request an order blank from the project. The system is copyrighted, but rights are granted to educational institutions and to bonafide computer clubs to make additional copies for their own noncommercial uses. A copy of the latest package of printed user manuals (about 250 pages) is available at a charge of $15, again made payable to the Regents of the University of California.

Though plans are in motion to convert the system to run on many different processors and configurations, the only systems currently supported use LSI-11, 8080 or Z-80 microprocessors with at least 48 K bytes of main memory, and IBM 3740 compatible standard floppy disk drive(s). For 8080 and Z-80 users, the method of adapting the system to run on new hardware is similar to that used by Digital Research Inc in distributing the CP/M operating system; and the Project will distribute a conversion package similar to theirs. Versions of the sys-

*As of this writing (1 July 1979), SofTech Microsystems Inc (94 Black Mountain Rd, Building 3, San Diego CA 92126) is the sole licensee of the UCSD Pascal system. Questions about prices and availability of the system can be directed to the above address.*

*Also, note that* UCSD Pascal *is a trademark of the Regents of the University of California.*

tem for other microprocessors are not likely to be ready for release until October 1978 at the earliest. Release on floppy disks other than those compatible with the 3740 format will depend upon availability of hardware to the Project.

In addition to the main software system, educational materials are available separately for an introductory course on problem solving and programming using Pascal. A textbook *(Microcomputer) Problem Solving Using Pascal* is available from Springer Verlag Publishers, 175 Fifth Av, New York NY 10010 ($9.80). The Project can supply a set of automated quizzes designed for use with the textbook in a self-paced course of study.

### Help from the User Community

Readers can help by letting their favorite hardware vendors know that they want UCSD Pascal to be available in machine independent form. The Project has noted an increasing number of manufacturers who report that customers are requesting Pascal, and this has a real influence on their business decisions. Readers can also help by joining the international Pascal Users' Group (send $4 c/o Andy Mickel, 227 EX, 208 SE Union St, University of Minnesota, Minneapolis MN 55455) and pressing PUG to establish a technical board to oversee UCSD Pascal as a community project.■

**Note on the Pascal User's Group**

*As of July 1, 1979 the Pascal User's Group (PUG) has over 3300 members in 47 countries. Those interested in joining can contact Andy Mickel at the University of Minnesota Computer Center, 227 Ex Engr, University of Minnesota, Minneapolis MN 55455, (612) 376-7290. The* Pascal Newsletter *is published four times a year on a July to June schedule, with a subscription fee of $6 per year. All issues for the current year are sent with a new subscription, and back issues are available.*

# In Praise of Pascal

David A Mundie

As has been pointed out in these pages before, personal computing will never achieve its full potential as long as our state of the art machines are hobbled down with a language as far from state of the art as BASIC is. Some have argued for designing a special high level language for microprocessors, but I personally fail to see why we don't just implement Pascal and be done with it. I would like to look briefly at the language itself and try to explain why it seems the logical choice to me.

I am an applications programmer with no theoretical interest in computing whatsoever. What I like about Pascal is not the theory of its design, though that seems sound enough, but rather the fact that it lets me formulate my problems in my own terms. In Pascal more than in any other language I know, I can remain on the abstract, algorithmic level where, as a human being, I function best. Because of this pragmatic bias, much of what follows will be an informal discussion appealing to the reader's intuitions rather than a technical demonstration. I shall use BASIC for comparative purposes, since it is the tyrant in the field.

I find Pascal easy to use because it allows me to define new data types which express my data meaningfully. It provides control structures with which I can express what I want done to my data clearly and naturally. Pascal allows and encourages me to formulate my thinking in a structured way. Let us examine these three aspects of Pascal in reverse order.

## Program Structure

Pascal is a resolutely structured language. A Pascal program is structured into blocks. Each block bears a heading which gives it a name and specifies its parameters. Roughly speaking, a block consists of a definition part, in which constants, types, variables, and subroutines are defined, and an action part, which contains the algorithm of the block. This rigorous separation of data definition and algorithm expression is partly responsible, it seems to me, for the greater legibility of Pascal compared to ALGOL.

Subroutines are themselves block structured and may thus be nested within one another. This allows the declaration of "local" variables and subprograms, meaning that storage may be allocated efficiently; yet it is easy to guard against unwanted side effects.

What does all this mean for the practicing programmer? The answer may perhaps best be seen in the light of a claim recently repeated by David Higgins in the October 1977 BYTE ("Structured Program Design," page 146). Higgins presents the now well established arguments in favor of structured programming, but goes on to contend that once a program is designed in a structured way, using for example Warnier-Orr diagrams, "it does not matter what programming language you code it in." This assertion seems pretty improbable on the face of it, and if true it would be a powerful argument against Pascal. I think that a rapid examination of two test cases will show it to be quite unjustified.

Let us take our test cases from the "bug" program which Higgins uses as his own example. Higgins would have us break the program down into three parts, as expressed in the following Warnier-Orr diagram:

$$\text{bug program} \begin{cases} \text{begin program} \\ \text{games } (1,g) \\ \text{end program} \end{cases}$$

Nothing in the BASIC listing which accompanies the article even remotely suggests this overall algorithm. Look at what we might have in an equivalent Pascal program:

```
program bug;
   begin
      beginprogram;
      games;
      endprogram
   end.
```

Need I point out that to all intents and purposes the Pascal program *is* the Warnier-Orr diagram, with only a few notational differences such as the replacement of the brace by the symbols begin and end? Are we really asked to believe that this one to one correspondence between the problem and the program does nothing to simplify the programming task? On the contrary, it simplifies matters enormously.

Considerations of space prevent me from giving the rival BASIC and Pascal versions in full. Another striking example is presented in figure 1 and listings 1 and 2, which show the Warnier-Orr diagram for the "turn" subprogram, Higgins' coding of the subprogram in BASIC, and the Pascal equivalent. Higgins calls his BASIC coding "simple and straightforward." Tastes differ but that is a phrase I would have reserved for the Pascal version. Higgins has had to fake truly structured programming in a language which fights his efforts every step of the way, and the results are tortured and confusing. In contrast, the Pascal coding is, once again, a nearly perfect reflection of the Warnier-Orr diagram, so much so, in fact, that most Pascal users will probably feel, as I do, that the diagrams are a useless intermediary step, less clear and bulkier than the program itself. The intent of the Pascal program segment is so transparent that in my opinion it could almost be understood by a complete programming novice.

Before leaving the topic of program structure, we should perhaps remark that Pascal subprograms (procedures and functions) bear names, not numbers, virtually eliminating the need for the comments which pepper any well documented BASIC listing. Furthermore, because Pascal subprograms can have parameters, the programmer is encouraged to use a single subprogram for a single task. Higgins has written separate subprograms for each body part, whereas for a Pascal user it is virtually impossible to resist the temptation of passing the arrays body, neck, head, etc, to a single procedure "give" as parameters.

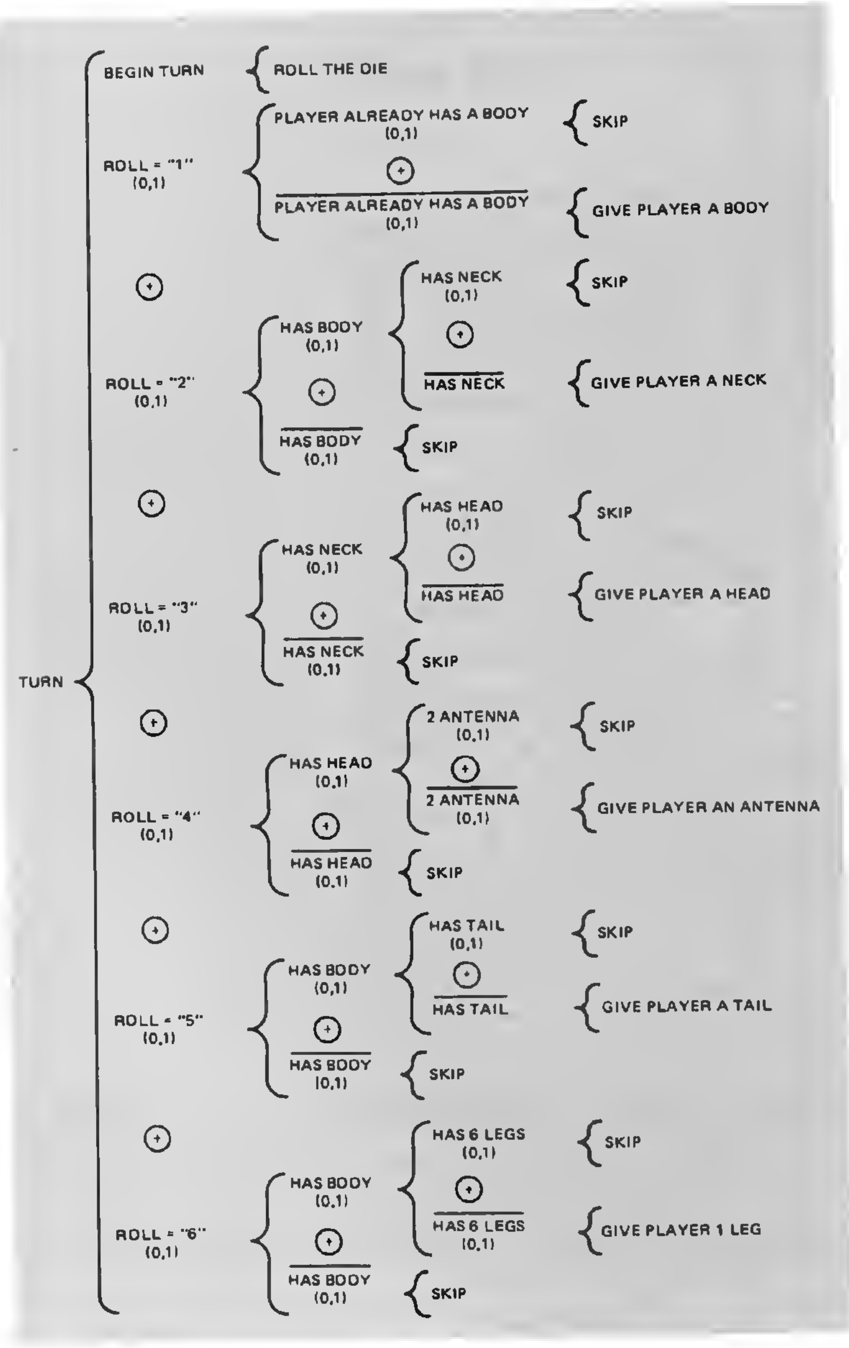


*Figure 1: Warnier-Orr diagram for subprogram "turn" of the bug program. This is clear, but note how much bulkier it is than the Pascal program in listing 2. The Warnier-Orr diagram won't even run on a computer.*

## Algorithm Expression

Program structure alone does not explain the relative clarity of the Pascal listing in listing 2. We may also use that listing to illustrate the tools which Pascal provides for expressing algorithms.

Logical operators: Pascal provides the logical operators (and, or, and not) which are so painfully lacking in BASIC and without which expressing an algorithm is so clumsy. The use of the operator and in the turn subprogram is a good example; or the reader may want to express "if (x=1) or ((y>2)and(z=3)) then. . ." in BASIC.

Conditional statements: Pascal's if structure groups statements with the conditions for their execution. The if statement is of the form:

```
if<expression>
   then<statement_1>
   else<statement_2>
```

The expression is evaluated as being either true or false. If it is true statement_1 is performed; otherwise statement_2 is performed. Suppose the expression is: X=1. In English the if statement translates to:

> if X equals 1 then perform statement_1; else perform statement_2.

Pascal offers a very flexible case statement which is remotely related to the computed GOTO statement to be found in some BASICs. It is much more powerful because, among other things, selector values need not be contiguous, and actions are grouped with the conditions for their execution. A good example of the case statement's clarity is to be found in the procedure "turn," where the action taken depends on the value of roll.

**Repetitive statements:** BASIC provides only one repetitive control structure: the FOR statement. But there are innumerable situations where we do not know ahead of time how many times a given action is to be repeated. In such cases BASIC users have two choices. One is to set up a dummy FOR statement with a jump out of it when a certain condition is met: whence the ubiquitous "FOR I=1 TO 9999" statements in BASIC programming. This is bad because it seriously disguises the intention of the algorithm. One's natural expectation is for such a loop to be executed 9999 times, but that is not the case. The other solution is for the programmer to fake an appropriate control structure with GOTOs or conditional jumps. That is what Higgins has done in his program to express the fact that the computer and the human take turns until the game is over:

```
210 REM TURNS (1,T)
220 LET EGAM = 0
230 GOSUB 390
240 IF EGAM = 0 THEN 230
250 REM END GAME
260 GOSUB 1150
```

This is no doubt the best one can do in BASIC, but just consider how much more elegant the Pascal version is:

```
repeat turns until endofgeme
```

This is typical of the way in which Pascal's control structures make algorithm expression a source of joy rather than a contortionist exercise. In addition to the repeat statement, Pascal offers a while statement for the case when an action is to be repeated as long as a condition is true.

**Data Definition**

Now that we have seen how much easier it is to express what one wants done to data in Pascal than in BASIC, let us turn to the wonderful data types which Pascal makes available for manipulation. Data types are the programmer's buffer between his abstract formulation of an algorithm and the messy realm of bit level details where that algorithm will eventually be executed. Pascal makes defining new types a trivial task. Once a new data type is defined, it is in effect indistinguishable from a predefined type and may be used in any way a predefined type may be. We leave BASIC behind at this point, since that language has no facilities for creating new types.

The bug program was too simple to provide examples of data structuring, so we shall have to turn elsewhere. Being a birdwatcher, I shall replace the traditional "Christmas card list" example by a bird data bank. I can do no more than skim the surface, so I ask the reader's indulgence if some of the listings are not fully explained. I am not trying to teach Pascal, but merely to spark intuitions.

Pascal distinguishes between simple

```
490 REM TURN SUBROUTINE
500 REM PLAY=1;PLAYERS TURN–PLAY=2;COMPUTERS TURN
510 REM ROLL DIE
520 LET ROLL = FIX@(((RND(0))*6.0))+1
530 PRINT:"ROLL IS A",ROLL
540 IF ROLL = 1 THEN IF BODY(PLAY)#1 THEN GOSUB 690 ELSE;ELSE;
550 IF ROLL = 1 THEN 650
560 IF ROLL = 2 THEN IF BODY(PLAY) = 1 THEN IF NECK(PLAY)#1 THEN GOSUB 760
570 IF ROLL=2 THEN 650
580 IF ROLL=3 THEN IF BODY(PLAY)=1 THEN IF NECK(PLAY)=1
    THEN IF HEAD(PLAY)#1 THEN GOSUB 820
590 IF ROLL=3 THEN 650
600 IF ROLL = 4 THEN IF HEAD(PLAY)=1 THEN IF ANTE(PLAY)#2
    THEN GOSUB 880
610 IF ROLL=4 THEN 650
620 IF ROLL = 5 THEN IF BODY(PLAY)=1 THEN IF TAIL(PLAY)#1 THEN GOSUB 940
630 IF ROLL=5 THEN 650
640 IF ROLL = 6 THEN IF BODY(PLAY)=1 THEN IF LEGS(PLAY)#6 THEN GOSUB 1000
650 LET A=3
660 RETURN
```

*Listing 1: BASIC listing for Warnier-Orr diagram in figure 1. This is the best one can do in BASIC, but is still a far cry from the clarity of the Pascal listing.*

```
procedure turn;
  begin roll:=trunc(random(1)*6)+1; writeln('roll is a',roll);
    cese roll of
      1: if(body[pleyer] ≠1)then give(body);
      2: if(body[player] =1)and(neck[pleyer] ≠1) then give(neck);
      3: if(neck[player] =1)end(heed[player] ≠1) then give(heed);
      4: if(head[player] =1)and(ante[pleyer] ≠2) then give(ente);
      5: if(body[pleyer] =1)and(teil[pleyer] ≠1) then give(teil);
      6: if(body[player] =1)end(legs[pleyer] ≠6) then give(legs)
    end
  end;
```

*Listing 2: The Pascal listing equivalent to listing 1. Note the clear affinity between the listing and the Warnier-Orr diagram. Notice that arrays are indexed using square brackets.*

and structured types. Let us examine each in turn.

Simple types: These are the basic building blocks of which any structured type, no matter how complex, is ultimately composed. In addition to integer, real, and character types, Pascal offers two additional simple types which as far as I'm concerned come close to exhausting the simple types needed in a general purpose language. The first is the defined scalar type, and is defined by simply listing the values which a variable of the new type may take on. Suppose I need a data type for the various habitats in which a bird may appear. In Pascal I write:

```
type h = (ocean,rivers,fialds,suburbs,forasts,
         mountains)
```

A variable of type h may take on any of the values listed. This means that while programming I may contlnue to think in terms of habitats, and am not forced to descend from that abstract level and think in integers, as I would have to do in BASIC. This also makes for virtually self-explanatory programs. Compare "IF HABITAT=3 THEN. . ." with the much more transparent "if habitat=fields then. . . ."

The second simple data type is the Boolean, and is extremely useful in programming since one is constantly controlling program flow with Boolean expressions. Boolean variables take on the values true and false. Languages without such variables must make do with integers, which muddles things since one's natural expectation is for integers to count something. The Pascal user may simply write "if good then. . .", which is the way we think; the BASIC programmer must write "IF GOOD = 1 THEN. . .", which is alien to the way we think.

A large part of Pascal's elegance comes from the fact that in most contexts these simple or scalar types may be used indifferently. Thus for example the type h as defined above could be used as the index variable in a for statement:

```
for habitat := oceen to mountains do
```

or in a case statement, or as the index type of an array:

```
if foundin [fields] then
```

Furthermore, functions may return any scalar type: we have already seen the function "endofgame" which returns a Boolean value.

Structured types: In addition to the simple types, Pascal offers five different structuring methods: arrays, records, sets, files, and pointers. These different methods may be combined in virtually limitless ways. One may have files of arrays, pointers to records, arrays of sets, pointers to files of arrays of records, and so on. This extreme flexibility of data structuring methods is one of Pascal's most exciting features. The type array should be familiar, but let us look briefly at the other four structured types.

**Sets**: Each bird in my hypothetical data bank has associated with it a set of habitats in which the bird may be found. Having defined the type h as above, all I need to do to set up a variable habitats which will be a set of different habitats is to write:

```
var habitats: set of h
```

When constructing the entry for the robin, I will write:

```
habitats := [fialds,suburbs]
```

thus assigning to the robin the set of habitats containing the two elements fields and suburbs. When going on a trip to the mountains, I can test whether mountains are in a given bird's set of habitats by the following simple test:

```
if mountains in habitats then
```

Imagine trying to do this in BASIC. Pascal provides a variety of set operators which allow set manipulation in all its generality.

Records: Let us imagine that each entry in my data bank will contain the bird's name, its length, and a set of habitats where it may be found. The entry cannot be an array, since components of arrays must all be of the same type. The appropriate data type is the record, defined in Pascal as follows:

```
typa bird =  record
               name: string;
               length: real;
               habitats: set of h
             and
```

This is a simple and logical way of grouping data of different types into a meaningful whole. Given variables robin and redbreast of type bird, a simple assignment statement will set one equal to the other:

```
robin := redbreast
```

To test whether a robin is more than 20 cm long, we would have:

```
if robin.length>20 then
```

and so on. These are simple examples, but they suffice to illustrate the flexibility of the record type.

Files: Now let us suppose that I have 600 entries of type bird in my data bank, and want to make a list of all the birds whose length is greater than 20 cm. It is pointless and wasteful to keep all 600 records in memory for such a task; all I

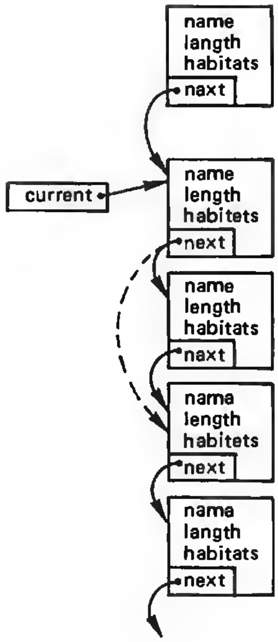


*Figure 2: A linked list of records of type "bird" with addition of the pointer field "next." Deleting the third record is a simple matter of changing a pointer field, as shown by the dotted line.*

really need is to store them in mass storage and read them in one at a time. In Pascal what I do is declare a file of records as follows:

```
var fb: file of bird
```

Now, supposing the file to have been written, all I need to perform the task is:

```
reset(fb) ;
repeat if fb↑.length>20
    then writeln(fb↑.name) ; get(fb)
until eof(fb)
```

Reset positions the file at its beginning; get advances it one record; fb↑ is the buffer variable containing the current record; and the writeln statement prints the bird's name. The Boolean function eof tests for the end of the file.

Pointers: Finally, let us suppose that I wish to update the data bank by deleting a bird. It is of course possible to do this by storing all the records in an array, but this is clumsy and inefficient, since all the records following the deleted record would have to be shifted one position. List processing provides a much better solution. The records are linked together into a list by inserting a pointer field "next" into each record. Each record will then "point" to the record following it in the list. Deleting a record becomes the simple matter of changing a single pointer value as illustrated in figure 2. Given the pointer "current" pointing to the item just before the one to be deleted, the following simple statement will do the trick:

```
current↑.next := current↑.next↑.next
```

Adding a new record is only slightly more complicated.

Let me repeat that these simple examples are not meant to do more than provide a brief glimpse of the marvels of Pascal's structured types. For full explanations the reader is referred to the texts in the references.

## Conclusion

Rapid though it has been, I hope that this survey of Pascal will have brought out some of the features which make it vastly superior to BASIC. BASIC offers an absolutely minimal set of features and expects you either to devise makeshift solutions or to design a new version of the language when they are inadequate. No wonder there are so many different versions of BASIC. Pascal offers a somewhat wider selection of features, but avoids the pitfall of trying to include every feature known to humanity. Pascal is a simple and streamlined language: the *Pascal Report* defining the language is a mere 32 pages long. Yet Pascal's designers seem to have chosen just those features which the user needs to expand the language when the need arises, so that it is a genuinely general-purpose language suited to a wide variety of problems. It is this combination of simplicity and power which seems to me to make Pascal the natural choice for a standard microprocessor language.■

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# Comments on Pascal, Learning How to Program, and Small Systems

Gary A Ford

The editorial in the December 1977 BYTE[1] asked if Pascal is the next BASIC. Implicit in this question is the suggestion that personal computing needs a widely used programming language. Ostensibly, this will facilitate exchange of software, and thus help eliminate the existing software vacuum for personal computer systems. Should Pascal be the language used to begin to fill this void? To answer this question, we should look at the history of Pascal to see for what purposes it was developed.

Wirth states two principal goals for Pascal: "to make available a language suitable to teach programming as a systematic discipline based on certain fundamental concepts clearly and naturally reflected by the language," and "to develop implementations of this language which are both reliable and efficient on *presently available computers*" (emphasis added).

With regard to the first of these goals, Wirth contends that "the language in which the student is taught to express his ideas profoundly influences his habits of thought and invention." My experience shows that this is a remarkably accurate statement. I have taught computer science to university undergraduates for several years, and recently taught several intermediate level courses to students with a variety of programming backgrounds. The students had all had two or three quarters of formal computer science courses at the same university during the previous year, and all were familiar with the same computers. However, some had learned to program in BASIC, some in FORTRAN, and some in a structured variant of FORTRAN which included, among other features, two varieties of if-then-else, five varieties of iterative statements, two varieties of multiple branch structures, and a simple but powerful procedure facility. The structured FORTRAN programmers proved to be significantly better performers in the intermediate level courses in all ways. They were much quicker to understand new algorithms, new data structures, and new applications. They were superior in applying this knowledge to new problems, which can, in part, be attributed to the fact that they were not thinking in the narrow terms required in BASIC and FORTRAN. They wrote better programs in assembly language, perhaps again because they could think in structured programming terms. They also, not unexpectedly, learned Pascal (which was taught in conjunction with a data structures course) much faster than the other students. In fact, some of the BASIC and FORTRAN programmers never did make the transition to Pascal; they wrote Pascal programs that looked like line by line translations of BASIC and FORTRAN programs. An informal follow-up of some of these students in more advanced courses showed that the BASIC and FORTRAN group continued to lag behind, especially in courses in analysis of algorithms and design of large systems.

Of course, this was not a controlled experiment, so the conclusions cannot be supported scientifically. However, I believe it is true that since so much of computer science involves abilities to analyze, to organize, and to plan, the thinking process taught in a first programming course, which in turn depends on the language used, has an enormous impact on the development of computer scientists.

Thus, Pascal sounds like a good language for beginners (ie: many of today's computer hobbyists). There are other reasons for supporting the spread of Pascal, including, for example, its out-

1. Page 17 of this edition.

standing data structuring facilities. Some problems are easily stated and solved in terms of such structures as sets, lists, sequences, trees, or groups of disparate items. Pascal allows the programmer to define and to deal directly with such structures, whereas BASIC and FORTRAN force the programmer to disguise these structures as arrays. Of course, obscuring the original ideas often leads to obscure program logic.

With regard to Wirth's second goal for Pascal, we suddenly have a problem. The personal computer systems of today are quite different from the "presently available computers" Wirth had in mind ten years ago. Therefore, some language features that are desirable for present personal computer systems are absent from Pascal. Perhaps the most important of these features are in the category of access to peripheral devices and processor hardware facilities.

Pascal has only two primitive IO operations: get and put. Each moves a single unit of data (character, integer, record, etc) from or to a sequential file. Files are not necessarily associated with or stored on secondary storage devices, although two special predefined files (named input and output) are available for those files associated with devices that will also be accessed by humans. There are in addition two predefined procedures (named read and write) that perform data transmission from or to files in particularly useful ways, but it is important to emphasize that these are procedures (subprograms) and not statements or operations in the language.

The peripheral devices of personal computer systems are extremely varied, and very few system configurations are exactly alike. Therefore, each user will need somewhat different IO capabilities in the language. Many users have an on line terminal, access to which requires the ability to access specific absolute addresses in memory or specific port addresses. Users with disks will need direct access file capabilities. Others may want the ability to process interrupts for real time applications. None of these capabilities exist in Pascal, and none can easily be implemented as a disguised sequential file.

The obvious conclusion is that if a push for Pascal as the language of personal computing is made, there will be a variety of nonstandard implementations. This is exactly what we have seen with BASIC. Implementors will add their own versions of their own favorite bells and whistles. We may expect numerous methods of specifying absolute memory addresses (peeks and pokes), direct access disk file statements, and all kinds of facilities to handle the exotic peripherals being attached to personal systems. In addition, implementors will want to add their own favorite data type (for example, Pascal does not have a built-in string data type), and their own favorite operator (for example, Pascal does not have an exponentiation operator). Next, seeing the size of the resulting compiler, implementors will begin to delete their least favorite standard features (often meaning the ones they least understand), in order to come up with a 4 K version of "eensyweensy Pascal."

One approach to preventing some of the problems just mentioned is to get all of us hobbyists together to agree (is this possible?) on a standard set of additions and deletions, or perhaps a few standard sets in order to develop 8 K, 12 K, 16 K, etc, versions. The traumatization of the language could be minimized by requiring that all the new features be implemented as procedures, rather than as new statement types, thus maintaining the syntactic integrity of the language. Of course, this would require a capability to link external procedures to each Pascal program, and none of these procedures could be written in Pascal. This means either that all users will need to know another programming language, or that the implementors of the new varieties of Pascal will have to supply customized procedures for each customer.

There is a fundamental flaw in this approach, however. Pascal was not intended to be all things to all people. It was designed with specific, well thought out, predefined goals. All aspects of the language were designed to complement each other in attaining those goals. Any deletion from the language, however minor it seems, will upset this balance, and thus damage Pascal's ability to achieve its goals. Deletions and additions will also change the character of the language, and it is this overall character of Pascal that has brought it so many devotees.

A better approach, I believe, is for those of us in personal computing to get together to agree on *principles* for the next widely used language, rather than on the features to add to or delete from an existing language. This is not any kind of vote against Pascal; to the contrary, I hope Pascal will become available to all hobbyists with systems that can support *standard* Pascal, and that it be used for all *suitable* applications programming. I have used Pascal for at least 95% of my own programming over the last three years, and I cannot recommend it too strongly.

If a new personal computing language were developed from guiding principles, I would hope that it would have much of the flavor of Pascal. I would hope It would be syntactically uncluttered like Pascal, not only because it makes the language easier to use, but also because it allows much simpler (smaller) language translators. I would hope it would have control structures at least as strong and as logical as those of Pascal, and data structuring facilities as simple and powerful as those of Pascal. It should be designed so that we can write almost all of our software in this one language, including both systems and applications programs. It should not try to provide every feature of every existing language, but rather, like Pascal, provide a small set of primitive constructs from which users can define their own powerful features. It should allow us to write truly portable programs and to maintain a library of procedures, since a good procedure facility, like that of Pascal, is perhaps the single most important tool for software developers. But whatever we choose to put in the language, let us design it from principles, and not evolve it from a set of independent features, as was the case with BASIC and FORTRAN. ■

## Editorial

# Is Pascal the Next BASIC?

**Carl Helmers**

One of the most interesting phenomena in the academic world of computer science of late is the language Pascal. This language is the subject of much intense activity, and is rapidly gaining acceptance as the language of choice for training and illustration of computer concepts to new students of the field. Characteristic of this phenomenon is the existence of on the order of 100 different implementations of the language for various computers and a very active "Pascal User's Group."

Pascal began in the late 1960s as a tutorial experiment of Professor Niklaus Wirth: a method of teaching the concepts of programming in a systematic fashion using a consistent and highly structured program representation. Historically, Pascal has antecedents in the ALGOL language but with the addition of concepts such as record and file structures which were missing in ALGOL's definition. The following passage by Professor Wirth gives the essence of Pascal's purposes. . .

*The development of the language Pascal is based on two principal aims. The first is to make available a language suitable to teach programming as a systematic discipline based on certain fundamental concepts clearly and naturally reflected by the language. The second is to develop implementations of this language which are both reliable and efficient on presently available computers.*

*The desire for a new language for the purpose of teaching programming is due to my dissatisfaction with the presently used major languages whose features and constructs too often cannot be explained logically and convincingly and which too often defy systematic reasoning. Along with this dissatisfaction goes my conviction that the language in which the student is taught to express his ideas profoundly influences his habits of thought and invention, and that the disorder governing these languages directly imposes itself onto the programming style of the students.*

*There is of course plenty of reason to be cautious with the introduction of yet another programming language, and the objection against teaching programming in a language which is not widely used and accepted has undoubtedly some justification, at least based on short term commercial reasoning. However, the choice of a language for teaching based on its widespread acceptance and availability, together with the fact that the language most widely taught is thereafter going to be the one most widely used, forms the safest recipe for stagnation in a subject of such profound pedagogical influence. I consider it therefore well worthwhile to make an effort to break this vicious circle.* [Quoted from the second edition of the *Pascal User Manual and Report*, by Kathleen Jensen and Niklaus Wirth, Springer Verlag, New York, 1974, page 133.]

Since the time of Pascal's creation by Professor Wirth, the language has become widespread, primarily because his tutorial purposes also happen to coincide with what one might want in a systems and applications programming language used in software development. In fact acceptance has been sufficiently widespread that there now exist implementations for some of the more common microprocessors in the personal computing field (using the *Pascal*

*User's Group Newsletter* as a source for this information in a listing of implementations in issue #8 recently published). What are the ramifications of Pascal as it might affect personal computing users?

At the present time, outside of low level assemblers, the personal computing field is dominated by one language, BASIC. It is the high level language of choice for users of the equipment and for manufacturers who sell to the users of the equipment. Any attempted personal computing system design these days must come up to the standards of a reasonable BASIC (such as the Microsoft BASIC used by MITS, OSI, Commodore and others) or it will be at a relative disadvantage in the marketplace. This dominance of BASIC as a language is a fact of life in this field. A decade and a half of language design evolution has occurred since BASIC first came on the scene, yet it still dominates at the user level. Why?

In a casual enumeration mode, I can list several fairly obvious and interrelated reasons why this has become the case; out of these reasons will come a similar scenario for development of Pascal as a future option for personal computers.

- Everybody knows BASIC.
- BASIC has a manufacturer independent standard definition.
- Lots of implementations of BASIC are available.
- Much personal use applications software already exists in BASIC.
- BASIC is friendly.

At a superficial level, these reasons are part of a self-sustaining loop of circular reasoning: Since BASIC is friendly, everybody wants to know BASIC; since so many people learn BASIC, there tend to be lots of implementations. Much software for applications has been written in BASIC. Since a manufacturer independent standard for BASIC exists, conversion of programs from one machine to another is simplified, thus making widely available software useful to people, and so on . . . ad infinitum. . . This is Professor Wirth's "vicious circle."

Like many similar conventions, BASIC has been bootstrapped into the public awareness over time, and has acquired a certain inertia of its own that will keep it going for years in the same way that FORTRAN seems to live forever. Let's examine the reasons in this list, and in so doing compare BASIC to Pascal, a language which is quite possibly in an earlier stage of a similar bootstrap cycle and may indeed become a much demanded "language of choice" for the user community. Vicious circles can have positive aspects: it all depends on which circle one has established. A contention I make is that the same sort of "vicious circle" can be, and indeed is being established for the language Pascal.

## Everybody Knows BASIC.

BASIC historically was introduced at a time when "big" computers dominated the field, and there was a need to partition the activities of such computers into small individually oriented packages for purposes of making the "big" computer available to many people. This partitioning succeeded admirably: when professor X (or Y or Z) wanted to make real exercises in programming available to students, BASIC was frequently employed, due to its availability and interactive simplicity. Like any technology, BASIC did not start out in an "everybody knows" state, but it got that way through its early availability and no small push from pedagogues of computer science.

Today, the teachers of programming are tending to push Pascal as the language of choice for teaching "good" programming concepts. The Pascal User's Group is evidence of the number of academic people who support the ideas of Professor Wirth to the extent of implementing their own local Pascal systems for educational purposes. (This is typically done using a number of techniques of machine independence conceived by early implementors of Pascal for purposes of spreading its implementations.) One result of this availability is that Pascal is becoming the tool of teaching programming concepts which Professor Wirth envisioned . . . and the beginnings of the "everybody knows" state for Pascal are already evident.

## BASIC Has a Manufacturer Independent Standard Definition.

This comment is nominally true of BASIC. Work is indeed in progress on an ANSI standard for BASIC, and there is of course the original Dartmouth College definition of BASIC. The fact that people are trying to define a standard form of BASIC, however, is a result of the fact that the implementations of BASIC have been somewhat subject to variations. In the personal computing world, there are numerous differences at a detail level between language extensions of various BASIC interpreters, some as basic as the variations in string and array handling in various forms of minicomputer BASIC.

BASIC language implementors are no different from implementors of a number of languages, often succumbing to the "wouldn't it be neat if" syndrome and throwing in features not part of the original definitions of the language. The hitch with such featurism is that if anyone uses the features, the programs written with the feature may no longer be portable.

Of course Pascal would be no more immune to featurism on the part of implementors; at least that would be an obvious contention since there is no fundamental difference between people who implement BASIC and people who implement Pascal. But before making such a statement, an examination for the motives of implementation featurism should be made. BASIC in its original definition is a very limited and parochial language, one which represents a viewpoint of quick implementation of programs with limited IO formatting, standard floating point operations, and no intent to service large or complicated applications. Thus, many of the "feature" temptations presented to BASIC implementors are a result of attempts to correct the deficiencies of BASIC by adding omitted items (for example, strings, implemented differently in various BASIC interpreters).

Pascal, on the other hand, by having a definition which is more general in scope than BASIC (although by no means complicated to use in simple problems) helps cut down these "feature" temptations on the part of its implementors. One basic example of this slightly more general definition is in Pascal's inclusion of extensible data types which can be declared, as well as file and record structures missing from BASIC. Pascal is a block structured language allowing multiple character strings for procedure and data names, and is thus closer to the natural symbolic thought processes of designing a program than is BASIC.

A classical contrast between the two languages in this area of features is to pose the problem: How would I use the language to include complex numbers for use in engineering analysis or physics? In BASIC, I might not even want to consider the possiblity of using the language for complex numbers because of the kluge that would result. Using Pascal, I would simply use the type extensibility of data to declare a complex number type and code various procedures to implement complex number operations. An example of this concept, which involves no features not inherent in Pascal's definition, is given on pages 42ff of the *Pascal User Manual and Report* quoted earlier. Of course, perhaps not all possible or desirable features were included in Pascal's definition, so dialects may occur there as well as in BASIC. But the necessity of dialects generated through extensions is probably less in Pascal, making the standard created by Professor Wirth a closer approximation to what actually gets implemented.

### Lots of Implementations of BASIC Are Available.

Here is where BASIC no doubt has a considerable lead over Pascal at the present time. But Pascal is rapidly gaining in a catch up mode. As noted earlier, there are presently nearly 100 different implementations of Pascal, mostly for minicomputers and larger computers ranging in size and scope up to a CRAY-1 implementation of Pascal. At the low end, according to the *Pascal User's Group Newsletter*, number 8, page 64, there are presently compilers implemented for the Motorola 6800, Intel 8080 and Zilog Z-80 microprocessor architectures (although the listing did not mention whether the compilers were self-compilers or cross compilers). Implementations are coming, part of the history of the language and the active following it has among computer science people.

### Much Personal Use Applications Software Already Exists in BASIC.

No argument here. The number of books and periodicals which publish programs in BASIC will probably exceed the number with Pascal representations of equivalent programs for a long time to come. But this is equivalent to saying that BASIC has been around longer in the public eye, for given time much of the same sort of software can and will be written in Pascal as more and more implementations become available.

### BASIC is Friendly.

BASIC is fundamentally an interactive approach to programming in which programs are entered in source form and tested within the confines of one session with effectively instant change from editing to execution. If Pascal is to become an equivalent "friendly" language, it must be implemented in a way which allows a similar instant change from editing the design to trying out the design of an application.

Whether this friendliness requirement can be best met by an interpreter or a compiler is an open question, but it is a definite requirement. In BASIC the rule to date has been interpretive, or semicompiled code, where semicompiled means that symbols for language tokens are replaced by compact codes. In Pascal to date, compilation has been the rule rather than the exception. It is conceivable that a compiled Pascal coupled with an editing and object code maintenance facility oriented to the block level might give sufficiently quick response at the terminal with much faster execution times associated with compiled code.

Another open question concerning Pascal is that of how much memory is required for a Pascal self-compiler or resident interpreter in a typical personal computer's microprocessor based system. I suspect that a compiler or interpreter of Pascal can be built which will fit within 16 K to 32 K bytes of memory, but whether this is really possible or not is by no means clear to me.

To sum up the thesis, Pascal is well on its way to becoming the kind of widely known language which will be taught as a matter of course to new students of programming. This in turn will tend to boost the long term acceptance of Pascal and get it established as one of the major languages, a process which at an earlier date occurred for FORTRAN and BASIC. For our own part, we at BYTE are interested in giving Pascal a boost. We have a survey article about Pascal in preparation at the present time. We would also like to talk to implementors of the language who would be interested in marketing Pascal compilers or interpreters through software book publications which include source code and machine readable object code. For those who desire more background information on Pascal, we recommend the Pascal User's Group, run by Andy Mickel at the University of Minnesota Computer Center, 227 Exp Engr, University of Minnesota, Minneapolis MN 55455, (612) 376-7290. The *Pascal Newsletter* is published four times per year, and at the time of this writing costs $4 per year.■

Note on the Pascal User's Group

*As of July 1, 1979 the Pascal User's Group (PUG) has over 3300 members in 47 countries. Those interested in joining can contact Andy Mickel at the University of Minnesota Computer Center, 227 Ex Engr, University of Minnesota, Minneapolis MN 55455, (612) 376-7290. The* Pascal Newsletter *is published four times a year on a July to June schedule, with a subscription fee of $6 per year. All issues for the current year are sent with a new subscription, and back issues are available.*

# Concerning Pascal:

## A Homebrew Compiler Project

**Stephen P Smith**

Your editorial in December 1977 BYTE[1] was commendable. It served to reinforce my conviction that Pascal is the next step up from BASIC for personal computing. As you and your readers know from the biographical sketch that preceded my article in November 1977 BYTE[2], a Pascal compiler is my pet microcomputer project. Because that sketch prompted a number of inquiries about the status of my work, I thought a letter to BYTE would be timely following your editorial.

My approach to the compiler is to start with a small subset of Pascal and add features as my resources and talents permit. I've begun by determining the minimum subset needed to describe its own compiler. Because statements written in the resulting language will still be valid Pascal, the initial version can be debugged and run as a cross compiler on any computer which supports the full language. When operational, my compiler will convert itself to machine code to be loaded on the target microcomputer. Further development will be done on that machine. Each subsequent revision will be written in the Pascal subset of the previous one.

At this writing, I have completed the parsing procedures and am testing them on a DECsystem 10 with the guidance of Dr Robert Mathis at Old Dominion University. The production of machine code is still some way off, because I feel I need more experience with the instruction set of the target machine, MOS Technology's 6502. I expected to get this experience with a 6502 based Challenger I ordered from Ohio Scientific in August, but it has yet to be delivered. Perhaps this spring I will have an operating compiler to report.

As an alternative to my subset approach, there is another way to implement Pascal. It reflects upon your editorial discussion of the compiler/interpreter alternative. I am developing a pure compiler, but the standard Pascal implementation is a hybrid. A program is available to convert source programs into assembly code for a hypothetical stack computer (HSC code). The assembled hypothetical stack machine code is then interpreted by the target machine. This technique has speeded implementation of Pascal at several installations, and might be useful for personal computing since the hypothetical stack machine code is itself portable. A club, for example, might maintain the source to hypothetical stack machine compiler on one member's computer which had the necessary resources. Other members need only support the hypothetical stack machine assembler and interpreter for their machines. Although operationally more cumbersome than direct machine language compilation, this approach might speed up the availability of Pascal and reduce the hardware requirement for applications users. ■

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1. Page 17 of this edition.
2. "Simulation of Motion: An Improved Lunar Lander Algorithm."

# A Proposed Pascal Compiler

**Kin-Man Chung**
**Herbert Yuen**

> A Note About the Tiny Pascal project . . .
>
> *The three part article "A 'Tiny' Pascal Compiler" plus the complete p-code to 8080 conversion program listing are included in this edition beginning on pages 59 and 203 respectively* . . . BWL

In the Languages Forum of the April 1978 BYTE, page 150[1], we read Stephen Smith's report on his *homebrew* compiler project. Actually, he is developing the Pascal subset compiler on a mainframe computer at a university and planning to transfer it to a microcomputer. He said he had a minor problem with code generation (using 6502 machine code). We think his project might progress more smoothly if he uses another approach—that of generating assembly code for a hypothetical stack machine. This is the same method professionals use for implementing portable Pascal compilers on big computers.

Our own homebrew compiler project was developed in house on a microcomputer that uses an 8080 processor and has a North Star disk system. We began in mid December of 1977. Our motivation came from the fact that the North Star disk BASIC, although very good for general programming purposes, was not fast enough for system software development and some graphic games. For instance, our 8080 assembler, written in BASIC, takes 1 to 3 seconds to assemble one single assembly instruction. Assembling a 500 line program takes about one half hour. From various sources of information we know that Pascal is one of the easiest languages to implement. It also has many nice features that are desirable in a high level language.

The Pascal subset is small, otherwise it would be very difficult to develop using a BASIC interpreter. All variables in the subset are 16 bit integers. Arrays are single dimensional. Character strings are declared as arrays and each character takes one array element; although wasting space, this is easy to implement. Procedures and functions may be recursive. Variables and constants, except arrays, can be passed as arguments to procedures and functions. Language statements include declaration, assignment, BEGIN-END, IF-THEN-ELSE, WHILE-DO, REPEAT-UNTIL, FOR-TO/DOWNTO-DO, CASE-OF-ELSE. The subset is big enough to provide useful features. The Pascal compiler can be written in the subset without much difficulty.

The actual coding of the compiler (in BASIC) began in January 1978. The compiler generates p-code for a hypothetical stack machine, the same one described in Wirth's book, *Algorithm + Data Structure = Programs.* (P-code is the intermediate code generated by the Pascal compiler. It is the machine language of a hypothetical Pascal oriented computer. Use of p-code makes the Pascal language portable since only a p-code interpreter needs to be written for a particular processor. This saves the user from writing the entire compiler for each individual machine.) Several instructions and input/output (IO) capabilities have been added. At the same time, an interpreter was also written (in BASIC) to execute and debug the p-code. It helps to verify the correctness of the codes generated by the compiler. In late January, after most parts

1. Page 21 of this edition.

of the two programs had been debugged, we began to design a run time support package in 8080 assembly language and also a translator that translates p-code to 8080 machine code. With the debug package and simulator in the system (see Kin-Man's article "An 8080 Simulator" in the October 1977 BYTE, page 70), we did not have much trouble debugging the run time routines. During March most of our time was spent in refining all the routines: revising some features and extensions in the compiler, adding local optimization capabilities in the translator and improving the efficiency of the run time routines. The run time routines, which perform all 16 bit integer arithmetic and logical operations and IO conversions, take only 1 K bytes of memory.

The first step in the bootstrapping process was to write the interpreter in Pascal since it is the slowest but shortest program. It was coded by straightforward translation from the BASIC version. Debugging was smooth and the entire program was up and running within a week. Compared to the BASIC version, the Pascal version runs about 15 times faster; slightly better than we expected. Our next step will be writing the translator and compiler in the Pascal subset. After that, further development can be done in Pascal without the BASIC interpreter.

For three months, each of us have been spending about 10 to 15 hours a week on this project. The first version (in BASIC) of the compiler and supporting software were completed with an estimated effort of two working months. Considering such a short time period and a functioning compiler, we believe we are approaching the task from the right direction. We hope that our project will attract the attention of many readers so that we can share our interest and experience in Pascal with them.■

# About The Language

# Pascal

## A Structurally Strong Language

**Stephen A Alpert**

People should be able to communicate their ideas to a computer in a language that people understand; not simply in a language they know. Additionally, if the computer can be made to understand the same language easily, all the more reason to consider its use. Such a language is Pascal. This language, perhaps more than any other common language, is the easiest to understand and more importantly, allows a straightforward presentation of most algorithms. Although many languages also make this claim, few have the overwhelming and energetic support from collegiate computer science departments. Let's consider some of the language features of Pascal.

This language is equipped with a precise syntactical description that defines both how programs may be constructed and how Pascal compilers should function. There is a required form for programs, statements within programs, and data operated upon by programs. At first glance, a naive user may rebel at this apparent lack of freedom (eg: BASIC allows a dimension statement virtually anywhere in a program). One soon learns that this structure admits very general programs and in no way limits the programmer in exercising his talents. On the contrary, it forces the user to think logically and plan out the program.

A program written in Pascal may utilize the free format form of programs that is conducive to structured programming. Unlike line oriented source languages, Pascal allows extra spaces, tabs and carriage controls to be inserted anywhere without significance except in the middle of identifiers or character strings. Comments may be inserted wherever spaces may be inserted and are delimited by "(* ... *)". A program is made up of two parts, a heading and a block. The heading contains the name of the program and lists its parameters. The parameters are somewhat implementation dependent but normally specify the names of file pointers from which the default input is received and to which output is sent. A typical heading is

```
program parser (input, output)
```

A block consists of six separate segments or sections of a program. All but the last part are optional. These are:

- Label declaration section
- Constant declaration section
- Type declaration section
- Variable declaration section
- Procedure and function declaration section
- Statement section

Labels in Pascal identify statements to which control may be transferred. Labels are numeric; more specifically, unsigned integers. Not every statement requires a label. In fact, most Pascal users consider programs better if they have fewer labels. At first glance, these declarations might seem a nuisance, but they force the user to think about the entire program before sitting down at a terminal.

The constant declarations allow a user to create synonyms for constants used in the program. Thus

```
const   pi=3.141592;
        e=2.7182818;
```

defines the constants "pi" and "e" for use throughout the program. Clearly, it no longer is necessary to type 3.141592 in the several places required by a program. Addi-

**PASCAL forces the user to think logically and plan out the program.**

**Most PASCAL users consider programs better if they have fewer labels.**

tionally, one may name character strings as well

```
const title='matrix inversion program v01';
```

The type declaration section allows creation of user defined named data types. This will be discussed in some detail later. Pascal has four predefined data types: integer, real, Boolean, and character. Most versions of BASIC support the first three types and strings. Data of type character is very convenient in a microprocessor environment since a byte is the basic unit of memory.

The variable declaration section requires the naming of all identifiers that will be used as variables within this block. FORTRAN, BASIC, APL, and LISP do not adhere to this convention. Again Pascal forces the user to think about what he wants to say before he says it. A sample variable declaration section might be

Arrays may be multidimensional and include arrays of arrays.

```
var    x,y:integer;
       cost:real;
       flag:boolean;
```

Pascal's design allows the user to combine the utility of type declarations and variable declarations into data forms that would shame BASIC and FORTRAN. We have already seen Pascal's predefined scalar variable types above. These are actually known as simple types.

Another simple type is the subrange type. Often a variable in a program may be expected to take on values only from a subrange of a simple type, say integers. For example

```
var asiz:1..100;
```

meaning "asiz" will be an integer whose values should lie between 1 and 100. Note that the compiler might choose to store "asiz" as a byte rather than a word if it was efficient enough to do so. Alternatively, if several variables are of the same range, a type statement could have been used

Items of different types may be aggregated into a single entity that can be stored as one logical unit.

```
type  lsiz=1..100;
var asiz, bsiz, f1:lsiz;
```

Another simple type is the symbolic scalar type. This feature permits identifiers to be used in place of a sequence of integers, greatly enhancing the readability of the program. Suppose a program needed to represent the months of the year as a variable associated with some billing information. The approach in BASIC would be to use the sequence 1, 2, . . . , 12. Pascal could use the subrange type 1 . . 12 or better

```
type
   months = (jan, feb, mar, apr, may, jun,
             jul, aug, sep, oct, nov, dec);
  var billmonth,duemonth:months
```

In the statement section of a program, "billmonth" may be assigned one of the symbolic scalars from "months" or tested to see how its value compares with "duemonth." There are several functions available that operate on symbolic scalars, for example, ord(billmonth) would yield a number between 0 and 11 indicating the position of that month in the list "months."

Simple types are part of a more general data description called a type. Types include pointers which are used when dynamic data storage is referenced, file pointers which are used to reference secondary data storage, and arrays which are used with vector data storage. An example of an array declaration is

```
var cost: array[months] of real;
```

Notice that this array will be indexed, or subscripted, by "months." In general, arrays may be indexed by any simple types, may be multidimensional, and may be of any type, including arrays of arrays.

Two additional types set Pascal in a class by itself; these notions allow powerful algorithm descriptions. The set type allows user manipulation of sets. Consider

```
var special: set of months;
```

The union, intersection, and set difference operators as well as relational operators may be applied to sets. A variable of scalar type may be tested for membership in a set of the same scalar type, for example

```
if billmonth in special then. . .
```

The last type is the record type. Items of different types may be aggregated into a single entity that can be stored as one logical unit, for example as one element of an array.

```
type
   customer = record
                name:array[1..20] of char;
                bal,bal30:real;
                datedue:daterec
              end;
   daterec =  record
                day:1..31;
                mo:months;
                year:integer
              end;
var
   database: array[1..100] of customer;
```

To reference fields of a record, the record name followed by a period, followed by the field name is used. Hence the over 30 day balance of customer 12 is "database[12].bal30" and the day of the due date of the current bill of customer 27 is "database[27].datedue.day." The full impact of record types cannot be explained in this short article; they must be used to be appreciated. One advantage of records is that items may be logically grouped together rather than stored in parallel arrays.

Procedure and function definitions would follow next in a program. They may be recursive and permit parameter passing in a style somewhat similar to ALGOL. Because of the position in a program of these declarations, procedures and functions may reference globally any variables or types defined in the main program. The body of a procedure or function is identical to the body of a program; hence, procedures may be defined within procedures, and so on. Any variables defined within procedures or functions are considered local to the procedure and are unique to each invocation of the procedure. The sample program in listing 1 has several examples.

The statement portion of a program is called a "compound." A compound is a sequence of the keyword begin, any number of statements separated by semicolons, and the keyword end. The program ends with a period. Each of the statements within a compound may be one of a variety of different kinds of statements. Assignments, like

```
database[i+k].bal:=total
```

are the most common statements. Pascal supports a large number of control statements which give the language its structure.

Pascal has a looping control similar to that of standard BASIC but the step or increment may be only +1 or —1. The **for** statement causes a single statement, which could be quite complex, to be executed some number, including zero, times. For example

```
for ind.=1 to 100 do
   begin
      due:=1.006*database[ind].bal;
      database[ind].bal:=0.0;
      sum:=sum+due;
      database[ind].bal30:=
        1.006* database[ind].bal30+due
   end
```

This segment shifts the balance 30 days, adds some interest charge and accumulates a sum of the recently aged balances. If in a **for** statement, the increment were to be —1, then the keyword downto would replace the keyword to.

Pascal supports both simple conditional and full conditional statements; that is

```
if <condition> then <statement>
              and
if <condition> then <statement>
                  else <statement>
```

Any dangling else, an else which follows a sequence of "if . . . then if . . . then . . .," is paired with the innermost if.

When working with records, partial ad-

*Listing 1: The Polish "compiler" listing. Notice that Pascal does not constrict the format of the program line. Indentation allows the program blocks to be easily separated from each other and makes the program easier to read.*

```
PROGRAM PARSE(INPUT,OUTPUT);
(*PROGRAM PARSES SIMPLE ARITHMETIC EXPRESSIONS
  INTD THEIR RESPECTIVE POLISH CODE   IT DOES
  THE PROPER TYPE CONVERSIONS NECESSARY FOR
  REAL AND INTEGER EXPRESSIONS ACCORDING TO
  THE FORTRAN CONVENTION:
         REAL: A-H, O-Z
         INTEGER: I-N
  VARIABLES ARE ONE LETTER LONG*)
LABEL 99; (*FDR ERRDR RESTART*)
CONST
  DDNTCARE='?'; (*MARKERS FOR CODE GENERATOR*)
  MAXPC=100;    (*MAXIMUM CODE SPACE*)
TYPE
  CODESPACE=1..MAXPC;  (*ADDRESS SPACE*)
  ATTR=(NONE,INT,REA); (*ATTRIBUTES OF OPCODES AND EXPRESSIONS*)
  LEXTY=(ADDOP,MULOP,LPAREN,RPAREN,IDENT,EOL);
         (*THESE LEXEMES FOR INPUT ASSUME A NON-HOSTILE USER*)
  INSTRUCTIDN=RECORD
                DPC:CHAR; (*DPCDDE*)
                ITYPE:ATTR; (*OPCODE TYPE*)
                ADR:CHAR   (*NAME OF IDENT*)
              END;
VAR
  CODE:ARRAY[CODESPACE] OF INSTRUCTION; (*WHERE CODE GOES*)
  PC:CODESPACE; (*PC OF CURRENT INSTRUCTION*)
  GATTR:ATTR; (*GLDBAL TYPE DF EXPRESSIDNS*)
  CH:CHAR;     (*CURRENT INPUT CHARACTER*)
  CHTYPE:ATTR; (*CURRENT CHARACTER ATTRIBUTE IF IDENT*)
  LEX:LEXTY;   (*LEXEME DF CURRENT INPUT*)
  BFR:PACKED ARRAY[1..80] DF CHAR; (*INPUT BUFFER*)
  BP:INTEGER; (*CHARACTER BUFFER POINTER*)
PRDCEDURE SCAN; (*PRDCESS NEXT INPUT CHARACTER*)
  BEGIN
    REPEAT
      BP:=BP+1;
      CH:=BFR[BP]
    UNTIL CH#' ';
    (*WDRRY ABDUT END OF LINE*)
    IF DRD(CH)=B
      THEN LEX:=EOL
      ELSE
        IF CH IN ['A'..'Z']
          THEN
            BEGIN
              LEX:=IDENT;
              IF CH IN ['I'..'N']
                THEN CHTYPE:=INT
                ELSE CHTYPE:=REA
            END
          ELSE
            CASE CH OF
              '(':LEX:=LPAREN;
              ')':LEX:=RPAREN;
              '+','-':LEX:=ADDOP;
              '*','/':LEX:=MULOP
            END
  END (*DF SCAN*);
PROCEDURE ERROR;
  BEGIN
    WRITELN(' ':BP+1,'↑ ERRDR'); (*CDMPENSATE FDR USER PROMPT*)
    GOTO 99
  END (*DF ERRDR*);
PRDCEDURE GENCODE(F:CHAR; I:ATTR; A:CHAR);
  BEGIN PC:=PC+1;
        IF PC>MAXPC
          THEN BEGIN WRITELN('OVERFLOW');ERROR END;
        WITH CODE[PC] DO (*INDEX INSTRUCTION*)
          BEGIN OPC:=F;ITYPE:=I;ADR:=A END
  END (*OF GENCODE*);
PROCEDURE LISTCODE;
  VAR LPC:CODESPACE;
  BEGIN
    FOR LPC:=1 TO PC DO
      WITH CODE[LPC] DO BEGIN (*INDEX INSTRUCTION*)
        CASE OPC OF
          '+':WRITE('ADD');
          '-':WRITE('SUB');
          '@':WRITE('NEG');
          '*':WRITE('MUL');
          '/':WRITE('DIV');
          'F':WRITE('FLOAT');
          'P':WRITE('PUSH') END;
        IF OPC#'F'
          THEN
            BEGIN
              IF ITYPE=INT THEN WRITE('I') ELSE WRITE('R')
            END;
        IF DPC='P' THEN WRITELN(CHR(11B),ADR) ELSE WRITELN
    END (*OF WITH AND FDR*)
  END (*OF LISTCODE*);
```

*Listing 1, continued:*

```
PROCEDURE FIXUP(AX:CODESPACE;   (*PC OF FIX LOCATION OF OPERAND 1*)
                LOP:CHAR;       (*CURRENT OPERATOR*)
                LATTR:ATTR);    (*ATTRIBUTE OF OPERAND 2*)
  VAR TPC:CODESPACE;
  BEGIN
    IF GATTR#LATTR  (*TYPES DON'T AGREE*)
      THEN
        BEGIN
          IF GATTR=INT  (*FLOAT OPERAND 2*)
            THEN BEGIN GENCODE('F',NONE,DONTCARE);GATTR:=REA END
            ELSE (*HAVE TO FLOAT OPERAND 1, MOVE CODE UP*)
              BEGIN
                IF PC=MAXPC THEN BEGIN WRITELN('OVERFLOW');ERROR END;
                FOR TPC:=PC DOWNTO AX DO CODE[TPC+1]:=CODE[TPC];
                PC:=PC+1;  (*TOOK ANOTHER WORD*)
                CODE[AX].OPC:='F'  (*FLOAT OPERAND 1*)
              END
        END;
    GENCODE(LOP,GATTR,DONTCARE) (*GENERATE OPERATION*)
  END (*OF FIXUP*);
PROCEDURE EXPR; (*HERE IS ALL THE WORK*)
  VAR
    LOP:CHAR;     (*CURRENT ADDOP*)
    LATTR:ATTR;   (*ATTRIBUTE OF OPERAND 2*)
    AXPC:CODESPACE;(*WHERE FLOAT OF OPERAND 1 GOES, IF NEEDED*)
  PROCEDURE TERM;
    VAR
      LOP:CHAR;   (*CURRENT MULOP*)
      LATTR:ATTR;(*ATTRIBUTE OF OPERAND 2*)
      AXPC:CODESPACE;(*WHERE FLOAT OF OPERAND 1 GOES, IF NEEDED*)
    PROCEDURE FACTOR;
      BEGIN
        IF LEX=IDENT  (*IDENTIFIER*)
          THEN
            BEGIN
              GATTR:=CHTYPE;
              GENCODE('P',GATTR,CH);
              SCAN
            END
          ELSE
            IF LEX=LPAREN
              THEN
                BEGIN
                  SCAN;EXPR;
                  IF LEX=RPAREN THEN SCAN ELSE ERROR
                END
              ELSE ERROR  (*JUNK INPUT*)
      END (*OF FACTOR*);
    BEGIN (*OF TERM*)
      FACTOR;
      WHILE LEX=MULOP DO
        BEGIN
          LATTR:=GATTR;  LOP:=CH;
          AXPC:=PC+1;  (*SAVE ADDR OF NEXT INSTRUCTION*)
          SCAN;FACTOR;
          FIXUP(AXPC,LOP,LATTR)
        END
    END (*OF TERM*);
  BEGIN (*OF EXPR*)
    IF LEX=ADDOP  (*LEADING SIGN*)
      THEN
        BEGIN
          LOP:=CH;SCAN;TERM;
          IF LOP='-' THEN GENCODE('@',GATTR,DONTCARE)
        END
      ELSE TERM;

        WHILE LEX=ADDOP DO
          BEGIN
            LATTR:=GATTR;LOP:=CH;
            AXPC:=PC+1;  (*SAVE ADDR OF NEXT INSTRUCTION*)
            SCAN;TERM;
            FIXUP(AXPC,LOP,LATTR)
          END
      END (*OF EXPR*);
    BEGIN (*OF MAIN PROGRAM*)
      WHILE TRUE DO (*INFINITE LOOP*)
        BEGIN
    99:     REPEAT
              WRITE('>>');  (*PROMPT USER*)
              BP:=0;  (*GET INPUT LINE*)
              WHILE NOT EOLN DO
                BEGIN
                  BP:=BP+1;READ(BFR[BP])
                END;
              READLN (*RESET EOL INDICATOR*)
            UNTIL BP#1;  (*GET A NON-EMPTY LINE*)
            BFR[BP]:=CHR(0);  (* <NULL> FOR EOL*)
            PC:=0;BP:=0;  (*SCAN FROM THE BEGINNING*)
            SCAN;
            EXPR;  (*DOES ALL THE WORK*)
            IF LEX=EOL THEN LISTCODE ELSE ERROR
          END
      END.
```

dressing can be done by using the "with" statement. This allows the fields of a record to be referenced as variables. The previous example then becomes

```
for ind:=1 to 100 do
    with database[ind] do
        begin
          due:=1.006*bal;
          bal:=0.0;
          sum:=sum+due;
          bal30:=1.006*bal30+due
        end
```

Three additional control statements are the while, repeat, and case statements. The while statement allows a given statement to be executed as long as some Boolean expression is true (the condition is tested first).

```
while <condition> do <statement>
```

The repeat statement allows one or more statements to be executed until a condition becomes true (the condition is tested last).

```
repeat <statement> { ;
<statement> } until <condition>
```

The brackets denote a portion that may occur zero or more times; for example

```
ind:=0;
repeat;
    ind:=ind+1
until (database[ind].bal>100.0) or
  (ind=100)
```

This will find the first customer whose balance is greater than $100, if one exists.

The case statement consists of an expression, known as the selector, and a list of statements, each labelled by one or more constants of the type of the selector. The statements whose constant is equal to the current value of the selector is executed. Some versions of Pascal admit subranges for labels and an else or otherwise clause within a case statement.

```
case database[ind].datedue.mo of
    jan,feb,may:    <statement 1>;
    mar,jun,jul:    <statement 2>;
    oct,dec:        <statement 3>
end
```

Statement 1 will be executed if the due month is January, February, or May, and so on. Notice that no statement is executed if the month is April, August, September, or November. Of course, the nesting of such control statements is permissible and allows much more complex control structures to be implemented.

The reset and rewrite statements initialize input and output channels, respectively. Some versions of Pascal do not require these for the default channels input and output. The IO commands are designed at two levels. To move primitive data to and from IO devices or files use the commands put or get respectively. To input or output an entire line or set of data we use read, readln, write, and writeln which are similar to FORTRAN IO commands. Formatting is done within the commands themselves. The read command will only input the necessary information (even if it must read several lines) while readln additionally discards the remainder of the current input line. The output commands, write and writeln, operate in an analogous fashion for output.

A significant example is now in order. Consider the problem of compiling an arithmetic expression. To greatly simplify the problem, assume all variables are one letter in length, no constants will appear, and the only operators will be +, —, *, and /. To make the problem interesting, assume that variables lettered a—h and o—z are of type real and the rest are of type integer. This is the same as the implicit types for FORTRAN. The program will produce code for a "stack machine." That is, the operators are applied only to operands already on the stack and the result will replace the operands on the stack. One task is the recognition of correct expressions. This may be done by several methods including precedence tables, LALR(1) parsers, and recursive descent. The latter will be used since it is the technique employed within most Pascal compilers. Recursive descent compilation utilizes a set of recursive procedures to recognize its input, with no backtracking. To understand the algorithm, consider the series of "syntax diagrams" in figure 1.

To generate a valid expression, for example, one enters the diagram from the left, selects an arbitrary path through the diagram, and exits to the right. Any box encountered is to be treated like a subroutine or procedure call. A circle or box with rounded edges is to be the current input item. An expression is thus an optional sign, a term, followed by any number (including zero) of addition or subtraction operators and terms. Similarly, one can define a term. These definitions build in the normal precedence of operators and correctly handle a unary minus. Notice that <expr> will call <term>, <term> will call <factor> and maybe <factor> will call <expr> again. This would occur whenever parentheses were encountered.

A second task to accomplish is to properly handle the necessary type conversion of intermediate results. Many textbooks refer to this problem when discussing syntax directed translation but few illustrate "real" solutions. As an example (using the above assumptions) consider

```
J + K * X
```

It is not known that this expression must

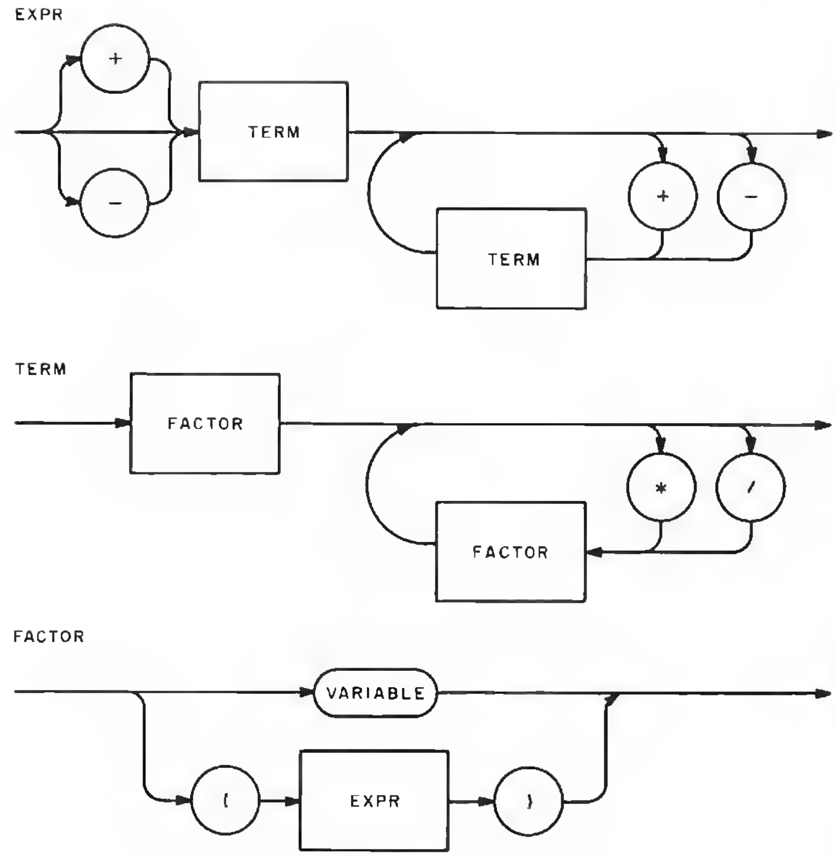


*Figure 1: Syntax diagrams for generation of valid expressions. The diagram "expr" is entered from the left and calls term. Term calls "factor" which may call expr, etc. This model assumes that the only operations are addition, subtraction, multiplication and division.*

have a real value until the X is seen. The recursive descent phase, independent of type conversion might translate this to

```
PUSH J
PUSH K
PUSH X
MUL
ADD
```

for its equivalent Polish Notation: J K X * +. However, what is really required is

```
PUSHI J
FLOAT   (convert the top of the stack)
PUSHI K
FLOAT
PUSHR X
MULR
ADDR
```

where the operators have either "R" or "I" suffixed to indicate a real or integer operator, respectively. The suffix for the PUSH instruction is known as soon as the variable name is seen. The types for the arithmetic operators and the insertion of the FLOAT instructions must be added somewhat after both operands have been seen; in other words, a fixup must be done. As one alternative, this may be accomplished by generating code in memory and keeping track of

**An expression is an optional sign, a term, followed by any number of addition or subtraction operators and terms.**

```
>>A+B
PUSHR     A
PUSHR     B
ADDR
>>A/I
PUSHR     A
PUSHI     I
FLOAT
DIVR
>>I/J
PUSHI     I
PUSHI     J
DIVI
>>J+K*X
PUSHI     J
FLOAT
PUSHI     K
FLOAT
PUSHR     X
MULR
ADDR
>>(I*J-(X+M))/(P+N)
PUSHI     I
PUSHI     J
MULI
FLOAT
PUSHR     X
PUSHI     M
FLOAT
ADDR
SUBR
PUSHR     P
PUSHI     N
FLOAT
ADDR
DIVR
>>A+B*
     ↑ ERROR
>>A*(B+I
        ↑ ERROR
>>I)*B
   ↑ ERROR
>>ZI
   ↑ ERROR
```

*Listing 2: Sample program execution. After outputting a prompt the program waits for an expression to be input. It then lists all of the instructions that would be generated for a compiler code.*

the type attribute of each operand and the addresses of where the last instruction for that operand was stored. If a type conversion is required on the first operand (of a binary operator), all code beyond the saved address is simply moved up one location and a FLOAT instruction is inserted. If a type conversion is required for the second operand, a FLOAT instruction is added as the last instruction in the evaluation of the second operand. *[In this paragraph and remaining text of the article, words in upper case refer to listing 1 . . .* RGAC*]*

The program in listing 1 is a solution to the expression evaluation problem. It is a direct implementation of the methods suggested. The main portion of the program is trivial; it asks for a line of input, calls procedure EXPR to parse the line, lists the output if there is no error, and repeats the process.

The type statements are important and quite varied. See that the constant MAXPC defines the maximum address space and is used in the declaration of the subrange type CODESPACE. The variables ATTR and LEXTY are symbolic scalar types and INSTRUCTION is a record type.

The variable CODE is an array of instructions. This is where the "compiled" code will reside. The type attribute of the second operand of an operation is stored in GATTR which is global to all the program's procedures.

The procedure SCAN picks up the next character(s), ignoring spaces and determines the correct token and type if it is a variable. Note the use of the case statement and the sequential nested conditionals.

The procedure ERROR outputs a line with an upward pointing arrow to indicate where the error occurred.

The procedures GENCODE and LISTCODE are responsible for encoding the instructions into the code array and decoding the code array for output respectively. The with statements simplify both the Pascal and compiled codes.

Any discrepancy in types of operands is resolved by FIXUP which inserts the code for the operator itself. In a full compiler, FIXUP would also worry about strings and other data types and issue the appropriate error messages when needed.

EXPR does most of the work, together with the procedures TERM and FACTOR. They function exactly as described above. They are quite simple in appearance but function correctly as the sample runs illustrate. The symbolic scalars ADDOP and MULOP are quite useful in this design.

When properly segmented, any program should be similarly constructed and as easy to read or modify. A lot may be gained from using a top down design. Given the time, anyone could stretch this program into a full compiler whose output was a similar Polish code, and alternatively encode this program into their favorite assembly language. All the hard work has really been done in expressing the algorithm to solve the problem.

I heartily recommend that anyone seriously interested in Pascal in particular and good programming style in general obtain the two books listed in the references. ■

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# Compilation and Pascal on the New Microprocessors

**Charles H Forsyth**

**Randall J Howard**

We are concerned with the use of high level languages, and in particular Pascal, on microcomputer systems. We are most interested in the use of such languages for what is termed, on larger computer systems, *systems programming*. This includes writing code to drive floppy disks, interpreters for APL or BASIC, or all those bits of code that people have until now written in assembler, and which in some way make their microcomputer systems friendly.

Microcomputer users show a generally high level of sophistication, so it might be surprising at first that so much of their code is still written in assembler. The advantages of writing in a high level language have been often described in computing literature: programs can be made more portable; they exhibit better structure; and they are easier to write and debug. In addition, it is much easier to let a compiler worry about the efficiency of the object code; and deficiencies of the object machine are hidden. With the 8 bit microcomputers like the Intel 8080 and Motorola 6800, we feel that there is little choice but to write in assembler (or interpreter), since the facilities provided by their order codes are simply insufficient to support most high level languages.

Compilation may be inappropriate for 8 bit microcomputers, but it is the most attractive alternative for the hybrid 8 and 16 bit microcomputers (such as the Motorola 6809), especially with respect to eliminating most assembly code on these machines. We also feel that Pascal has facilities that enable a compiler to generate better code for such machines than might be expected from compilers for other languages.

Jensen and Wirth provide the definition of and tutorial introduction to Pascal in the *Pascal User Manual and Report*. Aho and Ullman's book, *Principles of Compiler Construction*, provides an excellent description of the elements of a compiler.

## Options

Tiny BASIC, Tiny C, APL, and FOCAL are implemented on microcomputers with interpretive code. Interpretation has a number of advantages. Since the interpretive language is highly specialized, it can be made compact. New *macro operations* can be added easily as time and experience dictate. Array and structure addressing and the block copying associated with array and structure assignment may be made particularly cheap. When interpreting array indexing, run time checks of the index values against the array bounds are possible (although often left out) at little extra cost. This is true of other kinds of debugging facilities as well, such as value traces or stack tracebacks. Both compiler and interpreter are easy to write, especially if the interpreted code implements a stack machine. Interpretation's main disadvantage is that it is slow.

An alternative to interpretation that alleviates this latter problem of speed somewhat is *threaded code*, which has been described as "interpretive code which needs no interpreter" (see references 2 and 3). Rather than having a sequence of codes and

> The listings in this article were prepared by arrangement with Walter Banks of the University of Waterloo.

```
type
        index = 0..10;
        twiceIndex = 0..20;
        unsigned = 0..32767;
        short = -128..127;
        shortUnsigned = 0..255;
        thing = record
                        field1: 0..7;
                        field2: 0..31
                end;
        packedThing = packed record
                        field1: 0..7;
                        field2: 0..31;
                end;
var
        a, b: array [index] of integer;
        i, j: index;
        k: twiceIndex;

        s: set of (READY, BLOCKED, RUNNING, SWAPIN, SWAPOUT);
begin
        a[i] := b[j];       {the dreaded array-indexing example}

        k := i+j;                  {subranges are useful}

        s := [READY, BLOCKED, RUNNING];{set operations}
        s := s - [READY, RUNNING];
        s := s + [SWAPIN];
        s := s * [SWAPIN, BLOCKED];
end
```

*Listing 1: Pascal program fragment for array indexing.*

```
tsx                     /Enable indexing off sp
lda     A, j(X)         /Fetch address of j relative..
lda     B, j+1(X)       /to sp into (A,B) register pair
asl     B               /Shift (AB) pair left by 1..
rol     A               /yielding integer offset
add     B, b+1(X)       /Add in 16-bit array
adc     A, b(X)         /pointer 1 to (A,B) pair
sta     A, temp         /Transfer (A,B) pair to X reg..
sta     B, temp+1       /..not re-entrant
ldx     temp
lda     A, 0(X)         /Finally, fetch b[j] into..
lda     B, 1(X)         /(A,B) pair..
psh     A               /and push onto stack
psh     B
tsx                     /Following code is repeat of..
lda     A, i(X)         /above for getting address of..
lda     B, i+1(X)       /array element a[i]
asl     B
rol     A
add     B, a+1(X)
adc     A, a(X)
sta     A, temp
sta     B, temp+1
ldx     temp            /X now points at a[i]
pul     B               /Pop b[j] from stack..
pul     A               /into (A,B) pair..
sta     A, 0(X)         /and store in a[i]
sta     B, 1(X)

Total code: 52 bytes
```

*Listing 2: Motorola 6800 assembly code for the first line of the Pascal fragment shown in listing 1.*

an interpreter which reads them, calling out to the routines implementing each operation, threaded code simply contains the sequence of machine addresses of the routines to process each operation. These routines, much like the code segments called by the interpreter to implement the pseudo-machine, provide the run time support for the threaded code. Rather than return to an interpreter after it has done its work, though, a routine simply jumps (indirectly) to the next such routine in the code flow. Arguments are passed to these routines in various ways — for example, by placing values or addresses between the code pointers.

The third approach to language implementation is that traditionally adopted on larger machines: real code generation. This approach provides the fastest program execution at the possible expense of space used by the object code. On almost any machine, the high level constructs of flow of control and logical expressions as well as calls to the intrinsic built-in functions can be directly implemented as branch or jump instructions with relatively little expenditure of speed or time. However, for many of the existing microcomputers, code generation for even the simplest of the fundamental high level language constructs proves effectively impossible. Such constructs include most common arithmetic operations, array and structure accessing, and automatic storage manipulation. Particularly difficult on some machines are multiply, divide, modulus and string operations. Therefore it is important to determine what properties of a particular machine make it suitable for real code generation.

## 8 Bit Microcomputers

A detailed study of the common 8 bit computers available today (eg: Motorola 6800, Intel 8080) quickly reveals that such machines are not conducive to real code generation by compilers for high level languages such as Pascal.

On such machines, compilations of even the simplest arithmetic or pointer expressions lead to a very high object to source code ratio, if such constructs can be compiled at all. Listing 2 gives an example of code which might be compiled for a Motorola 6800 to implement the Pascal assignment statement: *a[i]:=b[j];* in listing 1. The assumption here is that automatic arrays are implemented as pointers on the stack to areas of storage residing elsewhere. In addition, we have assumed that the compiler keeps track of the stack offsets for its automatic variables relative to the moving stack pointer; we are using the notation *j* to represent the stack offset of variable j. In addition to this code segment, the procedure preamble must set up the pointers to the arrays a and b (stored at offsets *a* and *b* respectively), to point at the integer before the beginning of the array. Thus, for example, *a[1]* will then be identified with the beginning of the storage associated with the array a.

Beyond the actual code shown here, however, the most important insight to be gained from all of this is the sheer bulk of code that such a simple construct would generate (and it is not even reentrant at that). Imagine how large the object code size would be for even a reasonably short Pascal program.

Implementing threaded code is somewhat difficult on these machines because they require 16 bit memory pointers, an efficient mechanism for indirect addressing, and some method of incrementing such a pointer to the next 16 bit pointer. At least one of the above criteria is so troublesome on both the Motorola 6800 and the Intel 8080 that the threaded code becomes unwieldy. Thus, for these machines one has little choice but to interpret or write in assembler. This suggests that the interpreters themselves must be implemented in assembly language.

The above discussion is an attempt to analyze the reasons why programs written for 8 bit microcomputers have traditionally been interpreted or written in assembly or machine code, rather than being compiled into "true" code from a high level language.

## 16 Bit Microcomputers

Previously, the only alternative to the 8 bit architecture was that of the 16 bit microcomputer. Examples of such machines include the TI-990/4 and the DEC LSI-11. While the considerable costs of these processors tend to make them impractical for many computer experimenters, and for those applications in which many processors are required, it is instructive to consider what properties set these machines apart from their 8 bit counterparts with respect to code generation. In fact, it can be shown that, given a machine of sufficient sophistication, it should be possible for a compiler to do as good a job as an assembler programmer vis-à-vis machine resource utilization.

There are two main virtues of these 16 bit machines. In the first place, these machines have complete 16 bit instruction repertoires including hardware multiplication, division, and long shifts. As well, the 16 bit processors tend to have a good complement of addressing modes such as indexing, stack operations, automatic increment and decrement of pointers, and so on. (Here, as elsewhere in this article, the descriptive terms may seem fuzzy. *Good complement* does not admit of a precise meaning. With real machines, one usually loses clever addressing modes, for plenty of general purpose registers, and one must balance the benefits somehow. The final judgment will usually be that of the person writing the compiler.) With these attributes, it is a fairly straightforward task to construct a compiler for a high level language such as Pascal.

Let

$r$ := { **X, Y, S, U** }
$a$ := { **A, B, D** }
$x$ := **memory reference**
$c$ := **constant value**

| | |
|---|---|
| *x* | **long relative, short relative, direct** |
| **x* | **long & short relative indirect** |
| *$x* | **immediate byte** |
| **$x* | **extended** |
| ***$x* | **extended indirect** |
| *c(r)* | **±4, ±7, ±15 bit indexing** |
| **c(r)* | **±7 and ±15 bit indirect indexing** |
| *(r)+* | **Auto Increment by 1 or 2** |
| *-(r)* | **Auto Decrement by 1 or 2** |
| **(r)+* | **Indirect Auto Increment by 2** |
| **-(r)* | **Indirect Auto Decrement by 2** |
| *a(r)* | **Accumulator Indexing** |
| **a(r)* | **Indirect Accumulator Indexing** |

*Table 1: A summary of the Motorola MC6809 addressing modes.*

## 8 and 16 Bit Hybrids

The current trend in 8 bit microprocessor technology is towards a hybrid combination 8 and 16 bit machine. Essentially, these processors are capable of 16 bit operations while retaining 8 bit data paths throughout the processor architecture. A prime example of such a hybrid is the Motorola 6809, which is due for formal product release later this year. Table 1 gives a summary of the basic addressing capabilities of the Motorola 6809, expressed in a hypothetical assembler syntax which removes from the user the burden of understanding all of the details of the actual hardware addressing modes.

What advantages do these machines have over their pure 8 bit predecessors? In particular, these machines now have at least one accumulator for performing addition, subtraction, shifting and comparison operations on 16 bit data. A second feature of these machines is the 16 bit memory pointer, which, combined with the ability to automatically increment and decrement such pointers, provides a very general memory accessing capability. In addition, common high level language features such as stack frames and display pointers become quite easy with the general index and stack registers of the M6809. It is apparent that the Motorola 6809 is particularly well-endowed with addressing modes which tend to facilitate code generation for high level languages.

Consider again the array assignment which the 6800 handled so dismally. The Motorola 6809 code for the same construct is given in listing 3. (Note that the syntax of our assembler code is intended to be more or less consistent amongst the examples, and not necessarily that of the manufacturer's assembler. It is in fact the syntax used by our UNIX assemblers for these machines.) Code for the PDP-11/45, considered to be a good instruction set given in listing 4, is included for comparison.

It is rather precipitous to deduce much from this one example, although array indexing does exercise many of the addressing modes of a machine, and such assignment statements can provide a check on the register usage of a compiler. How a particular architecture fares with more general arithmetic expressions and function and procedure call, save, and return sequences would provide further basis of comparison. Indeed, other examples that we have tried suggest that the results of this comparison are typical.

```
/ 'X' points to top of stack (display)
lda     D, i(X)       / i
asl     B
rol     A             / *2
add     D, $a-2       / +offset of 'a'
lea     Y, D(X)       / +stack top
lda     D, j(X)       /j
asl     B
rol     A             / *2
add     D, $b-2       / +offset of 'b'
lda     D, D(X)       / +stack top
sta     D, (Y)        / a[i] := b[j]

Total code: 20 bytes
```

*Listing 3: Motorola MC6809 assembly code for array indexing program fragment.*

```
/ r5 points to the "top" of the
/ stack frame
mov    j(r5),r0          /j
asl    r0                / *2
add    r5,r0             /+ display pointer
mov    i(r5),r1          /i
asl    r1                / *2
add    r5,r1             /+ display pointer
mov    b-2(r0),a-2(r1)            / a[i] := b[j];

Total code: 22 bytes
```

*Lisitng 4: DEC PDP-11 assembly code for array indexing example.*

## Special Advantages of Pascal

We feel that the use of Pascal and a competent compiler can lead to better code in many cases on hybrid 8 and 16 bit machines than can be achieved with many other languages. Obviously, the best results will require that Pascal be properly used – that subranges be used where possible, for example – and that these be declared to be as small as possible. A Pascal program can contain a great deal of information that allows even a straightforward compiler to generate code which makes good use of the available registers. The Pascal declarations of listing 1 provide illustration for the following discussion, and the code given is for the Motorola 6809. Remember that the intent is not to describe an implementation of Pascal.

The declaration of scalar and subrange types essentially allows the declaration of *small* integers and makes known the detailed characteristics of variables of such types to the compiler. Variables may thus be completely bounded, and the compiler can compute upper and lower bounds on the value of an expression.

In our example, variables of type *short* or *shortUnsigned* may be loaded into the 8 bit accumulators of the 6809, and both registers may be used simultaneously. A variable may be recognized as *unsigned* if there are no negative values in the subrange to which it belongs. In the assignment statement *k := i+j;* the variables *i*, and *j*, are both in the range 0 thru 10. The result is thus in the range 0 thru 20, and an 8 bit accumulator may again be used to compute this result. (All of this is particularly useful if array indexing is also involved.)

The Pascal *set* type may be regarded as providing a readable way to do "bit twiddling." A set is typically implemented as a sequence of bits, one for each element of the base type of the set. The variable *s* might then be a byte in which the low order bit corresponds to the element READY, the next to BLOCKED, and so on. The sequence of assignments might then be compiled as in listing 5.

Pascal, of course, provides pointers, record structures and arrays.

The use of pointers is strictly controlled: arbitrary arithmetic operations on pointers are not allowed. About the only things that may be done with a pointer variable are: indirect addressing, assigning another pointer to it, or passing it to a procedure or function. This structured use of pointers and indexing results in a very stylized use of pointers in the compiler's internal representation. This in turn allows the compiler to detect the places where double indexing may be used to advantage rather easily, on machines like the 6809 which have this feature.

Indexing of an array of records does require multiplication of the index by the width, in bytes, of the record. Often, this may be accomplished by a shift. Of course, this cannot always be done, since records need not be a power of 2 in length, though a compiler could arrange to round the size of a record up to an appropriate boundary if the difference were small. In any event, provided the size of the record is no more than eight bits (as an unsigned quantity), the code for the multiplication could reasonably be included in line.

We wondered how often division or multiplication is used in the UNIX system (an operating system developed at Bell Labs), and wrote a simple command file which would compile each of the source programs of the system and scan the resulting assembler for *mul* and *div* instructions. The number of multiplications was of interest in light of the above discussion; the number of divisions was collected as well, since these would have to be interpreted by subroutine on the 6809, and we wanted to know how many occurred in critical code. The results are shown in table 2.

Only one of the divide instructions occurs in a routine that might be regarded as significant, with respect to increasing system overhead, were a subroutine called to do the divide piecemeal; and that division was performed at a low priority level. 31 of the divide instructions in the device driver routines were in disk drivers, which had to compute track and cylinder offsets. The multiplications in all cases were of small amounts; it seems that (most likely by accident) record structures used in the kernel happened to be a power of 2 in length. It would have been more instructive, perhaps, to examine user programs, but in that case it would have been more difficult to separate multiplications written explicitly from those created implicitly by array indexing.

A Pascal programmer may declare particular record or array types as *packed*, which is a hint to the compiler that the programmer would prefer elements of the given type to occupy as little space as possible even if there is a cost in increased code to access them. This leaves the unit of packing to the compiler. For example, the types *thing* and *packedThing* (see listing 1) describe packed and unpacked records with similar fields (to Pascal, these record types are not compatible in any way). In a *thing*, both *field1* and *field2* will likely be bytes, but if a compiler implements the notion *packed* completely, then in a *packedThing*, *field1* will likely occupy three bits, and *field2* five bits, ie: they would share the same byte of storage. Packing of records on microcomputers is

```
/ X is display pointer
/ equates are in octal
READY = 01
BLOCKED = 02
RUNNING = 04
SWAPIN = 010
SWAPOUT = 020
lda     A, $READY+BLOCKED+RUNNING / immediate load
sta     A, s(X)
/
lda     A, s(X)
anda    A, $![READY+RUNNING] / complement
sta     A, s(X)
/
lda     A, s(X)
ora     A, $SWAPIN
sta     A, s(X)
/
lda     A, s(X)
anda    A, $[SWAPIN+BLOCKED]
sta     A, s(X)
```

*Listing 5: Set assignment code for the Motorola MC6809 processor.*

often much easier than on the larger processors, because microprocessors do not have the alignment problems that plague compiler writers on those machines.

Finally, as in many other languages, the order of evaluation of expressions is left to the implementor, but since side effects are not allowed, no legal Pascal program can possibly be harmed by this. This has two related effects: in arithmetic expressions, the compiler may evaluate the operands in the order that leads to the least amount of code, and in Boolean expressions the left-hand side of the logical operators *and* and *or* need not be evaluated if the expressions on the right determines the truth value of the entire expression. Faster or smaller code will usually result if a compiler takes advantage of these properties.

## Pascal: Problems?

We feel that there are a number of areas where Pascal is likely to require expensive mechanisms, and which would be inappropriate for a systems programming environment. One solution might be to implement a subset of the language, leaving these hard

| Section | Lines of C Code | Number of Multiplications | Number of Divisions |
|---|---|---|---|
| UNIX Kernel | 6,013 | 4 | 9 |
| Device Drivers | 8,640 | 62 | 41 |

*Table 2: A search through a particular operating system to determine the number of multiplications and divisions used. This was done to determine how important the speed of a multiplication and division routine would be to a typical program.*

features aside, but in most cases, since the expensive mechanisms are only invoked if the programmer asks for them, it should be sufficient to have the compiler avoid including the associated run time procedures when they are not requested. (This is worth mentioning, if only because this rule is often not followed.) We shall first mention those constructs which are expensive, but which appear only by programmer request.

The semantics of Pascal's *file* variables, and the input/output (IO) system in general tend to reflect characteristics of a batch environment, with a restricted character set. The basic IO procedures are badly designed for an interactive terminal. The *read* and *write* procedures are fairly expensive to implement, since they are extremely general and all encompassing.

On machines like the 6809 which lack a divide instruction of any sort (let alone a 16 bit one), division will be done by calling a run time support routine. Only if the programmer explicitly writes either a divide, or modulus operation, will the call be generated. Floating point numbers will be interpreted, as usual.

Pascal allows procedures and functions to be defined inside other procedures and functions. This requires either a display, which must be copied, or a system of pointers by which a routine may access the variables owned by routines in an outer scope. (The latter is the most likely choice.)

Strings, arrays, records and large sets (if implemented) may all be assigned or passed as parameters to routines. These operations require block copies, but only if the operations appear in the source program. Copying of actual parameters may be avoided, of course, by declaring the matching formal parameters as *var* parameters.

The remaining points concern some philosophical concerns about Pascal and its implementation. (Input and output might also be considered in this class.)

## Philosophy

It has been observed that much of the checking done at run time in other languages may be done at compile time in Pascal. This is not always so, and run time checks are required on assignments of a variable from a larger subrange to a variable in a smaller subrange of a given type, or on similar use in array indexing, and pointers must always be checked to ensure that they are not *nil*. It might be argued that run time checks might not be done at all. It is better to arrange for them to be turned on and off, as required, in different sections of code.

The *Pascal Report* (see references) does not put boundaries on the number of elements in the base type of a *set* type, but it does say that an implementor will likely choose the word length of a given computer as that limit. Otherwise, routines are required to perform various Boolean operations on large bit strings. Unfortunately, a great many Pascal programs in existence, most notably those for the CDC 6600, assume that it is possible to delcare or use a *set of char*, as in:

```
if c in ['a'..'z'] then
    { c is a letter }
```

where *c* is declared as a *char*. The CDC Pascal compiler restricts the number of elements in the base type of a set to about the number of bits in a word (58), but the CDC character set is small enough that it (nearly) fits within a set. On a microcomputer with the ASCII character set even 16 bits is clearly insufficient, and larger sets may need to be implemented.

There is no method provided to initialize variables in their declaration. This is of consequence when one wishes to create a table with values that remain constant throughout the life of the program (eg: a translation table). The only way to do this in standard Pascal is to write a sequence of assignment statements. This will typically result in several bytes of code for each assignment, as well as forcing two copies of each data value in the table. On a large machine like the CDC 6600, this may be of little consequence, but on a microcomputer with little core, this is a distinct disadvantage. Of course, various implementations of Pascal have provided a means to do this sort of thing efficiently, but this results in a portability problem because each implementor tends to have slightly different rules about where and how these initializations may be accomplished.

## Conclusions

For languages like Pascal, compilation is the preferred method of implementation on hybrid 8 and 16 bit microprocessors. The object code size on these machines for common constructs in these languages seems to compare quite favorably with that for larger processors like the PDP-11 or the Honeywell 66/60. We illustrated this with a very simple array operation; the reader can try other operations.

When choosing a programming language, one typically considers not only the ease or difficulty of implementation and the efficiency of the compiled code, but stylistic qualities as well. For example, we have found the C language a pleasant and effective language for developing programs, but it does not, of course, follow that everyone else would. The same holds true for Pascal.

We merely note that the Pascal is interesting, in that Pascal programs may be so written as to allow a compiler to compile code which makes efficient use of 8 bit accumulators on machines that have them, and that amongst the other major high level languages this is an unusual property (PL/I is a likely exception). Whatever the language used, we hope to see the day when on microcomputer systems, as on UNIX, the use of assembly language for a program of any size is greeted with surprise, shock, despair, dismay, and outright hostility.■

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# Pascal versus BASIC:

## An Exercise

**Allan Schwartz**

### Introduction

Pascal is one of the newest high level languages on the personal computing scene. Pascal has been accepted at many universities for several years. It is being used more and more in industry outside of education, and has just recently been introduced in microcomputers. Why is there so much enthusiasm about Pascal?

Pascal is a general purpose language, the product of the long evolution of computer languages. It has a simple but elegant syntax and has been implemented in both large systems (CDC 6000, IBM 360 and 370, Burroughs 6700, etc) and microcomputers (LSI-11, 8080, 8085 and Z-80).

### Historical Background

Just as computer hardware has been continuously evolving during the past 25 years, so too have computer software requirements. Originally, computers were employed to work on mathematical tasks such as solving ballistics problems, or generating tables of logarithms. Later it became economically feasible to use computers for data processing or working with voluminous amounts of data such as census data or bank statements. Recently we have seen computers participate in various customized, dedicated applications like the control of traffic lights, microwave ovens and automobile ignitions.

We have seen a variety of applications and language requirements lead to an evolution of computer languages. "Programming" originally entailed the translation of simple algorithms into machine code and bit by bit loading of the computer's memory via the front panel. Later, assembly languages were used, followed by equation or formula translators such as FORTRAN. When it was discovered that computing involved mostly computing decisions and repetition, the language ALGOL (*ALGO*rithmic *L*anguage) was designed to express algorithms more clearly and conveniently. The need for a language to structure and represent all of the data and files in business data processing applications was filled by COBOL. Today we have Pascal, which has flexible data representations, sufficient flow of control statements to represent algorithms, and a clear, simple syntax making it a favorite for a variety of applications. Pascal is the result of several evolutionary steps in the history of computer languages.

Why is Pascal so appealing? First, it is an expressive language. It has several control structures that make the coding of algorithms very natural. Second, Pascal has flexible data representation.

### Expression of Algorithms in Pascal

Figure 1 presents an algorithm to compute the greatest common divisor (GCD) of X and Y. The greatest common divisor of the integers X and Y is the largest integer that will divide evenly into both X and Y. Note that three assertions are stated in the flowchart. The first, a necessary precondition, states that X and Y must be positive integers. The second is a loop invariant such that, when control passes through that path in the flowchart, the GCD(X, Y) is equal to the GCD(A, B). The third, a post condition, states that A is equal to B, which is equal to the result, the GCD(X, Y).

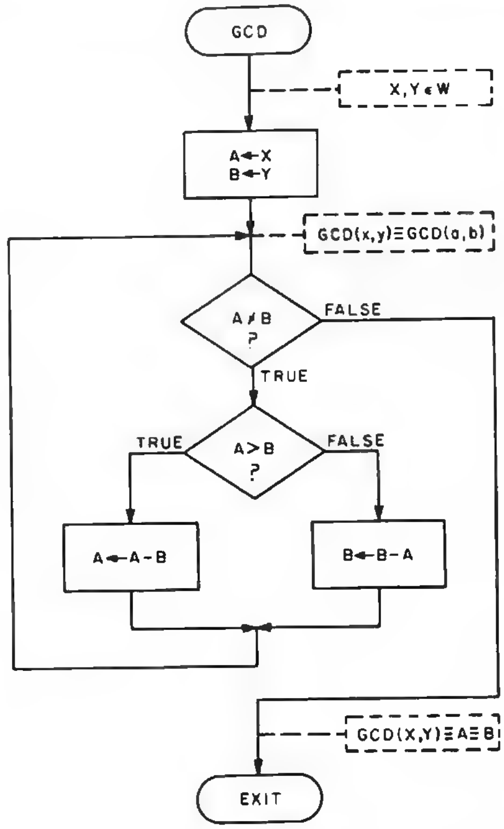
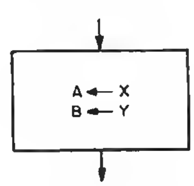



*Figure 1: An algorithm to calculate the greatest common divisor (GCD) of two integers. (The greatest common divisor of two integers is the largest integer that will divide evenly into the two integers.)*

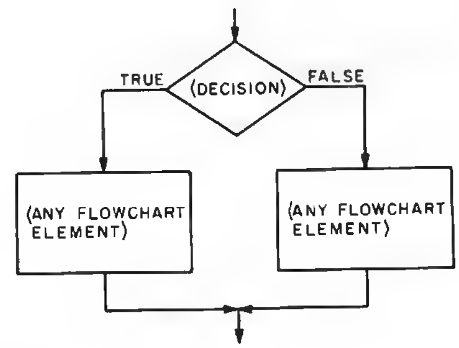
If we can prove these three points are true, then the algorithm is correct – that is, it will compute the greatest common divisor of X and Y. The loop invariance is easily proved, because if B is greater than A, the GCD(A,B) equals GCD(A, B–A) (a more rigorous proof is posed as an exercise in Wirth's book [see references]). The post condition is also easy to prove, because the path to this exit is taken only when A equals B, and then the GCD(A, A) certainly equals A.

We are now reassured that if the precondition is true, the algorithm will compute the desired result. Now, how do we code this algorithm into our favorite programming language? Before we answer that question, let's look at the elements of the flowchart. The flowchart in figure 1, and indeed any computable algorithm, is made up of three elements: *sequence*, *selection* and *repetition*. Sequences are represented in the flowchart by rectangular boxes such as:



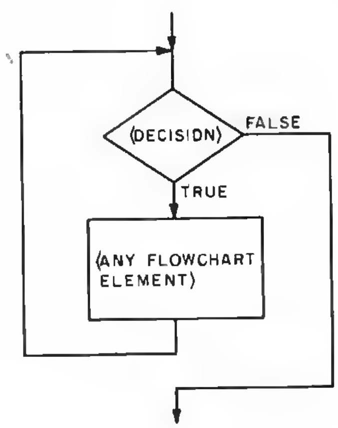

Note that this flowchart element has one entry (the arrow going in) and one exit. [*In BYTE's use of flowcharts, a top to bottom flow of control is assumed with arrows used for exceptions; in this article we make a stylistic exception, using extra arrows to emphasize flow. . .*CH]

The second flowchart element is selection. Selection is represented by:



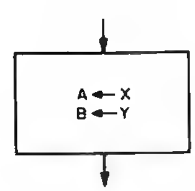

A selection flowchart element requires at least two or three boxes; however, it always has one entry and one exit.

The third flowchart element is repetition. It is represented by:




This form of repetition is called a "while loop," because while the decision is true, the element is repeated. Again, this element has one entry and one exit.

These flowchart elements have been translated directly into Pascal statements (see listing 1). Note that the sequence element




is translated into the two Pascal assignments:

*a* := *x*; *b* := *y*

Now some of the syntax details of Pascal become evident. The assignment operator is *:=*, which is different from the FOR-

TRAN or BASIC "=" in that the := operator in Pascal is used for assignment only, while the = in BASIC and FORTRAN is used as both the assignment operator and the equals sign. Statements are separated by semicolons, and any number of statements may be typed on one line. If the above sequence were a subelement of a selection element, it would be bracketed by **begin** and end keywords. For example:

**if** *(x>0)* **and** *(y>0)* **then**
  **begin** *a* := *x*; *b* := *y*
  **end**

Any number of elements combined into one sequence element by begin and end brackets forms a *compound statement.*

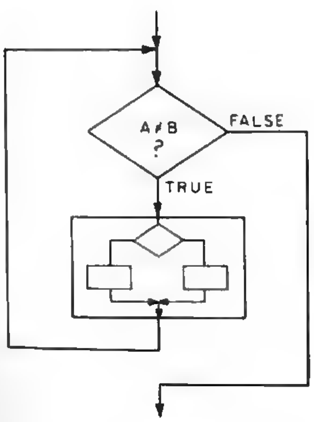
The selection flowchart element is translated into the Pascal if statement:

**if** *a>b* **then** *a* := *a–b*
  **else** *b* := *b–a*

And the repetition flowchart element is translated into the Pascal while statement:

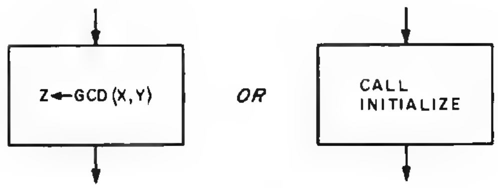
**while** *a* <> *b* **do** *<statement>*

The expression *<statement>* is called a *metavariable*. For an explanation, see the accompanying text box. Notice, though, that the metavariable *< statement >* in the greatest common divisor while clause is an if statement.




The real power in Pascal's algorithm descriptive capability lies in this sort of nesting. For example, any element can occur as a subelement of the while or if statement. These are called *structured* statements, and they can be nested to any depth.

Look again at the greatest common divisor (GCD) function in listing 1. Note that the routine consists of a heading and a variable declaration statement followed by one compound statement, bracketed by **begin** and **end**. Functions and procedures in Pascal can be thought of as named statements with local variables. They always have one entry and one exit, and therefore, a call is flowcharted as a sequence element such as:



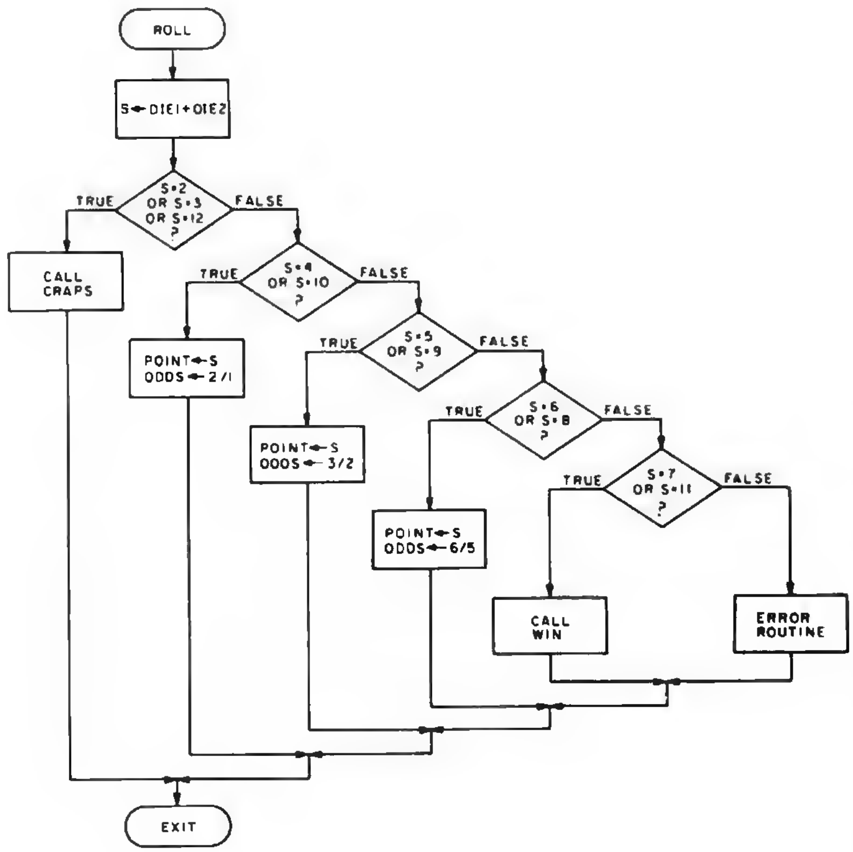




*Figure 2: Flowchart for a portion of the dice game "craps." The five IF tests can be implemented in Pascal with one case statement.*

> **Metavariables**
>
> *Bracketed symbols such as ("< statement >") all call metalinguistic variables (or metavariables) or syntactic units. They represent a class of possible language elements. They are nonterminal symbols; that is, the symbol "< statement >" itself will not appear in a Pascal program. It represents a set of legal symbols that can appear in its place in the program. Nonterminal symbols are bracketed by "<" and ">" and are printed in italics to distinguish them from terminal symbols such as* **for** := **if do**. *Terminal symbols are usually printed in heavy type if the symbol is a language key word, and appear exactly as they would in the Pascal program.*

Pascal has a second selection statement called the case statement. This statement is a concise representation of the special case of nested if statements. An example of this is the "craps first roll" algorithm used to implement the dice game called craps. A pair of dice can obviously have only one summed value from 2 to 12 on any given throw, making this an ideal use for the case statement (see figure 2). The five nested decisions can be represented with the following Pascal case statement:

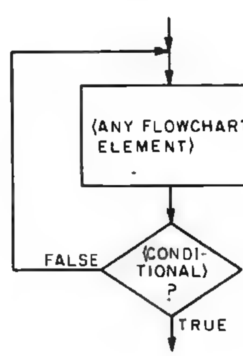
```
s : = die 1 + die 2;
case s of
   2, 3, 12 :
      craps;
   4, 10 :
      begin point : = s; odds : = 2/1
      end;
   5, 9 :
      begin point : = s; odds : = 3/2
      end;
   6, 8 :
      begin point : = s; odds : = 6/5
      end;
   7, 11 : win
end  {of case statement}
```

Of course, this could be represented using **if** statements; however, the case statement is much more concise and clear. When the decisions in a group of nested **if** statements are mutually exclusive, that is, if any one being true implies that the rest are false, then a case statement is probably the appropriate representation.

Pascal allows two other forms of repetition: the repeat statement and the **for** statement. The repeat statement:

```
repeat
   <any statement>
until <condition>
```

is represented by:




Repetitions can always be expressed as either repeat statements or while statements. However, one form usually sounds better. For example:

```
repeat shoot craps
until broke or out of time
```

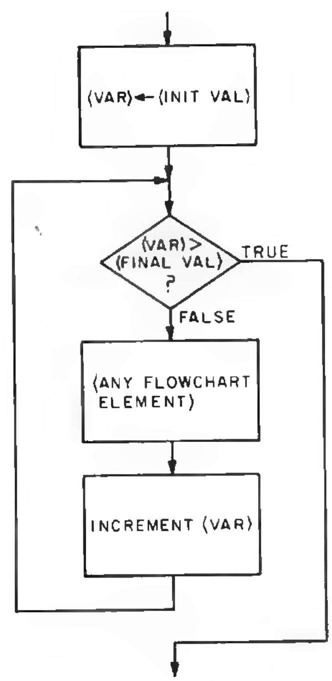
is equivalent to

```
shoot craps;
while not broke
and not out of time
do shoot craps
```

The for statement

```
for <var> :=
   <init val> to <final val>
   <any statement>
```

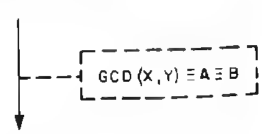
is represented by:




Notice that again there is one entry and one exit for this flowchart element.

Another element we might see in a flowchart is an arrow coming out of a subelement, perhaps to a different page of the flowchart. This exit from the normal flow of execution is the only use of the Pascal **goto** statement. Indeed, very few Pascal procedures need **goto** statements to express the algorithm. Goto statements can fog the otherwise clear logic of a routine.

A final element that might be found in flowcharts is an assertion and commentary such as:



The Pascal greatest common divisor (GCD) function has all of these elements in an appropriate place in the source code. Pascal allows comments, delimited with braces, { and }, to be freely inserted anywhere a blank can be inserted.

We can conclude that for each Pascal language statement there is a corresponding flowchart element, and vice versa. Therefore, one could easily flowchart any algorithm just from its Pascal listing. Compare the Pascal program in listing 1 to the FORTRAN and BASIC programs in listings 2 and 3. They are fundamentally identical, but all of the statement numbers and GOTOs in the FORTRAN and BASIC versions obscure the logic. You might maintain that, for so simple an example, there is no advantage for Pascal. One could flowchart the greatest common divisor (GCD) algorithm just from the BASIC listing. Of course you could, but how about flowcharting that 1200 line FORTRAN headache you wrote a year ago that has returned to haunt you?

### Data Representation in Pascal

Pascal has several flexible forms of data representation. A variable can be defined as a scalar (single value) or a structured type. The different scalar types are: real, integer, character, Boolean, and user defined or enumerated. The structured types include arrays, records, sets and files.

Users can define their own scalar types by enumeration. For example, in a traffic control program, there might be a variable called *signalcolor* which has a value of yellow, green or red. Or, in a microwave oven program, there might be a variable called *temp* which represents the cooking level specified. These concepts are represented by the following Pascal declarations:

```
type color = (red,yellow,green);
   cooking level = (warm,defrost,simmer,
                    roast,reheat,
                    maxpower);
var signalcolor: color;
   temp: cookinglevel;
```

In this example the type declaration describes the user defined types and the var declaration specifies variable names and their associated type.

Another innovation in Pascal is the ability to specify a subrange of a scalar type. For example, if the variable *count* is to be an integer between 1 and 10, the declaration would be:

```
var count: 1..10;
```

To further demonstrate these features, a BASIC program that would benefit from Pascal data representation is next explored.

### Mastermind Codebreaker Example

The Mastermind codebreaker algorithm I have chosen for this exercise was presented by WL Milligan in the October 1977 BYTE, pages 168 thru 171. His BASIC version is reproduced in listing 4. A Pascal translation is presented here in listing 5. Let us compare the two.

The first 15 lines of the Pascal version correspond to lines 10 to 45 in the BASIC version. These are the type declarations and the global variable declarations. These global variables can be referenced from within any

```
function gcd(x,y: integer): integer;
   var a,b: integer;        {x,y > 0}
   begin
      a := x;  b := y;
      while a <> b do     {GCD(X,Y) = GCD(A,B)}
         if a>b then a := a-b
                 else b := b-a;
                          {GCD(X,Y) = A = B}
      gcd := a
   end
```

*Listing 1: Pascal function to calculate the greatest common divisor of two integers.*

```
100   LET A=X
110   LET B=Y
120   IF A=B THEN 190
130      REM . . . GCD(X,Y) = GCD(A,B)
140      IF A>B THEN 170
150         LET B=B-A
160         GO TO 180
170         LET A=A-B
180   GO TO 120
190   REM . . . GCD(X,Y) = A = B
200   RETURN
```

*Listing 2: BASIC subroutine to compute the greatest common divisor of two integers.*

```
          INTEGER FUNCTION GCD(X,Y)
          INTEGER A,B,X,Y
          A=X
          B=Y .
    120   IF (A.EQ.B)  GO TO 190
C            . . . GCD(X,Y) = GCD(A,B)
             IF (A.GT.B)  GO TO 170
                B = B-A
                GO TO 180
    170         A = A-B
    180      CONTINUE
          GO TO 120
C
C         . . . GCD(X,Y) = A = B
    190   RETURN
          END
```

*Listing 3: FORTRAN function to compute the greatest common divisor of two integers.*

procedure. The type declarations define new variable types such as:

```
type colors = (colorless, red, blue,
               brown, green, yellow,
               orange, space);
     row    = array [1. .4] of colors;
     eval   = record
                black,white: 0. .4
              end;
```

This means that a variable of type *colors* has a value equal to one of these enumerated items. A variable of type *row* is an array of four *colors*. The type *eval* represents a codemaker's response to a guessed row. What does this represent in the game? This response is the number of exact color and position matches (black key pegs) and the number of out of position color matches (white key pegs). The codemaker responds with between 0 and 4 black and white key pegs. The type *eval* in the Pascal version accurately models this: a record consisting of two components, *black* and *white*, each an integer between 0 and 4.

The variable *version* represents the version number, either 1 or 2. The 10 possible rows of code pegs in the game are recorded in the Pascal structure declared as:

```
var rows: array [1. .10] of row;
```

Note that the careful selection of data representation makes the program much more clear and concise. The ability to deal with structures as a whole instead of just their elements tends to tighten up the logic of the program. For example, the BASIC lines:

```
820 REM ASSIGN NEXT ROW
830 FOR J=0 TO 3
840 LET R$(I+1,J)=D$(J)
845 NEXT J
```

are functionally equivalent to the Pascal assignment:

```
rows[i+1] := hyp {assign next row}
```

Also, the BASIC lines:

```
10 REM MASTER MIMO "CODEBREAKER"
20 REM CDOED IN RT-11 BASIC
30 RANOOMIZE
40 OIM R$(9,3),S(9,1)
45 DIM A$(6),B$(3),C$(3),O$(3)
50 REM IMITIALIZATIOM
60 FOR J=0 TO 6
70 REAO A$(J)
80 NEXT J
90 OATA "REO","BLUE","GREEN","YELLOW","BLACK","WHITE","SPACE"
100 LET L0=0
110 LET L1=0
120 LET L2=0
130 LET L3=0
140 PRINT "MASTER MINO CODEBREAKER"
145 PRINT "PLEASE BE PATIENT. SOMETIMES I TAKE A FEW MINUTES ON MY MOVE"
150 PRINT "WHICH VERSION (1 OR 2) ";
160 IMPUT V
170 LET V=V+5
180 REM ASSIGN COLORS AT RANDOM FOR ROW 1
190 FOR J=0 TO 3
200 LET R$(0,J)=A$(INT(V*RNO(J)))
210 MEXT J
220 REM START MAIN PLAY OF GAME HERE
230 REM I IS THE ROW COUNTER
240 FOR I=0 TO 9
245 PRINT
250 PRINT "MY MOVE FOR ROW"I+1" IS"
260 PRIMT R$(I,0),R$(I,1),R$(I,2),R$(I,3)
270 PRINT "HOW MANY BLACK PEGS  ";
280 INPUT S(I,0)
290 IF S(I,0)<>4 THEN 320
300 PRINT "THANKS FOR THE GAME"
305 PRINT
310 GO TO 870
320 IF S(I,0)<>3 THEN 360
330 LET S(I,1)=0\REM IF 3 BLACKS THEN 0 WHITES
340 GO TO 380
360 PRINT "HOW MANY WHITE PEGS  ";
370 INPUT S(I,1)
380 REM GENERATE HYPOTHESIS
390 FOR I0=L0 TO V-1
400 FOR I1=L1 TO V-1
410 FOR I2=L2 TO V-1
420 FOR I3=L3 TO V-1
430 LET O$(0)=A$(I0)
440 LET O$(1)=A$(I1)
450 LET D$(2)=A$(I2)
460 LET D$(3)=A$(I3)
470 REM CHECK ALL ROWS FROM FIRST TO CURRENT FOR CONSISTENCY
490 FOR R=0 TO I
500 FOR J=0 TO 3
510 LET C$(J)=R$(R,J)
520 LET B$(J)=D$(J)
530 NEXT J
540 REM USE ROW EVALUATION SUBROUTINE TO CHECK CONSISTENCY OF
550 REM HYPOTHESIS AGATNST EACH ROW
555 LET N=0\LET M=0
560 GOSUB 910
570 REM CHECK FOR AGREEMENT OF BLACK & WHITE COUNT
580 IF N<>S(R,0) THEN 700
590 IF M<>S(R,1) THEN 700
600 NEXT R
610 REM MAKE SURE THAT HYPOTHESIS ROW DOESNT DUPLICATE ROW 1
620 LET Z=0
630 FOR J=0 TO 3
640 IF R$(0,J)<>D$(J) THEN 660
650 LET Z=Z+1
660 NEXT J
670 IF Z=4 THEN 700
690 GO TO 820
700 NEXT I3
710 NEXT I2
720 NEXT I1
730 NEXT I0
740 PRINT "I HAVE REACHED AN IMPASSE IN MY THINKING"
750 PRINT "COULD YOU HAVE MADE AN ERROR?"
760 GO TO 870
770 LET L0=I0
780 LET L1=I1
790 LET L2=I2
800 LET L3=I3+1
810 REM DO NOT RECHECK ELIMINATED POSSIBILITIES
820 REM ASSIGN NEXT ROW
830 FOR J=0 TO 3
840 LET R$(I+1,J)=D$(J)
845 NEXT J
850 NEXT 1
860 PRINT "I AM STUMPED -- YOU WIN"
870 PRINT "ANOTHER GAME  ";
880 INPUT R$
890 IF R$="Y" THEN 150
900 STOP
910 REM SUBROUTINE TO EVALUATE RESPONSE
920 REM COUNT BLACKS FIRST
930 FOR J1=0 TO 3
940 IF C$(J1)<>B$(J1) THEN 960
950 LET N=N+1
960 NEXT J1
970 REM NOW COUNT WHITES
980 FOR J1=0 TO 3
990 FOR J2=0 TO 3
1000 IF J1=J2 THEN 1080
1010 IF C$(J1)=B$(J1) THEN 1080
1020 IF C$(J2)=B$(J2) THEN 1080
1030 IF C$(J1)<>B$(J2) THEN 1080
1040 LET M=M+1
1050 LET B$(J2)="X"\REM DUMMY WRONG VALUE
1070 GO TO 1090
1080 NEXT J2
1090 NEXT J1
1100 RETURN
1110 STOP
2000 END
```

*Listing 4: Codebreaker portion of W Lloyd Milligan's Mastermind game written in BASIC. The program appeared originally in the October 1977 BYTE, pages 169 and 170 (see page 49 of this edition for a description of Mastermind). Compare this with the Pascal version in listing 5.*

```
610 REM MAKE SURE THAT
    HYPOTHESIS ROW DOESN'T
    DUPLICATE ROW 1
620 LET Z=0
630 FOR J=0 TO 3
640 IF R$(0,J)<>D$(J) THEN 660
650 LET Z=Z+1
660 NEXT J
670 IF Z=4 THEN 700
690 GO TO 820
```

are functionally equivalent to the Pascal statement:

if *hyp* <> *rows[1]* then goto 820

Mr Milligan's BASIC version is well written and well structured. It contains three key routines: initialization (lines 50 to 210); generate hypothesis (lines 380 to 845); and evaluate response (lines 910 to 1100). However, due to the inexpressiveness of BASIC, it takes careful study, even of this well-written BASIC program, to recognize its structure. On the other hand, looking at the Pascal version of the same algorithm, the expressiveness of the language shows the structure at a glance. Similarly, the use of meaningful variable names and Pascal record structures makes the data representation readable. Table 1 describes which variables in the Pascal version are used in the same context as variables in the BASIC version.

As careful as you are when coding BASIC, bugs are bound to creep in. For example, in the BASIC version (listing 4), lines 610 thru 690 are unnecessary. Additionally, there is no path through lines 770 to 810. Coding errors rarely creep into Pascal programs because the compiler enforces variable declarations and type agreement. For example, *evaluations[5] := rows[5]* is illegal because they are not type-compatible. Also *c := brown-red* is illegal because arithmetic is undefined for our user defined *colors* type. And, *version := 3* is illegal because the value 3 is outside the legal range for *version*.

## Other Pascal Attributes

We have looked at some of the noteworthy features in Pascal. There are also the powerful features of block structured scope of names, recursion and dynamic allocation of storage. Pascal is known as a very "safe" language because it optionally has extensive compile and run time type checking including type compatability, subrange bounds and array index bounds. Pascal has many other data representations not illustrated here, such as sequential files, arrays, pointers and sets. I can't begin to explain all of these features here, but you don't have to under-

*Listing 5: Pascal version of the Mastermind BASIC program in listing 4.*

```
program mm2(input,output);

label   870;

type    colors = (colorless, red, blue, brown, green, yellow, orange, space);
        row    = array [1..4] of colors;
        eval   = record
                    black, white: 0..4
                 end;


var     evaluations: array [1..10] of eval;
        rows:        array [1..10] of row;
        name:        array [colors] of packed array [1..6] of char
        color:       array [0..7] of colors;
        redrow: row;  { First hypothesis checked }
        last:   row;  { Last hypothesis formed   }
        version: 1..2;    maxcolor: orange..space;
        i: 1..9;  j: 1..4;  ch: char;



procedure initialization;
    var c: colors;  i: 1..4;
    begin                                name[green]  := 'GREEN  ';
        name[red]      := 'RED    ';     name[yellow] := 'YELLOW';
        name[blue]     := 'BLUE   ';     name[orange] := 'ORANGE';
        name[brown]    := 'BROWN ';      name[space]  := 'SPACE  ';
        for c := colorless to space do
            color[ord(c)] := c;
        for i := 1 to 4 do
            redrow[i] := red;
        last := redrow;
        writeln(' MASTERMIND CODEBREAKER');
        writeln(' PLEASE BE PATIENT. SOMETIMES I TAKE A FEW');
        writeln(' MINUTES ON MY MOVE.  WHICH VERSION (1 or 2)?');
        read (version);
        maxcolor := color[version+5];
        { Assign colors at random for row 1 }

        for i := 1 to 4 do
            rows[1,i] := color[ trunc((version+5)*random(0.0)+1.0) ]
    end   {   Of Initialization Routine     } ;



procedure checkconsistancy (hypothesis,previousrow: row;
                                   var e: eval);
    label 1090;
    var j1,j2: 1..4;
    begin
        { Count blacks first }
        e.black := 0;
        for j1 := 1 to 4 do
            if hypothesis[j1] = previousrow[j1] then
                e.black := e.black + 1;
        { Now count whites }
        e.white := 0;
        for j1 := 1 to 4 do
            begin
                for j2 := 1 to 4 do
                    if (j1≠j2) and
                       (hypothesis[j1] ≠ previousrow[j1]) and
                       (hypothesis[j2] ≠ previousrow[j2]) and
                       (hypothesis[j1] = previousrow[j2]) then
                       begin
                            e.white := e.white + 1;
                            { Dummy wrong value }
                            previousrow[j2] := colorless;
                            goto 1090      { Exit J2 loop }
                       end;
                1090:
            end
    end  { Of Check Consistancy Procedure }
```

*Listing 5, continued*

```
function formhypothesis: Boolean;
    label 820;
    var i1,i2,i3,i4: colors;
        r: 0..9;
        hyp: row;
        eval1: eval;
        viable: Boolean;

    begin    { forming Hypothesis }
        viable := true;
        for i1 := last[1] to maxcolor do
        for i2 := last[2] to maxcolor do
        for i3 := last[3] to maxcolor do
        for i4 := last[4] to maxcolor do

            begin
                last := redrow;
                hyp[1] := i1; hyp[2] := i2; hyp[3] := i3; hyp[4] := i4;
                { Check all rows so far for consistancy }
                r := 0;
                repeat
                    r := r + 1;
                    checkconsistancy(hyp,rows[r],eval1);
                until (eval1 ≠ evaluations[r]) or (r = i);
                if eval1 = evaluations[r] then
                    { Make sure that hypothesis doesn't duplicate row 1;
                      if it hasn't then we have a viable hypothesis       }
                if hyp ≠ rows[1] then goto 820;
                    { Otherwise, keep searching....NEXT i4,i3,i2,i1 }
            end;
        viable = false;        { No viable hypothesis left }
        820:  if viable then
            begin    { Do not recheck eliminated possibilities }
                last := hyp;
                rows[i+1] := hyp        { Assign next row }
            end
        else begin
                writeln (' I HAVE REACHED AN IMPASSE. ');
                writeln (' COULD YOU HAVE MADE AN ERROR?')
            end;
        formhypothesis := viable        { Return with function value }
    end    { Of Form Hypothesis Procedure      } ;


begin      { Mastermind Codebreaker }

    repeat
        initialize;
        { Start main play of game here }
        for i := 1 to 9 do
            begin
                writeln;     write ('MY MOVE FOR ROW',i: 2,' is');
                for j := 1 to 4 do
                    write (name[rows[i,j]]: 8); writeln;
                writeln ('HOW MANY BLACK PEGS?');
                read (evaluations[i].black);
                if evaluations[i].black = 4 then
                    begin
                        writeln ('THANKS FOR THE GAME'); goto 870
                    end;
                if evaluations[i].black = 3 then
                    evaluations[i].white := 0
                else begin
                        writeln (' HOW MANY WHITE PEGS?');
                        read (evaluations[i].white)
                    end;
                if not formhypothesis then goto 870
            end;
        writeln (' I AM STUMPED —— YOU WIN!');
870:    repeat
            writeln (' ANOTHER GAME?'); read (ch)
        until (ch = 'Y') or (ch = 'N')
    until ch = 'N'
end    {    Of Main Program  }
```

stand all of them before you write your first Pascal program.

The main selling feature of Pascal is that properly developed programs are extremely easy to debug. Once you get a clean compile, the program usually runs! Why? Because the algorithms are expressed *clearly and naturally*. The range of all control variables are well specified and can be enforced at run time. The data types all agree and are appropriate to the problem. The program is readable – data types mean what they say – and it is therefore maintainable. Pascal encourages the methodical and systematic development of algorithms, an important structured programming method.

I hope this survey of Pascal has whet your appetite for the language. If so, read more about Pascal in this issue, then pick up any of the books in the references and dive in!

Pascal is a rich and fertile language that emphasizes the expression of algorithms and data representation naturally and clearly. When will your microcomputer speak Pascal?■

**REFERENCES**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Other books:

Dahl, O J, Dijkstra, E W and Hoare, C A R, *Structured Programming,* Academic Press, New York, 1972.

Jensen, K and Wirth, N, *Pascal User Manual and Report* (second edition), Springer-Verlag, New York, 1976.

Wirth, N, *Algorithms + Data Structures = Programs,* Prentice-Hall, Englewood Cliffs NJ, 1976.

| BASIC Version | Pascal Version |
|---|---|
| **Lines 220 to 270 and 850 to 900**<br><br>I<br>DIM R$(9,3)<br>R$<br>DIM S(9,1) | **program** *mm2*<br><br>*i: 1 . . 9; j: 1 . . 4*<br>*rows:* **array** *[1 . . 10]* **of** *row*<br>*ch: char*<br>*evaluations:* **array** *[1 . . 10]* **of** *eval* |
| **Lines 50 to 210**<br><br>J<br>DIM A$(6)<br><br>V | **procedure** *initialization*<br><br>*i: 1 . . 4; c: colors*<br>*name:* **array** *[colors]* **of** *string*<br>*color:* **array** *[0 . . 7]* **of** *colors*<br>*version: 1 . . 2* |
| **Lines 380 to 845**<br><br>I0,I1,I2,I3<br>L0,L1,L2,L3<br>V<br>DIM A$(6)<br>DIM D$(3)<br>R<br>J<br>N,M | **procedure** *formhypothesis*<br><br>*i1,i2,i3,i4: colors*<br>*redrow, last: row*<br>*maxcolor: orange. . space*<br><br>*hyp: row*<br>*r: 0 . . 9*<br><br>*eval1: eval* |
| **Lines 910 to 1100**<br><br>J1,J2<br>DIM C$(3)<br>DIM B$(3)<br>N,M | **procedure** *Checkconsistency*<br><br>*j1,j2: 1 . . 4*<br>*hypothesis: row*<br>*previousrow: row*<br>*e: eval* |

*Table 1: A comparison of the variables used in the two versions of the Mastermind game (see listings 4 and 5).*

### What Is Mastermind?

One of the most interesting conventional (ie: noncomputer) games on the market is "Mastermind," distributed by Invicta Plastics, Suite 940, 200 5th Av, New York NY 10010, and available in many local stores. Mastermind involves deductive logic, hypothesis testing and probabilistic inference. In Mastermind, the players take turns as "codemaker" and "codebreaker." The codemaker sets up a concealed row of four colored pegs from a set of Red, BLue, BRown, Green, Yellow and Orange pegs. It is acceptable to use the same color or colors more than once. In version 2, a more advanced game, empty Spaces are also permitted.

To challenge the computer program you are the codemaker. Write down a code. A row of four colors invokes the codebreaker computer program. It will take up to ten tries (rows) to discover the secret arrangement of colors in the concealed row. After printing each guess, the program will prompt you for the number of black and white key pegs.

The number of black pegs corresponds to the number of correct colors in correct positions. An important rule is that no position in the try is counted more than once.

When evaluating the program's try it is necessary to count black and white pegs carefully. If you make a mistake counting the number of exact or inexact correspondences, the program may exhaust all possible arrangements without finding a possible valid try. In this event the message:

I HAVE REACHED AN IMPASSE.
COULD YOU HAVE MADE AN ERROR?

is printed.

*(Adapted from W Lloyd Milligan's article, "Mastermind," October 1977 BYTE, page 168.)*

# Pascal versus BASIC: Round 2 Includes FORTRAN

Lawrence C Andrews
2634 Wycliffe Rd
Baltimore MD 21234

The article "Pascal versus BASIC: An Exercise," by Allan M Schwartz (page 41) is a typical example of a language chauvinist using a language ineptly and then pointing to the faults in the code he has written as inherent properties of the language.

The function GCD (page 45) that he has written (leaving aside the BASIC version) has several faults, to wit:

1) X and Y are not declared in the Pascal version.
2) The FORTRAN version will develop an infinite loop if X or Y equals zero (no comment there excludes X, Y greater than zero).
3) The FORTRAN version *never* defines the functional value of GCD and so will not even compile in a good compiler.
4) There sure are a lot of GOTOs and statement numbers in his program; in particular, statement 180 is totally useless. GOTO 180 should be GOTO 120.
5) There is no reason to have any GOTOs. It could be written as in listing 1.
6) If you don't mind downward branching GOTOs (generally considered to be harmless) function GCD can be written as shown in listing 2.

As in Pascal the flow is clear and flowcharting is simple (Warnier-Orr diagrams are still better). I don't run down Pascal but I fail to see why Schwartz runs down FORTRAN just because he writes a pidgin dialect inexpertly. In FORTRAN, as in Pascal, "Go to statements can fog the otherwise clear logic of a routine," as Schwartz states in his article. FORTRAN 77 with IF. . . THEN . . . ELSE statements, and zero trip counts on DO loops, removes most of Schwartz's FORTRAN objection. Anyone can write a bad program in any language. Pascal is no exception to that statement.■

```
      INTEGER FUNCTION GCD (X,Y)
      INTEGER X,Y, A,B, LIM
C. . .  X,Y .GT. 0
      A = X
      B = Y
      LIM = MAX0 (A,P)
      DO 1000 I = 1, LIM
      IF (A .GT. B) A = A-B
      IF (B .GT. A) B = B-A
      GCD = A
      IF (A. EQ. B) RETURN
1000  CONTINUE
      END
```

*Listing 1: The GCD function written in FORTRAN with no GOTO statements.*

```
      DO 1000 I = 1, LIM
      IF (A .GT. B) A = A-B
      IF (B .GT. A) B = B-A
      IF (A. EQ. B) GO TO 2000
1000  CONTINUE
2000  GCD = A
      RETURN
      END
```

*Listing 2: A much shorter version of the GCD function using one downward branching GOTO statement.*

*Originally appeared in April 1979 BYTE magazine.*

# Pascal versus COBOL:

## Where Pascal Gets Down to Business

**Kenneth L Bowles**

With a few important extensions, Pascal can be an extremely powerful tool for writing interactive business application programs on microcomputers and minicomputers. Pascal provides data structuring facilities generally superior to those of COBOL, and its control constructs allow a systematic and modular approach to program design that reduces development effort and improves reliability compared with BASIC or FORTRAN. The extensions needed make it easy to write interactive programs, use random access (floppy) disk files, handle business arithmetic, and recover from error situations.

### A Case Study

In this article we will illustrate the use of Pascal for a program application one might find, with variations, in many small businesses. More general descriptions of the language are contained elsewhere in BYTE and in many published introductory textbooks.

The business we have in mind keeps records of information about transactions with its customers, and also records containing descriptive information about the people with whom it deals. The descriptive records might apply to clients of a law firm, patients of a medical or dental clinic, suppliers of a hardware store with a large and diverse stock, houses currently listed by a real estate firm, users of hardware and software products handled by a computer store, and so on. The transaction records would describe orders for goods to be sold, deliveries, invoices sent, payments, requests for information, promotional literature sent, customer property sent out for repairs, medical tests ordered, etc. Typically each record in the file of descriptive records would correspond to many transaction records. Depending upon circumstances, the transaction records might be stored intermingled with the descriptive records (just as in the shoe boxes that some small businesses now use) or in a separate disk file. They might be stored on the same floppy disk if the files are small, or they might be stored on different disks. In any event, we assume that the number of items in the descriptive file is so large that manual processing of the transactions information represents a significant cost to the business for record keeping. We also assume that the business is small enough that it cannot afford to have its own full time data processing department.

We now consider how Pascal programs written for a small computer might help in the operations of a hypothetical small business, the Zyx Gizmo Store. With many competing manufacturers producing gizmos, it is necessary for Zyx to keep track of many different sizes, shapes, qualities and specialized forms of gizmos. Moreover, the buyer can start with a basic model, later adding modules to obtain a larger and more sophisticated gizmo. Gizmos require periodic maintenance and corrective repairs. Zyx stocks some replacement parts which are installed in customers' gizmos by the Zyx repair department or sold to users who do their own repair work. Some replacement parts are too expensive to stock locally, and Zyx must order them from regional distributors when needed. Gizmos are complicated enough to use that many users require textbooks or short training courses to understand how to use them. Zyx sells the textbooks and runs periodic training seminars for which users pay a small fee. Both the training and repair problems are made complex by the rate at which the technology of manufacturing gizmos is advancing, as new models are introduced by the manufacturers each year. While the similarity of the gizmo to the microcomputer is easily recognized by many readers, the gizmo model could apply equally well to technology based devices being sold in many fields today.

We can assume that Zyx is large enough to employ several salespeople, repair people, and at least one full time administrative assistant in addition to the owner of the company. In general, when a situation arises requiring communication with a customer, any one of these people may have occasion to refer to the filed records on previous transactions involving that customer. If the customer telephones to request advice about an apparently malfunctioning gizmo, the responding Zyx employee usually needs information about the make, model, size and other details describing the customer's gizmo. If a customer asks Zyx to order an additional module from a national distributor, he or she may call Zyx to inquire about the fate of the order before delivery is actually completed. If a manufacturer of modules for gizmos introduces a new line of devices, Zyx may wish to save on promotion costs by contacting only customers known to be using gizmos compatible with that manufacturer's devices. For these and many other reasons, designated employees of Zyx should have ready access to records on the customer's dealings with the firm. These records make it possible for Zyx to render a personalized service that probably is the main reason why customers come to the Zyx store for their gizmos rather than to a national or regional distribution company.

Of course now that low cost microcomputers have become moderately powerful, it is possible, in principle, for Zyx to maintain its descriptive and transaction records on customers in a floppy disk or small hard disk system. Ideally, the cost of adding a microcomputer to a small business operation is only a fraction of the value received, both in labor costs and in improved customer relations. Moreover, the company could use the microcomputer for maintaining its accounting records, sending bills, keeping track of inventory and so on. We say *ideally* because the effort to write a suite of programs to access and maintain the necessary files can be quite substantial if the programming is done in BASIC or FORTRAN (or assembly language). Using Pascal the effort should be very much less than the equivalent effort using BASIC or FORTRAN.

Since COBOL is becoming available on microcomputers, some comments on COBOL versus Pascal are appropriate. Here the principal issue has more to do with the operating system, within which business programs written in the language will run, than with the language comparison. Given reasonable operating system support of the language, no one versed in Pascal would consider backing up to COBOL. COBOL's principal attraction in the business computing community has been that it is the most standardized of all the widely used languages. COBOL provides facilities for storing dissimilar types of information mingled together in transaction records intended to be stored in off line media like disks and magnetic tape. Pascal too has very powerful facilities for storing complex data records, and its facilities for building complex programs are far superior to those of COBOL.

Regarding the operating system support, we'll assume in the rest of this article that the user's Pascal program is developed under, and runs within, the UCSD (University of California at San Diego) Pascal Software System (see "UCSD Pascal: A Machine Independent System," page 3). This system provides what amount to language extensions to Pascal which facilitate the use of Pascal in writing interactive business programs. Some of these extensions will be mentioned at points in the discussion where they are used in our example. The accepted informal standard for the Pascal language, as described by Niklaus Wirth in his revised report on Pascal (*Pascal User Manual and Report*, K Jensen and N Wirth, Springer Verlag, New York/Heidelberg, 1975), lacks definition of several facilities that are really essential if the language is to be convenient for writing business programs. On the other hand, Pascal provides an extremely high level from which these facilities can be added.

## Transaction Records

In Pascal, the programmer is required to declare what type of information will be stored under the identifier of each variable. Readers of BYTE should be familiar with the concept of type as it refers to an integer (whole number), real (floating point number), or string (of characters) item stored in the program's memory. Readers may also be familiar with the concept of an array containing a collection of items all of the same type. In effect, an array is a composite type associating one identifier with a collection of many similar data items, ie: all integers or all reals, etc. Pascal allows one to declare one's own composite type containing a collection of items of dissimilar types. Listing 1 gives a concrete example that might apply to the records of the Zyx company.

In Pascal, any type declarations one wishes to make must appear in the main program or in a block (subroutine) before any variable identifiers are declared following the reserved word var. In the example above, representing part of a block, the variable identifier *inrec* is to be used for temporary working storage of a customer record read in from an external device such as disk. *outrec* is to be used to collect several data items together before writing out to the external device. Both variables are declared to be laid out in memory according to the type declaration for *customer*. In other words, the declaration of *customer* describes the various fields of information that will be found in any record of that type, whether currently stored in main memory or on an external medium.

The first field within a record of type *customer* is a name consisting of up to 30 characters. The name is of type, *string*, which is a UCSD extension of the standard Pascal concept of a packed array of characters. The type *string* is really just a predeclared record type within standard Pascal. In addition to the packed array of characters, the record also contains a single byte field representing the number of characters currently containing useful string information. In UCSD Pascal, a variable of type *string* with no reference to the maximum length (like the *[30]* in the *name* field) will be given a default maximum length of 80 characters. Characters are ASCII and are synonymous with the concept of 8 bit bytes.

The identifier *chargesunpaid* is an extended precision integer represented internally as a 32 bit binary number and limited to storing numbers with up to eight decimal digits of precision. Associated with *chargesunpaid* is a scale factor of two decimal digits, designed to represent dollars and cents. Both the extended precision concept and the decimal scaling factor are UCSD extensions to standard Pascal intended particularly for business use. Where no precision or scaling factor is mentioned in the type portion of an integer declaration (as with the fields *areacode*, *prefix* and *extension*), the system assumes that the programmer wants the standard integer precision on the machine being used. On most microcomputers this will be 16 bits, equivalent to about 4.5 decimal digits.

*telephone* is the identifier of a field within the *customer* record layout, where *telephone* is itself a record containing three fields, each of which is an integer. Depending upon the purpose one might have in mind for the data on telephone numbers, it might be better to represent the telephone

```
type customer =
    record
        name: string[30];
        chargesunpaid: integer[8:2];
        telephone:
            record
                areacode: integer;
                prefix: integer;
                extension: integer
            end;
        address:
            record
                street: string[40];
                citystate: string [40];
                zip: integer[5]
            end
    end {customer};

var
    x,y: real;
    i: integer;
    inrec, outrec: customer;
```

*Listing 1: User declared composite type declaration in Pascal. In Pascal, the programmer is required to declare what type of information will be stored under the identifier of each variable. Examples of standard predeclared types include integer and real. Pascal allows one to declare one's own composite type containing a collection of items of dissimilar types. In this example, the type "customer" has been created, consisting of a record of the variable's name, chargesunpaid, telephone and address. String is a predeclared composite type provided by UCSD's Pascal system.*

number field as a string of ten characters. We have used this representation mostly as an illustration of the language facilities.

*address* is also the identifier of a field which is itself a record containing three fields. Both *telephone* and *address* are said to be "nested" inside the record of type *customer*. Pascal would allow us to nest record type fields within either *telephone* or *address* if we wished to do so, and those record fields could in turn contain other records. In this respect Pascal and COBOL are similar, though the Pascal facilities for record declarations are generally more flexible. As in COBOL, one can declare that a particular transaction record may be used with several distinct field layouts, allowing a file to contain records with several different formats.

In Pascal, one refers to a complete record by its identifier alone. We could transfer the entire content of *inrec* to *outrec* using the statement:

*outrec := inrec*

No concept similar to COBOL's MOVE CORRESPONDING statement is available to allow the transfer of similarly named fields between records declared to be laid out differently.

If we wish to refer to a single field of a Pascal record, it is necessary to name both the record identifier and the field identifier. Thus we might assign a value to the *name* field of *outrec* as follows:

*outrec.name* := 'John Q. Public'

In the situation of complex record types with many nested records, one can often simplify the extra writing needed to refer to all the nested record identifiers by using the Pascal *with* statement.

### Interactive Input and Output

Input and output (IO) is the area of greatest importance in business applications where the standard Pascal definition lacks a few essential features. Standard Pascal input and output *do provide* an orientation similar to some implementations of COBOL in that a file (an IO device) has an associated buffer variable of the same type as that of the file itself. In the next section we'll consider files associated with record types.

Published discussions of input and output in Standard Pascal are generally limited to handling files of type *char*, meaning that input and output are assumed to consist of a stream of characters. The standard identifier *text* is a convenient way to declare a file identifier as in:

*fid: text;*

which is equivalent to:

*fid: file of char;*

The standard Pascal read and write statements provide automatic formatting of external character strings representing integer or floating point numbers into and from their corresponding internal integer and real representations.

While the concept of type *text* is useful when working with magnetic tape devices or with card input and line printer output, it has proven difficult to use with interactive devices. The UCSD Pascal system is extended for this purpose. The principal problem with type *text* for interactive files is the standard Pascal definition of the *read* statement. *read(fid,x)* is equivalent to:

*x : fid ↑;*
*get (fid)*

in which the content of the buffer variable is first assigned to the variable *x*, following which a new character is loaded into the file's buffer variable from the external device. This is inconvenient when one would like to place a prompting message on a video display screen, using a simple write statement, following which the program should wait for input demanded by a read statement. The standard mechanism implies that the system looks ahead for a character to be loaded into the buffer variable. This is a great idea for tape files, but not at all convenient for interactive devices. UCSD Pascal extends this concept by associating type *interactive* with interactive devices. Type *interactive* is the same as type *text* except that the buffer variable is loaded from the external device *before* the value in the buffer variable is moved to the program variable. In more explicit terms:

```
var fid: interactive;
    .
    .
    .
get(fid);
x : = fid ↑
```

where the last two lines represent *read(fid,x)*.

UCSD Pascal extends the idea of types *text* and *interactive* by allowing a string to be handled with minimum fuss. On *read(fid,strg)* (or just *read(strg)*, when referring to the standard system file *input*), one types characters at a video display keyboard with each character appearing immediately on the screen. If a character is mistyped it can be erased from the screen and the input buffer by pressing the backspace key. If one wants to erase the entire input buffer for a clean start (with all typed characters wiped off the screen), one presses the delete or rubout key. The read operation is terminated when return is pressed, whereupon one can determine the number of characters actually input into the variable *strg* by using the built-in *string* function *length(strg)*. On output, the *write* statement determines how many characters to send from a string variable using the length field associated with that variable. For example,

*write*('Hello There');

and

```
strg := 'Hello There';
    .
    .
    .
write(strg);
```

would both produce the same 2 word message on the output device. As in Standard Pascal, the width of the field of characters sent from the *write* statement can be controlled as follows:

*write(strg: width)*

### Disk Input and Output

One of the main reasons for using a disk file is to allow rapid *random* access to any selected record in the file. Access to a floppy disk record takes roughly 0.25 seconds, whereas access to a record on a tape cassette or cartridge can take many seconds or more than a minute. Interactive business processing usually requires files to be maintained on an external medium like disk or tape because the main memory of a microcomputer or minicomputer is usually not large enough to contain a complete file at one time. Random access is almost mandatory in most cases to avoid long waiting times for the people using the computer.

For example, the Zyx company might have a database of customer records in a file *fcust* declared as follows:

*fcust: file of customer;*

within the variable declarations of a Pascal program. When a customer arrives to ask for information, a Zyx staff member wants immediate access to the record associated with that customer in the disk file. Standard Pascal provides no way to reach the customer's record without sequentially reading many other records: usually starting at the beginning of the file. UCSD Pascal allows one to position the record number pointer of the file using the built-in seek statement, for example:

*seek(fcust, recnumber)*

Following execution of this statement, the standard procedure call *get(fcust)* would load the selected record numbered *recnumber* into the buffer variable of the *fcust* file. Contents of the buffer could then be altered directly or moved to other variables in the program. *get* causes the record number pointer associated with the file to be advanced to the next record in sequence. If you want to change the contents of the buffer variable and then return the changed contents to the disk record numbered *recnumber* using *put(fcust)*, you would first have to call *seek* again. The *get* and *put* procedures of Standard Pascal are designed with sequential tape files in mind, and they can also be used for sequential reading of disk files. Use of the *seek* procedure as described allows random access to disk files with minimum alteration of the standard language.

Several aspects of disk file handling are very important for simplifying the task of the business application programmer, though not specified as part of the Pascal language. For example, standard floppy disk media are usually partitioned into sectors of 128 bytes each. In some operating systems, such as the Digital Equipment RT11 operating system, a file is made to appear as partitioned into physical records of 512 bytes called blocks (UCSD Pascal system uses this convention). Typically, the record layout a programmer wants to use (such as *customer* in our example) does not result in a neat fit with the sector or block size demanded by the operating system. This means that a logical record associated with a record type declaration in Pascal may occasionally be split between two physical records on the disk. The operating system should allow the Pascal programmer to *get* a record from the disk or *put* a record to the disk without concern for this complication. The system should maintain a directory of disk files so that the programmer need not be concerned with the actual location of a file on the disk, but only with the number of a logical record counting from the beginning of the file.

The programmer of a business applications program package needs to have a simple way to cause a program to call for changes in the library of disk files maintained by the program. For example, an obsolete copy of a master file might be removed from the directory, or its directory name changed. The UCSD Pascal system provides these and other facilities to make disk file handling as painless as possible on a small machine.

## Keeping Track of Categories of Data

One of the common problems in business programming is identifying people or things with certain groupings or categories in order to simplify the handling of data on those people or things. For example, the Zyx company might want to characterize some cus-

```
type
    manuf = (able, baker, charlie, davis, edwards, jones, smith, none);
    customer =
        record
            name: string[30];
            chargesunpaid: integer[8:2];
            equipment: set of manuf;
            telephone:
                record
                    areacode: integer;
                    prefix: integer;
                    extension: integer
                end;
            address:
                record
                    street: string[40];
                    citystate: string[40];
                    zip: integer[5]
                end
        end {customer};

var
    x,y: real;
    i: integer;
    supplier: manuf;
    inrec, outrec: customer;
```

*Listing 2: An expansion of the Pascal code in listing 1 illustrating the use of sets. The type manuf has been added, which can be associated with a variable allowed to assume only the values enumerated in the declaration. For example, the new variable supplier, of type manuf, may take on the value of any of the items in the manuf list such as able or davis, but no others outside the type.*

tomers as primarily oriented to gizmos made by certain manufacturers, such as the Able, Baker, Charlie, Davis, Edwards, Jones and Smith companies. Within the product lines of these companies, Zyx might also want to have ready access to a record showing which selection of all the possible gizmo modules a customer might have. Thus, when a customer makes an inquiry or a manufacturer brings out a new type of module, Zyx staff members could reduce the effort in knowing how to deal with the customer. For example, a printed promotional brochure might be sent only to the customers associated with an appropriate combination of categories.

In virtually any programming language, this problem can generally be solved by storing descriptive strings as additional fields of the *customer* record. However, the strings can take up far more space than one would like (particularly on a minifloppy disk!), and they are awkward to use when you are simply searching through a file for records corresponding to a particular combination of categories. For example, we might want to search the file to identify all customers who own gizmos made by the Able, Jones and Smith companies who also have a particular type of add-on module. (If you are having trouble relating to gizmos, how about S-100 bus microcomputers with a minimum of 16 K bytes of memory?)

To solve the space problems in storing categories information, a standard technique in traditional programming languages involves deciding on a set of codes to represent the various categories. In our simple example enumerating the gizmo manufacturers, we might store a single letter representing each manufacturer, such as A for Able, B for Baker, and so on. But how do we store the information that a particular customer is associated with two or more of these codes? Without a complex indexing mechanism, a random access disk file virtually requires that all logical records be of the same size. Do we provide an array for storing these codes? How long does the array need to be to account for all possible combinations of codes for our customers? Are we willing to put up with inaccurate data on a few customers in order to save large amounts of file space for the great majority of customers? How do we write a search program to go through the file quickly to find all the customers associated with a specific combination of categories? The reader might well pause at this point to consider how to accomplish these tasks with his or her favorite programming language.

The Pascal facilities for handling sets are designed to make program solutions for problems like these as painless as possible. For example, we might expand the declarations given earlier as shown in listing 2.

We have added the declaration of a new type *manuf* which can be associated with a variable allowed to assume only the values enumerated in the declaration. For example, the new variable *supplier* is allowed to be assigned the value *able*, or *jones*, from the list of enumerated identifiers.

Also declared as a new field of the *customer* record type is *equipment*, a set of members selected from the type *manuf*. If a customer of Zyx owned gizmos made by Baker, Edwards and Smith companies, the following assignment statement might appear in a simple program:

*outrec.equip := [baker, edwards, smith]*

where the quantity in brackets on the right side is a set constant stating that items are present from the three manufacturers noted. For an interactive business file maintenance program, the record of a new customer showing no association with a manufacturer would most likely be initialized using an empty set constant:

*outrec.equip := [ ]*

Then, when the customer acquired his or her first gizmo, we might find a statement such as:

*outrec.equip := outrec.equip + [edwards]*

which would form the union of the old value of the *equip* set with a new set constant value. In other words, *equip* would now have a notation indicating the presence of *edwards* in addition to what was previously noted in *equip*. We could continue adding notations of other gizmo acquisitions when appropriate. In fact this process is likely to assign a value to a simple variable of the set type associated with *manuf*; then that variable would be used elsewhere in the program to augment the noted membership of *equip*.

Pascal's facilities for handling sets are advantageous in many ways. A set is generally stored in memory as an array of binary bits which are made accessible in a special way. In UCSD Pascal, a set is stored as a string of bytes, each byte containing up to 8 bits to indicate whether a corresponding value is present in the set. Only the number of bytes needed to hold the declared number of set members need be stored. If, as is usual, one needs several dozen members in a set for a business application, the space occupied is very little more than the minimum needed. UCSD Pascal allows a set to have as many as 4080 members.

Once the value of a set field of a record has been assigned, it is readily possible to test whether a customer record is associated with a desired combination of members. For example, to determine whether a customer is noted as owning gizmos made by Baker, Edwards or Jones companies, we could use an *if* statement such as:

```
if (outrec.equip * [baker,edwards,jones]) <> [ ]
    then
        begin . . . end;
```

Here the expression within parentheses (on the left of "<>") isolates the members of *equip* falling in the group Baker, Edwards and Jones. The parenthesized expression is said to be the intersection of the value in the *equip* field in *outrec* and the set constant within square brackets. The comparison indicated by <> then asks whether the result of the intersection operation has left any members by asking whether the result is an empty set. If not, then at least one of the three members must be present, and the compound statement *(begin . . . end)* following *then* is executed.

The alternative to this test for set membership would usually be a complex sequence of IF tests in the traditional languages. The set combining and testing operations can be implemented efficiently by the Pascal system. Thus they allow a program to be written more simply and occupy less space. They also make the operations undertaken by the program more obvious to anyone versed in Pascal, thus making a complex program more easily maintainable and bug free.

### There's a Lot More

It is not possible to present a comprehensive view of how one uses a language for complex business programming within a short article. For example, we have not described the use of Pascal *subrange* variables, which allow a programmer to state that a variable is permitted to contain only certain declared values. If an attempt is made to assign to the variable a value outside the declared range, the program either terminates abnormally or (if Pascal is extended in a simple way) the programmer may provide a *recovery block* in which corrective measures may be taken. Data validation is one of the most common problems in business data processing. At UCSD, we feel that the addition of a simple recovery block mechanism is essential to allow reduction in program complexity for handling the many exceptional circumstances that show up in business data, without unnecessary interruption of processing.

### A Note on Pascal Extensions

Though Pascal does seem to require a few extensions to make business application programming truly practical, the language provides an extremely powerful base from which to work. One of the strengths of Pascal, according to the intentions of its designer, is that it offers all this power in a remarkably simple and self-consistent form. The necessary extensions can be made in ways that generally retain this consistency so as to be relatively obvious to the programmer. We feel that Pascal is by far the best language available for adaptation to interactive business processing on small machines. We would be happy to send further information about how we use the language for business or real time applications to anyone who writes to us.

The questions of whether standard Pascal should be extended, and how, are currently being debated intensely in the international Pascal Users Group. Each special interest community of Pascal users has its own list of extensions considered essential to make the language a practical tool for developing software products in that community. Even the question of what extensions are essential is being debated, since it is possible to use the facilities of the standard Pascal language to create a library of routines to handle the user's special problems in most cases. In general, an implementor should consider extending the language only in cases where the result will be simpler and more reliable or efficient programs.

This article discusses extensions that the author feels are essential for business applications. Other communities with very strong interests in Pascal work with real time applications, development of system software such as operating systems and compilers, interactive systems such as computer assisted instruction, scientific computations, and so on. Of course these communities do overlap substantially. If the essential extensions needed by all these communities were added to the standard Pascal language, the simplicity and self-consistency that make the language so important would probably be destroyed. Therefore, it is very unlikely that an eventual formal standard for the Pascal language will include any but the most widely needed extensions currently under discussion.

This situation leaves many Pascal advocates very much worried that there will be no effective standards for the extended language features needed by the special interest communities. There has been discussion within the Pascal Users Group about the possibility of encouraging development of common interest supersets of the language for specialized uses. Ideally, language standardization is a process which should proceed slowly giving attention to the ideas of all experts who wish to be heard. In practice, the use of Pascal is growing so fast throughout the computer industry that close coordination of the extensions made by many implementors has become virtually impossible. We at UCSD have set ourselves the limited goal of seeking coordination and cooperation on Pascal extensions for system programming (including those for business and real time applications) among a number of industrial firms that seem most active in use of the language, particularly as regards small computers. For reasons associated with their own proprietary interests, these firms will generally be able to cooperate on only some of the most widely used language extensions within their special interest communities. A Pascal language extensions workshop was held at UCSD in July of this year primarily to help bring about this coordination. We intend to continue working as closely as possible with the international Pascal Users Group, and to take guidance from the PUG leadership on extension issues whenever practical.■

# A "Tiny" Pascal Compiler

## Part 1: The P-Code Interpreter

**Kin-Man Chung**
**Herbert Yuen**

Roughly speaking, a compiler is a program that translates the statements of a high level language (such as Pascal or FORTRAN) into a semantically equivalent program in some machine recognizable form (such as machine or assembly code). The former is usually referred to as the source program while the latter is called the object program. An interpreter, on the other hand, reads in the source program and starts execution directly, without producing an object program.

There is little doubt that compilers and interpreters are a necessary part of any computer system. The reason most personal computer systems do not have high level language compilers is not that there is no need for them. Compilers, being inherently more complex than interpreters, require more effort to write and more computer memory to run. The main advantage of a compiler over an interpreter is the relative speed. A compiled program typically runs an order of magnitude faster than an equivalent program executed interpretively. In fairness, it must be also pointed out that interpreters are usually easier to use, and more suitable for an interactive environment.

This series of articles is an attempt to describe how a compiler for a subset of Pascal was implemented on an 8080 computer system. It is not our intention to go into details for the reasons for the choice of the language. Pascal is widely recognized as superior to many other languages. For an overview of the language, readers are referred to August 1978 BYTE.[1] The publication, *Pascal: User Manual and Report*, by Kathleen Jensen and Niklaus Wirth (Springer-Verlag, 1974) should also be consulted as the authoritative source book on the language in its original form.

This is not, of course, the first Pascal compiler ever written for microcomputers. However, instead of waiting for a Pascal compiler to be written for our particular processor, we decided to undertake the project ourselves. In this way, we can add or subtract features from the original Pascal to suit our needs and system capabilities, so that it can be easily integrated with other system software developed so far.

### 2 Stage Compiler

The compiler is divided into two stages: a p-compiler and a translator. Instead of having the compiler generate machine code directly, it generates code for a hypothetical machine, called the p-machine. These codes, called p-codes, are then converted into the target machine codes by the translator. Dividing the task of a compiler into two stages offers several advantages. The compiler can be written abstractly, without committing oneself to a particular machine and worrying about details of code generation and optimization. Such a compiler is said to be portable, meaning that it can be used on other computer systems with minimal start up effort. It is only at the last stage of code translation from the p-codes to actual machine codes that we have to commit ourselves to a particular machine.

Another advantage this method offers is greater flexibility when writing the compiler. The compiler and the translator can be coded and debugged separately. The flexibility of such a compiler was apparent to us as we started to introduce more and more Pascal features into our original minimal

1. All of the Pascal articles from this issue are included in this volume.

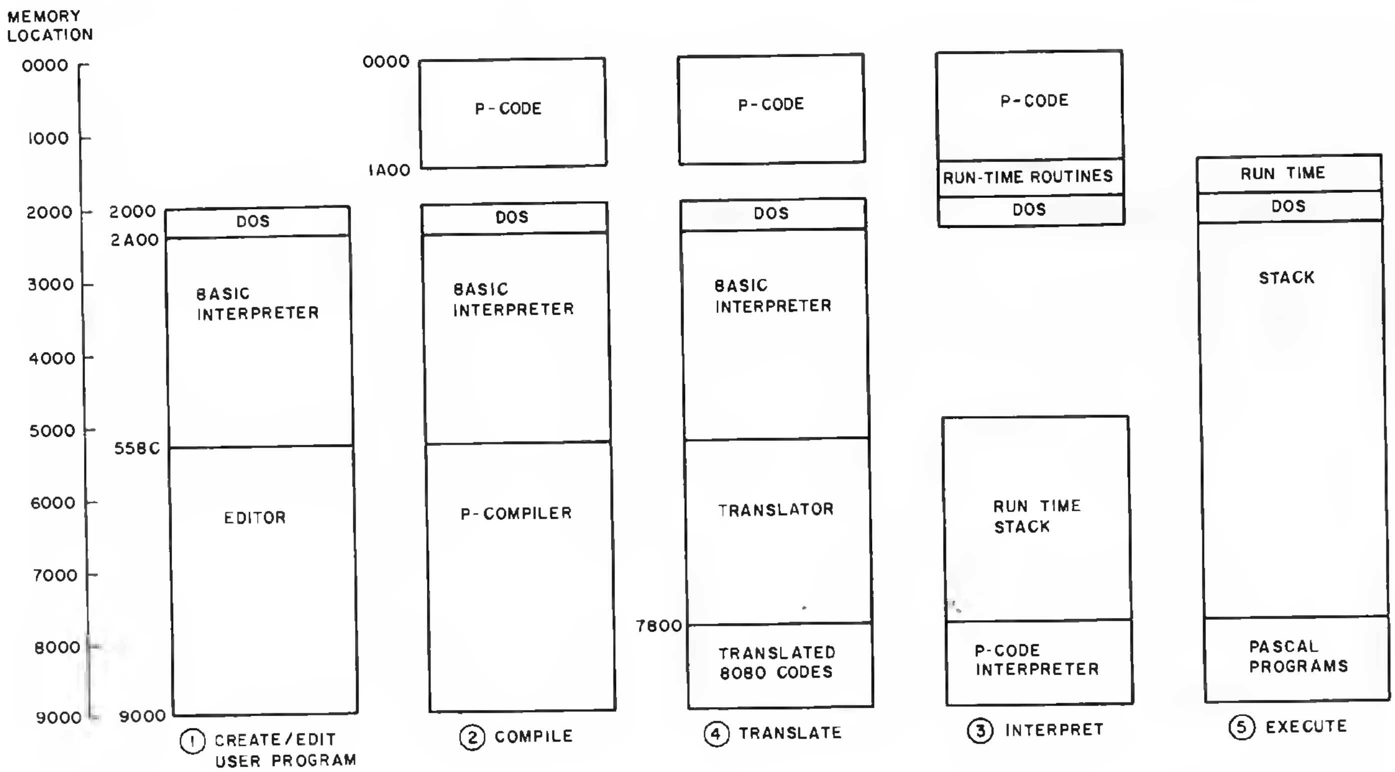


*Figure 1: Memory overlay structure of the modules of the compiler. The North Star DOS and BASIC start at hexadecimal 2000 and take up approximately 14 K bytes of memory. The p-compiler is the largest BASIC program of the system; in its compressed form (void of all comments and blanks) it occupies 14 K bytes. It reads Pascal source programs created by the editor from disk files, and generates relocatable p-codes directly in memory. We use hexadecimal 0000 to 19FF for p-codes and find it adequate for Pascal source programs under about 300 lines in length. The smaller translator (9 K bytes) produces 8080 codes directly filled into memory. The origin of the codes can be specified. The run time routines (which total 1 K bytes of memory) are needed only when the translated 8080 codes are being executed. The interpreter is written in Pascal, compiled and translated. The BASIC interpreter is no longer needed when it or any other Pascal program is being run.*

subset. Seldom was it necessary for us to introduce new p-codes other than those originally specified.

There is also one more reason for breaking the compiler into two stages: most small computers do not have enough memory space to store the complete compiler. After the p-codes are generated, the p-compiler is no longer needed, and can be overlaid with the translator. Therefore the compiler and the translator can share the same memory locations.

Actually we also use two other utility programs: a text editor and a p-code interpreter. The editor is used to prepare the Pascal source programs. The interpreter is used to interpret the p-codes produced by the p-compiler. This provides another alternative for running the Pascal programs. Because it is equipped with various debugging aids, such as setting up breakpoints in p-codes and outputting values for variables, debugging can be easily done. Only after a program is verified to be correct is the translator loaded, and 8080 code produced. This allows easy development of the Pascal programs without sacrificing efficiency at run time. Figure 1 shows the overlay structure for the various modules of the compiler. Figure 2 shows the logical flow during a program development.

In this part of the series on our project, we will describe the general plan. The Pascal subset is defined using syntax diagrams. A description of the p-machine and its codes are also given. We will discuss the p-compiler, translator and run time routines in the following parts.

**Bootstrap Compiler**

How does one introduce a new language into a computer system with limited computer resources? By computer resources we mean not only the computer hardware like memory and peripherals, but also software tools. We have learned from experience not to attempt programs with the complexity of a compiler in machine or assembly language. This left us with BASIC. Although it is not the most desirable language to write a compiler with, it turned out to be adequate. Some careful thought is needed, of course, to handle recursive subroutine calls from BASIC, a feature central to our compiler writing.

The alternative to BASIC is to go to a commercial computer and write the whole or part of the compiler in an appropriate language. The finished product (or part of it) can then be transferred to the smaller computer. This is, however, a luxury most of us cannot afford.

Of course, the compiler written in BASIC would be very inefficient and slow. But this actually would not matter, since it would only be used as a *bootstrap* compiler. The concept of bootstrapping should be familiar to most personal computer owners. We usually use it when initially starting up our computers. After turning on the power, a bootstrap loader is first loaded into the computer (either manually or through the use of read only memory). This bootstrap loader is then used to load the loader, which in turn loads the monitor into memory. The bootstrap loader is a smaller version of the loader; it is just big enough to load the main loader and not adequate to be a general purpose loader.

The same idea can be applied to compiler writing. A compiler for a small subset of a language is first written. This subset should be big enough so that a compiler for a bigger subset of the same language can be written in it. The larger compiler is then written and compiled, using the first compiler. Next, a compiler for a still bigger subset of the same language can then be written and compiled, using the second compiler, and so on until a compiler for the complete language is produced. In actual practice, no more than three stages are used. It does not matter if the first compiler is very inefficient. The idea is to get a working, albeit primitive and inefficient, compiler with minimum starting effort.

## Pascal Subset Syntax

The syntax of Pascal can be described precisely by using a notation usually called Backus-Naur form (BNF). This is a collection of rules for the grammar of the language. Instead of dealing with Backus-Naur form directly, we use an equivalent but more understandable notation: the syntax diagrams. Figure 3 describes the syntax of the Pascal subset we are interested in.

In the syntax diagram, the square boxes are called nonterminal symbols, while the ovals are called terminal symbols. Terminal symbols are the basic building units of the language and require no further expansion. In our case, the names that represent the terminals are also their textual representations in the language. The nonterminal symbols in the syntax diagrams can be expanded using rules specified in another syntax diagram, and there is a syntax diagram for each nonterminal symbol in the syntax diagram. A branch in the diagram represents options allowable by the grammar. When all nonterminal symbols are eliminated by expansion in this fashion, we would have a valid program. We start off a compilation with the nonterminal program. Looking at the syntax diagram we see that a program is a block followed by a period (.). Looking at the syntax diagram for block, we notice that it can have an optional declaration part followed by the main body which begins with the string begin, followed by any

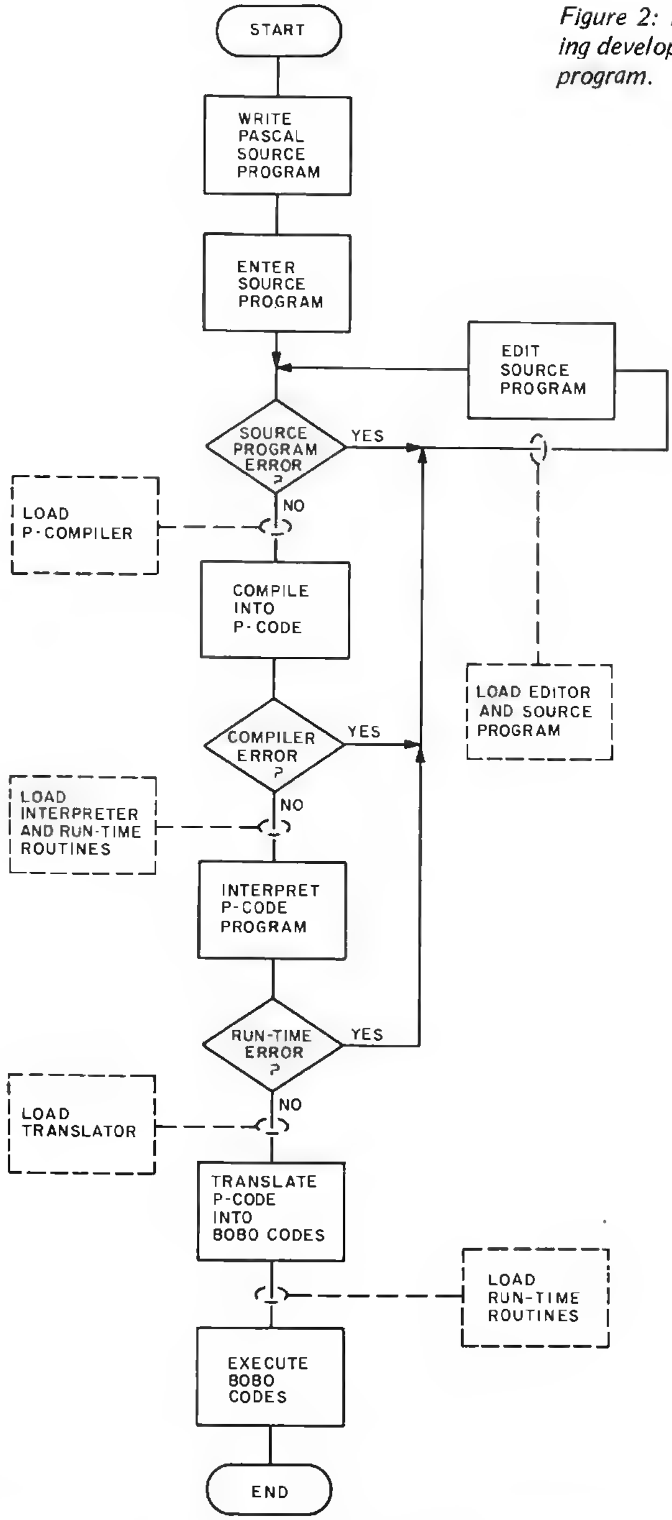


*Figure 2: Flowchart showing development of a Pascal program.*

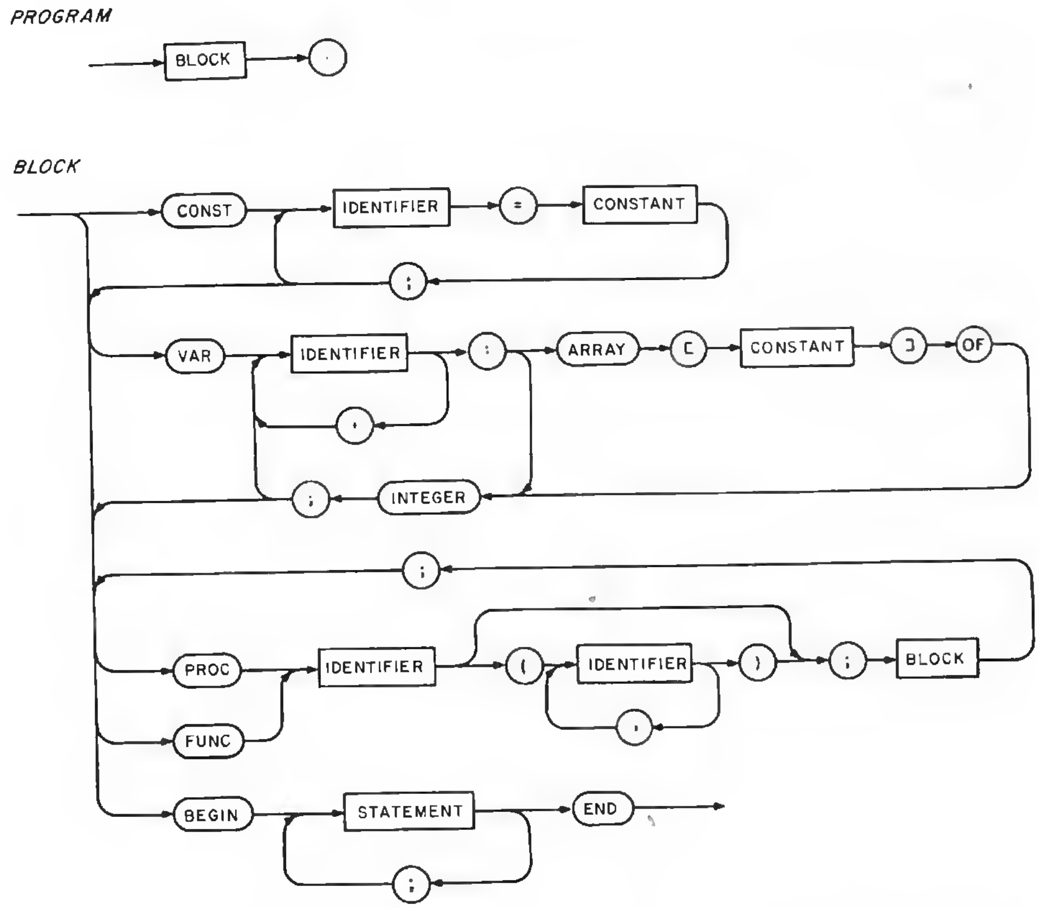


*Figure 3: Syntax diagrams of the Pascal subset. For the syntax diagrams of the full Pascal set refer to the book by Kathleen Jensen and Niklaus Wirth, entitled* Pascal: User Manual and Report. *These diagrams totally define the subset of the language that we are using.*

number of the nonterminal symbols, statement, separated by semicolons (;), and then the string end. The statement block can be further expanded by the syntax diagram for statement, and so on.

The reason we go through the details here is because it is important to precisely describe the features we want to include in our language before starting to write the compiler. It is the first step towards writing the compiler. These syntax diagrams will later become flowcharts for the syntax analyzer of the compiler.

Readers familiar with Pascal will no doubt notice several important features missing from our subset. There is no GOTO statement. The only data type we have is integer and integer array of one dimension. Also missing from the subset is the structured data type, pointer type, user defined type, and file type. A less obvious omission is passing the parameter of a procedure by address; the parameters are passed by value only. Aside from the fact that these features are difficult to implement, they are not indispensable in our bootstrap process. Of course, features like user defined type and structured type are some of the unique features of Pascal, and should not be omitted in the long run. But we feel that they can be added later.

We have also included some trivial but nevertheless useful enhancements to the language, which we hope do not deviate from the standard too much. One is the addition of the optional clause else to the case statement which provides an exit path if the value of the variable does not fall into any of the case labels. Another is the inclusion of format controls in the read and write statements. Following an expression in a *write* statement, a pound sign, #, indicates numeric form and a percent sign, %, indicates hexadecimal format. If there is no format control, a character whose ASCII code equals the expression is output. Also a hexadecimal constant is prefixed by %. This allows processing of hexadecimal numbers without conversion by the user.

To allow interfacing Pascal programs with assembly programs, a facility is provided to read or write a byte from or to absolute memory locations. The array *mem* is a reserved array name that is used to do this.

For instance:

*mem* [*i*]:=*mem*[*j*];

reads the byte from the memory location *j* and writes it back to memory location *i*. Machine language subroutines can be called from Pascal programs. The statement:

*Call (i);*

can be used to make a call to memory address *i*.

**The P-Machine**

The p-machine is a stack oriented machine consisting of four registers and two memory storage areas. Memory is separated into program storage and data storage areas. The program storage area contains the pro-

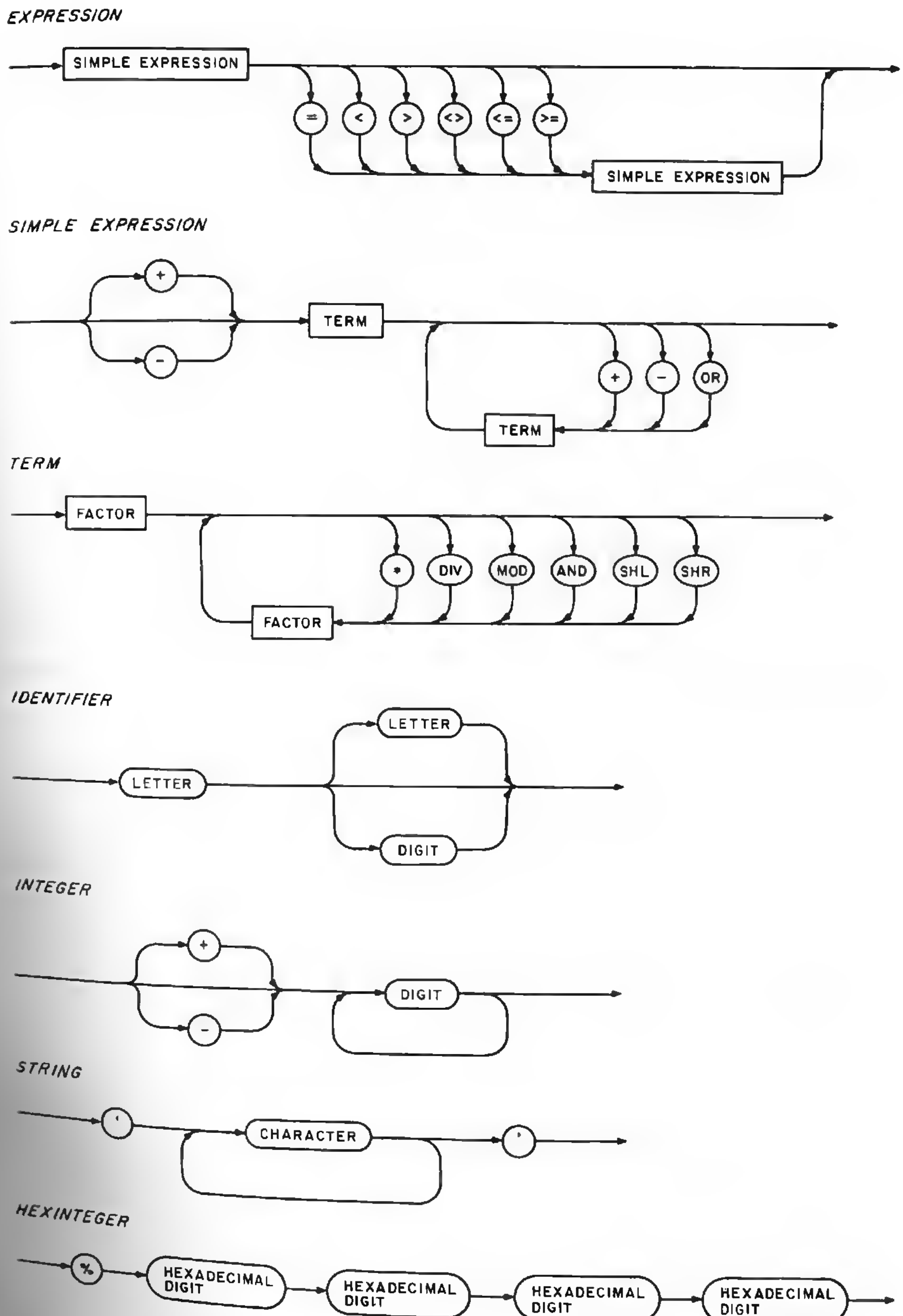


*Figure 3, continued: Elementary constructs for Pascal subset. HexInteger is usually not defined in Pascal but is used here so that actual memory locations can be easily manipulated.*

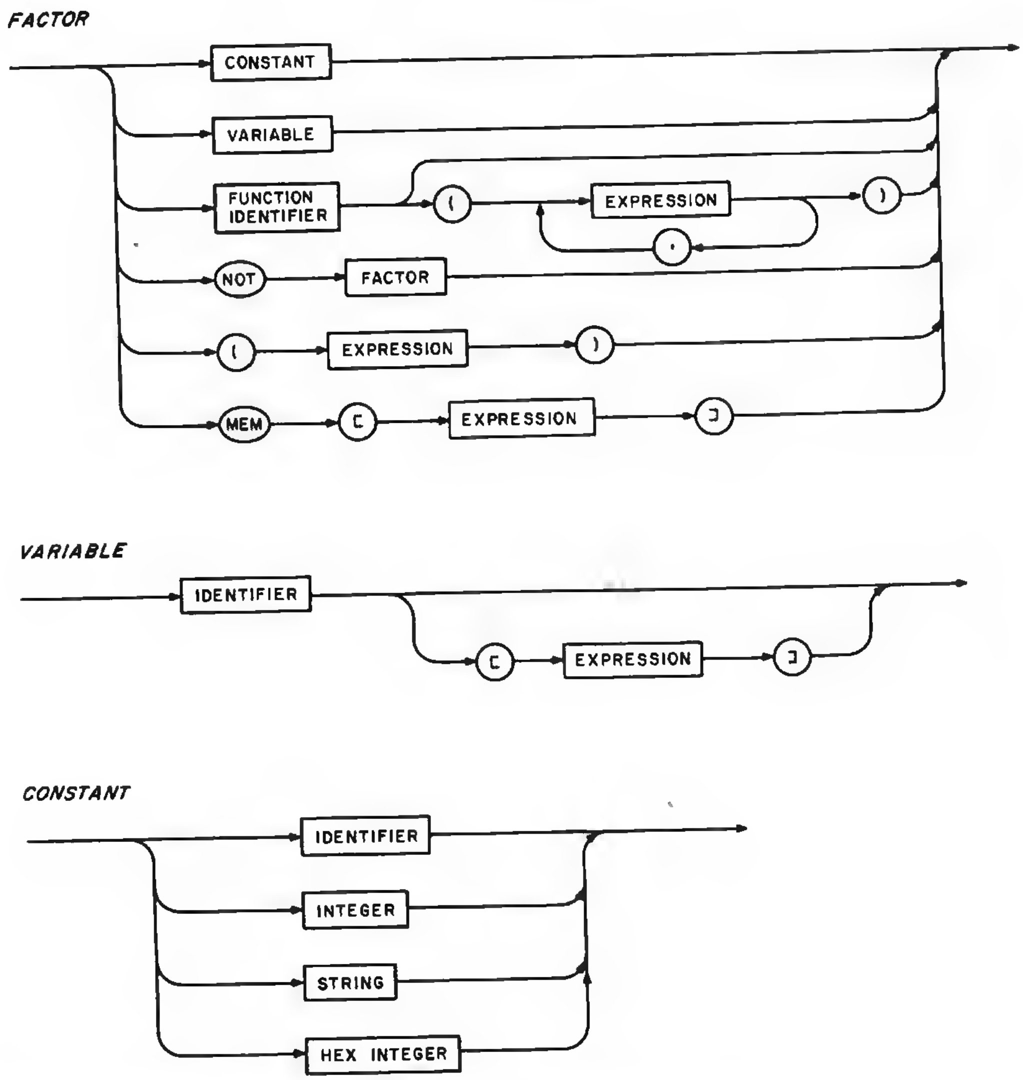


*Figure 3, continued: Notice that some of the diagrams, for example FACTOR, contain themselves in their own definitions. This is known as a recursive definition.*

gram codes (p-codes), and remains unchanged during program execution. The data storage area contains the values of variables. It is also used to store temporary values during arithmetical and logical operations.

Though the variables can be fetched and stored in a random fashion, the data storage area operates as a stack with respect to arithmetical and logical operations and run-time storage allocation. Arithmetical and logical operations are done on the top elements of the stack, and the results of the operations are pushed back on the stack. In this respect, one might call it a zero address machine, since operations (except store and load instructions, which must specify an address) are done without reference to any address. Later we will discuss the use of the stack during run time storage allocation.

The four registers in the p-machine are the program counter, P, which points to the next executable instruction in the program storage; the instruction register, I, which contains the current execution instruction; the stack pointer, T, which points to the top of the stack, and the base address register, B, which contains the current base address. The functions of the first three registers should be quite clear from the above discussion. The function of register B will become clear after we discuss storage allocation.

Each variable in a Pascal procedure has a scope and lifetime. The scope of a variable is the range within which it can be referenced. The scope of a Pascal variable is simply the procedure block to which it belongs. The lifetime of a variable is from the time storage is allocated for it to the time storage is disallocated. In Pascal, this is the time the procedure defining the variable is activated to the time a return is

STATEMENT

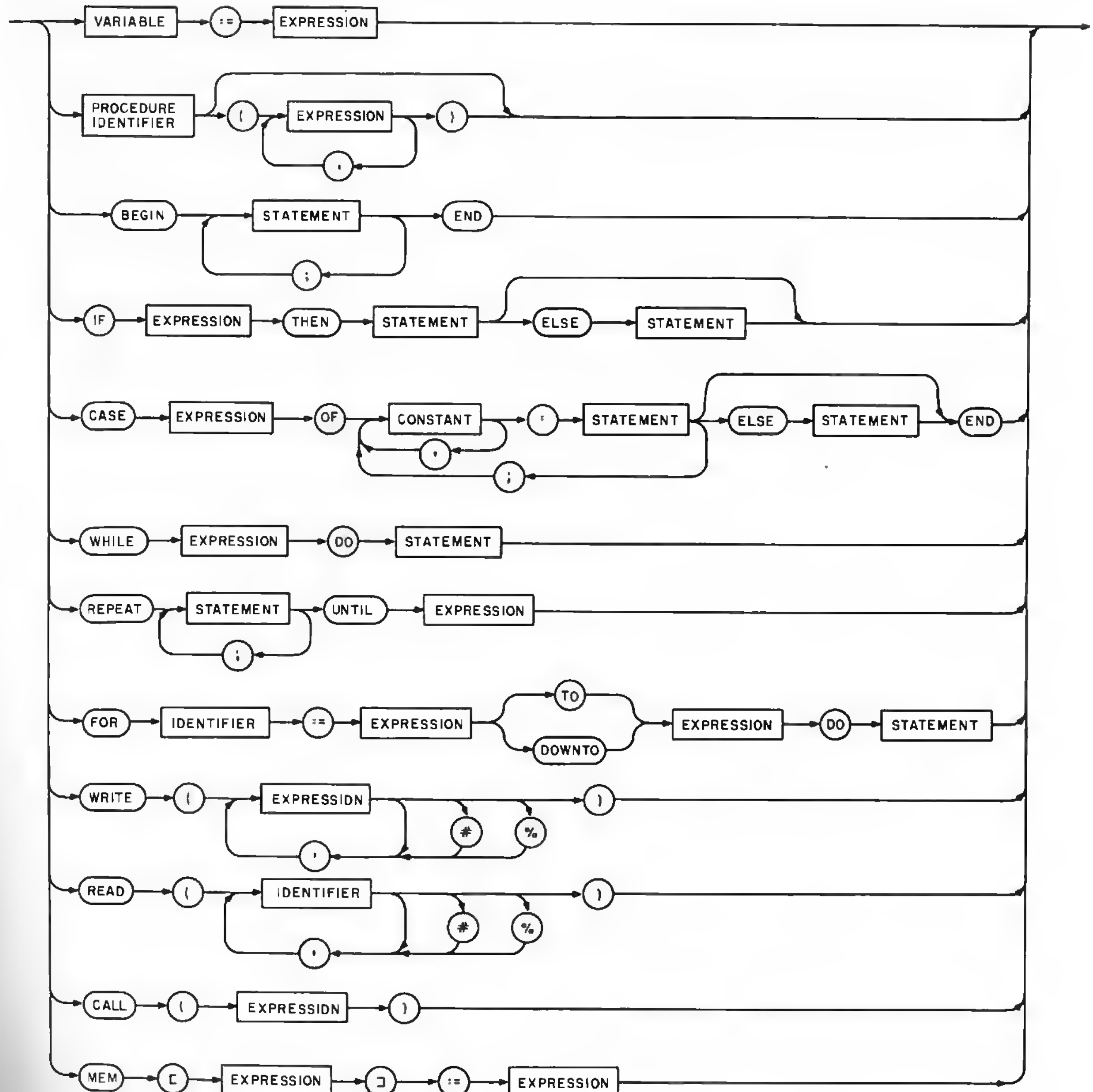


*Figure 3, continued.*

executed by the procedure. This is different from the way variables are treated in BASIC, where the scope of a variable is the entire program and its lifetime the entire execution time.

Since procedure activation is strictly a first in, last out process, the use of stack is an appropriate strategy. When a procedure is activated, storage for its local variables is allocated on the top of the stack, and is disallocated when the procedure is terminated. Thus the stack contains all the variables of the currently active procedures. The variables of the last activated procedure are on the top of the stack, those of the second to last activated procedure next to it, and so on.

Since storage allocation is not static, addresses cannot be assigned at compile time, but must be calculated at run time. The base register, B, always points to the starting location of the segment of the data block in the stack. The addresses generated by the compiler are not absolute addresses, but displacements from some base addresses. If the variable is local, then its address is the

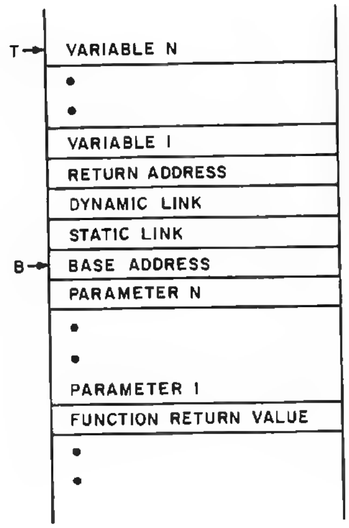


*Figure 4: A typical activation record for a function. For a procedure, the function return value is omitted. Note that the procedure and function parameters, as well as the function return value, are below the base register B, and thus would have negative displacements.*

displacement from the current base register B; but if the variable is from an outer procedure, then the base address for that procedure should be calculated, and added to the displacement.

To do this, and to ensure proper procedure or function linkage, extra storage is allocated on the stack when a procedure is activated. Figure 4 shows the various quantities present in each of the procedure blocks. The function return value is used only for function calls, and storage is allocated for any parameters needed by the procedure or function. The base address contains the value of the current base register B, and the return address contains the program return address at the place of the call. The functions of the dynamic linkage and the static linkage need further explanation.

The dynamic linkage forms a chain that reflects the procedure activation history. It points back to the base address of the procedure that was activated immediately before this one. For instance, if procedure A calls procedure B, which calls procedure C, then the dynamic link chain points from C to B, and then to A. It is used to ensure that the program returns to its previous state when exiting a procedure. In particular, the base register B must be loaded with the correct base address of the calling procedure. This would be easy to do if we follow a step through the dynamic link chain.

The static link, on the other hand, reflects the static hierarchical structure of the procedures. Each active procedure has a link that points to the procedure (also active) that immediately contains it. The static links actually form a tree, with the main program block as the root. These links, which in general are different from the dynamic links, are used to let programs have access to the correct base address of the variables in an outer procedure, since at compiler time, only the static relationship among the procedures are known. The compiler therefore generates the pair (static level difference, relative displacement from the base address) as addresses for variables. The calculation of the addresses from these pairs would presumably slow down the process, but it is a small price to pay for nice features like recursive procedure calls.

### The P-Codes

The p-machine has only 11 basic instructions, which are listed in table 1. For the sake of simplicity and easy handling in this version of the implementation, all instructions are four bytes long. The contents of the four bytes are as follows:

byte 1: op – the operation code.
byte 2: can be (i) v – static level difference.
or (ii) c – condition code in a jump instruction.
or (iii) 255 – denotes absolute addressing.
or (iv) not used for some instructions.
bytes 3,4: can be (i) d – displacement from the base address.
or (ii) n – numeric constant.
or (iii) a – address in the p-code program.

The OPR (arithmetic and logical operations) and CSP (call standard procedure) are further subdivided into more instructions. The complete set of instruction mnemonics and operations is listed in table 2. The LODX and STOX instructions are used to load and store array elements with the value of the array subscript on top of the stack. The call standard procedure (CSP) instruction is primarily used for input and output (IO) operations. Besides the basic function of inputting and outputting single characters, additional procedures have been implemented to relieve the user from writing IO conversion routines in Pascal for numeric and hexadecimal numbers. In the future, more procedures can be added to handle the input and output of other data types such as floating point numbers and file records for tape or disk. Meanwhile these seven instructions are sufficient for convenient use in writing the bootstrap compiler and its related software.

Readers are urged to read the p-code interpreter listing which simulates the operations of the p-machine. The program statements are straightforward and self-explanatory. Familiarity with the p-machine instruction set is essential in understanding the code generation part of the p-compiler.

**The P-Code Interpreter**

Since the p-machine is a hypothetical computer, there has to be some method of executing the p-codes generated by the compiler. There are two simple solutions to this problem. One is to write an interpreter which can decode and execute the p-codes. The other solution is to write a translator which can decode the p-codes and output equivalent executable machine codes for an existing computer. Both methods have been used in our compiler system. The first method, although it runs slower, is good for developing programs because many debugging facilities can be implemented in the interpreter. The second method is good for production programs which may need faster execution speed. A p-code to 8080 machine code translator will be described in part 3 of this series.

The p-code interpreter is made up of two major modules:

- Main program.
- Procedure which simulates the p-machine.

Every call to the simulator will execute one p-machine instruction. Each p-machine instruction cycle can be divided into four stages:

- Fetch a p-code from memory.
- Increment the program counter.
- Decode the instruction.
- Execute the instruction.

Several global variables are used to hold the values of the p-machine registers such as program counter, stack pointer, current instruction, etc. A one-dimensional array represents the data stack. Functional operations of the various p-machine instructions are coded directly from the instruction set defined in table 2. The main program simply initializes the program counter to zero and then calls the simulator repeatedly to simulate machine execution. This sounds simple but not useful, because the user has

| Op Code (Hexadecimal) | Mnemonic | | Operation |
|---|---|---|---|
| 00 | LIT | 0,n | load literal constant |
| 01 | OPR | 0,n | arithmetic or logical operation |
| 02 | LOD | v,d | load variable |
| 12 | LODX | v,d | load indexed variable |
| 03 | STO | v,d | store variable |
| 13 | STOX | v,d | store indexed variable |
| 04 | CAL | v,a | call procedure or function |
| 05 | INT | 0,n | increment stack pointer |
| 06 | JMP | 0,a | jump unconditional |
| 07 | JPC | c,a | jump conditional |
| 08 | CSP | 0,n | call standard procedure |

*Table 1: Basic p-codes. The v in call, load and store instructions is the difference in static level between the current procedure and the one being called or the one which contains the variable from the base address. An address in a p-code program is shown by a. The condition code, c, can either be 0 or 1.*

| Mnemonic | | Description |
|---|---|---|
| LIT | 0, n | load literal constant |
| OPR | 0, 0 | procedure return |
| OPR | 0, 1 | negate (sp) |
| OPR | 0, 2 | add (sp) to (sp−1) |
| OPR | 0, 3 | subtract (sp) from (sp−1) |
| OPR | 0, 4 | multiply (sp−1) by (sp) |
| OPR | 0, 5 | divide (sp−1) by (sp) |
| OPR | 0, 6 | low order bit of (sp) |
| OPR | 0, 7 | (sp−1) modulo (sp) |
| OPR | 0, 8 | test for (sp−1)=(sp) |
| OPR | 0, 9 | test for (sp−1)<>(sp) |
| OPR | 0,10 | test for (sp−1)<(sp) |
| OPR | 0,11 | test for (sp−1)>=(sp) |
| OPR | 0,12 | test for (sp−1)>(sp) |
| OPR | 0,13 | test for (sp−1)<=(sp) |
| OPR | 0,14 | logical (sp−1) OR (sp) |
| OPR | 0,15 | logical (sp−1) and (sp) |
| OPR | 0,16 | logical NOT of (sp) |
| OPR | 0,17 | shift left (sp) logical |
| OPR | 0,18 | shift right (sp) logical |
| OPR | 0,19 | increment (sp) by 1 |
| OPR | 0,20 | decrement (sp) by 1 |
| OPR | 0,21 | copy (sp) to (sp+1) |
| LOD | v,d | load a word |
| LOD | 255,0 | load a byte from absolute address (sp) |
| LODX | v,d | load a word with index address (sp) |
| STO | v,d | store a word |
| STO | 255,0 | store a byte to absolute address (sp−1) |
| STOX | v,d | store a word with index address (sp) |
| CAL | v,a | procedure call |
| CAL | 255,0 | call procedure at absolute address (sp) |
| INT | 0,n | increment sp by n |
| JMP | 0,a | jump to location a |
| JPC | 0,a | jump to location a if low order bit (sp)=0 |
| JPC | 1,a | jump to location a if low order bit (sp)=1 |
| CSP | 0,0 | input 1 character |
| CSP | 0,1 | output 1 character |
| CSP | 0,2 | input an integer |
| CSP | 0,3 | output an integer |
| CSP | 0,4 | input a hexadecimal number |
| CSP | 0,5 | output a hexadecimal number |
| CSP | 0.8 | output a string |

*Table 2: The p-machine instruction set. The stack pointer, sp, points to the top element of the stack. The content of the stack element is represented by (sp). The operands of the OPR instructions are replaced by their results on the stack. The result of the six relational operations is 1 if the test is true and 0 if false. With the exception of single operand OPR instructions, all instructions adjust the stack pointer, sp, after execution.*

**North Star BASIC**

A brief summary of North Star BASIC (version 6, release 3) is given for readers not familiar with its particular features.

Variable names are one or two characters long: an alphabetical character followed optionally by a decimal digit. There are four types of variables: numeric, string, array of numeric, and function. The string variables are names postfixed by a dollar sign $, while function names are prefixed by FN. Functions (and the parameters) are defined by the declaration DEF, and ended by FNEND (for multiline function). The parameters in the function definition are local to the function, and would not affect variables in the calling program.

Strings cannot be dimensioned. The DIM declarations for strings declare the maximum length of the string variables, not their dimensions. The notation A$ (3, 5) denotes the substring of A$ from position 3 to 5. Thus if A$=ABCDEFG, A$ (3, 5) is the string CDE. This substring expression can be used both on the left or righthand side of an assignment statement.

Multiple statement lines are allowed. Statements within a line are separated by either colons, :, or back slashes, \.

Absolute memory locations can be accessed from BASIC programs. The function EXAM(I) returns the content of memory at address I; and the instruction FILL I, J writes a value of J into memory address I.

Another feature of North Star BASIC is its ability to read from or write to disk files. The statement OPEN #0, "FNAME" assigns disk file "FNAME" to file unit #0. A subsequent READ #0,A$ reads A$ from the disk file, and a WRITE #0,A$ writes A$ to the disk file. A built-in function TYP can be used to check the type of data to be read. It has a value of 0 when the end of file is reached.

G: *go* — Set program counter to zero; initialize other counters; start execution.
S: *single-step* — Execute one p-code; display the mnemonics of the next p-code pointed by the updated program counter.
R: *run/restart* — Start execution from current program counter until the program ends or a breakpoint is reached. This command is used to continue execution at a breakpoint.
B: *set breakpoint* — A p-code address is entered as a breakpoint after the interpreter prompts with a ?. Up to five breakpoints may be set.
C: *clear* — All breakpoints previously set are cleared.
Y: *display breakpoint* — Display the breakpoints already set.
X: *examine status* — Display the values of: current program counter, base address, stack pointer, the top two elements of the stack.
K: *stack content* — A value is entered as the stack pointer after the interpreter prompts with a ?. It will then display the values of six stack elements starting from this stack pointer.
T: *trace* — Display the address and mnemonics of the 16 p-codes last executed. This command is usually applied at a breakpoint. It is used for tracing the logic flow of the program.
E: *examine program* — A p-code address is entered as a display pointer (DP) after the interpreter prompts with a ?. It will then display the mnemonics of the p-code at this address. This command and the U and N commands are used for examining the p-codes anywhere in the program without altering the current program counter.
U: *up* — Decrement the display pointer by one and display the mnemonics of the p-code pointed by it.
N: *next* — Increment the display pointer by one and display the mnemonics of the p-code pointed by it.
Q: *quit* — Terminate the interpreter program and return to operating system.

*Table 3: Interpreter commands. All commands for the p-code interpreter are single characters. A command is entered after the interpreter prompts the user with a > on the video display. Additional information is needed for some commands such as breakpoint and stack addresses. On entry to the interpreter it will ask for the starting memory address of p-codes and initialize the program counter to zero. On exit it will display the number of p-codes executed.*

no control of the program during execution until it terminates.

In order to enable user control of an executing p-code program, the main program must accept commands from the user which instruct it to call the simulator a specified number of times or to display register and stack contents. This is the simple idea of a debugging interpreter. The debugging aids commonly known include single step execution, set and reset of breakpoints, and display of register and stack contents. A number of these debugging facilities have been incorporated in the p-code interpreter. Table 3 shows the 13 interpreter commands and their functions. Note that the trace command is particularly useful in analyzing mysterious logic flow of a program, such as discovering the path along which a breakpoint is reached. This command is more convenient to use and much faster than single step execution. The limits on the number of breakpoints and the number of instructions traced can be changed easily in the program.

The first version of the p-code interpreter was written in BASIC. While developing the p-compiler, different constructs of Pascal statements were tested one at a time using the interpreter to verify the correctness of the p-codes generated. After the compiler was debugged, the interpreter was rewritten in Pascal. The program logic is very similar to the BASIC version. Since the program structure of the Pascal version is neat and highly readable, the debugging time is minimal. The Pascal source program is shown in listing 1. The program design is rather straightforward. Readers with some programming experience in any high level language should be able to read and understand it without the help of a flowchart or further explanation on program logic. Note that in the main program and procedure *exec*, the case...of statement is put to good use. In the BASIC version the interpreter commands have to be tested within a FOR loop by comparing the input character with a string array, and then an ON...GOTO statement is used to branch to various parts of the program.

It must be emphasized again that the interpreter executes p-codes and not Pascal statements. Therefore the user is required to have some knowledge of the p-machine and p-codes. In addition to this, the p-compiler should be instructed to list p-codes together with Pascal program statements during compilation. They will be cross-referenced when running the interpreter. Obviously this procedure is not as convenient and easy to use as an ordinary BASIC interpreter, but still it provides the only way for debugging Pascal programs in our present version. A new debugging scheme is being planned for the future which will enable the user to debug programs at the Pascal statement level. This means the user may refer to variables and arrays and statements rather than stack contents and p-code addresses. Part 2 will go into details of the design and implementation of the p-compiler.■

*Listing 1: Pascal source code for the p-code interpreter as output by the authors' system. This version implements all of the commands in table 3.*

```
P-CODES STARTS AT 0000
WANT CODE PRINTED?N
   0 ?$P.INTS
   0 ( P-CODE INTERPRETER   HY 1  3/31/78   BY  H YUEN )
   0     ( LAST MOD 4/12/78 )
   0 CONST U=15;BPLIM=5;SIZE=500;SIZE1=480;
   1 VAR Z,P,B,T,BP,P0,TP,CMD,I,J,K,STOP:INTEGER;
   1      S:ARRAY[SIZE] OF INTEGER;
   1      TRACE:ARRAY[U] OF INTEGER;
   1      MN:ARRAY[26] OF INTEGER;
   1      8REAK:ARRAY[BPLIM] OF INTEGER;
   1
   1   ( IMPORTANT GLOBAL VARIABLES:
   1    P:PROGRAM COUNTER      B:BASE POINTER
   1    T:STACK POINTER       BP:BREAK POINT INDEX
   1   TP:TRACE STACK PTR      K:INSTRUCTION COUNTER
   1    S:DATA STACK           Z:STARTING ADDR OF P-CODE )
   1
   1 FUNC 8ASE(LEV);
   1  VAR 81:INTEGER;
   2  BEGIN B1:=B;
   5   WHILE LEV>0 DO BEGIN
   9    81:=S[B1];LEV:=LEV-1 END;
  17   8ASE:=B1
  18  END (BASE);
  20
  20 PROC INIT;
  20  VAR I:INTEGER;
  21  BEGIN T:=0;B:=1;P:=0;STOP:=0;
  30   S[1]:=0;S[2]:=0;S[3]:=-1;
  48   P0:=0;TP:=U;K:=0;
  46   FOR I:=0 TO U DO TRACE[I]:=-1
  55  END (INIT);
  63
  63 PROC CRLF;
  63  BEGIN WRITE(13,10) END;
  70
  70 PROC EXEC;
  70  VAR X,A,L,F,IDX:INTEGER;
  71  8EGIN X:=P SHL 2 + Z;
  78   A:=MEM[X+3] SHL 8 +MEM[X+2];
  90   TP:=TP+1;IF TP>U TNEN TP:=0;
 180   TRACE[TP]:=P;
 183   P:=P+1;P0:=P;K:=K+1;
 113   F:=MEM[X];
 116   IF F<=8 TNEN IDX:=0
 121    ELSE BEGIN IDX:=1;F:=F-16 END;
 129   CASE F OF
 130 8:BEGIN T:=T+1;S[T]:=A END;
 142 1: CASE A OF
 147   0 :BEGIN (RETURN)
 151       T:=B-1;B:=S[T+2];P:=S[T+3] END;
 166   1 :S[T]:=-S[T];
 176   2 :BEGIN T:=T-1;S[T]:=S[T]+S[T+1] END;
 194   3 :BEGIN T:=T-1;S[T]:=S[T]-S[T+1] END;
 212   4 :BEGIN T:=T-1;S[T]:=S[T]*S[T+1] END;
 230   5 :BEGIN T:=T-1;S[T]:=S[T] DIV S[T+1] END;
 248   6 :S[T]:=S[T] AND 1; (TEST FOR ODD)
 259   7 :BEGIN T:=T-1;S[T]:=S[T] MOD S[T+1] END;
 277   8 :BEGIN T:=T-1;S[T]:=S[T]=S[T+1] END;
 295   9 :BEGIN T:=T-1;S[T]:=S[T]<>S[T+1] END;
 313   10:BEGIN T:=T-1;S[T]:=S[T]<S[T+1] END;
 331   11:BEGIN T:=T-1;S[T]:=S[T]>=S[T+1] FND;
 349   12:BEGIN T:=T-1;S[T]:=S[T]>S[T+1] FND;
 367   13:BEGIN T:=T-1;S[T]:=S[T]<=S[T+1] FND;
 385   14:BEGIN T:=T-1;S[T]:=S[T] OR S[T+1] FND;
 403   15:BEGIN T:=T-1,S[T]:=S[T] AND S[T+1] END;
 421   16:S[T]:=NOT S[T];
 431   17:BEGIN T:=T-1;S[T]:=S[T] SHL S[T+1] END;
 449   18:BEGIN T:=T-1;S[T]:=S[T] SHR S[T+1] END;
 467   19:S[T]:=S[T]+1;
 478   20:S[T]:=S[T]-1;
 489   21:BEGIN (COPY)
 493       T:=T+1;S[T]:=S[T-1] ENO
 503    ELSE BEGIN WRITE(' ILLEGAL OPR');CRLF;STOP:=I END
 521   END (CASE OF A);
 523 2:BEGIN (LOAD)
 527    L:=MEM[X+1];
 532    IF L=255 THEN S[T]:=MEM[S[T]]
 539    ELSE BEGIN IF IDX THEN A:=A+S[T];
 549         T:=T+1-IDX;S[T]:=S[BASE(L)+A] END
 564   END;
 565 3:BEGIN (STORE)
 569    L:=MEM[X+1];
 574    IF L=255 THEN BEGIN
 578     MEM[S[T-1]]:=S[T];T:=T-2 END
 589    ELSE BEGIN
 590     IF IDX THEN A:=S[T-1]+A;
 599     S[BASE(L)+A]:=S[T];T:=T-1-IDX END
 614   END;
 615 4:BEGIN (CALL)
 619    L:=MEM[X+1];
 624    IF L=255 THEN BEGIN CALL(S[T]);T:=T-1 END
 635    ELSE BEGIN
 636     S[T+1]:=BASE(L);S[T+2]:=B;
 649     S[T+3]:=P;8:=T+1;P:=A END
 668   ENO;
 661 5:IF T>(SIZE1-A) THEN 8EGIN
 671    WRITE(' STACK OVFL');CRLF;STOP:=1 END
 687   ELSE T:=T+A;
 693 6:P:=A; (JMP)
 780 7:BEGIN IF S[T]=MEM[X+1] TNEN P:=A;  (JPC)
 714    T:=T-1 ENO;
 719 8:CASE A OF (CSP)
 724   8:BEGIN T:=T+1;READ(S[T]) END;  (IN CNAR)
 736   1:8EGIN WRITE(S[T]);T:=T-1 END; (OUT CHAR)
 748   2:8EGIN T:=T+1;READ(S[T]#) END; (IN NUMBER)
 768   3:BEGIN WRITE(S[T]#);T:=T-1 END;(OUT NUMBER)
 772   4:8EGIN T:=T+1;READ(S[T]%) END; (IN HEX)
 784   5:BEGIN WRITE(S[T]%);T:=T-1 END;(OUT HEX)
 796   8:8EGIN (OUT STRING)
 800      FOR IDX:=T-S[T] TO T-I DO WRITE(S[IDX]);
 828      T:=T-S[T]-1 END
 827   ELSE BEGIN WRITE(' ILLEGAL CSP');CRLF;STOP:=1 END
 845   ENO (CASE OF A)
 846 ELSE BEGIN WRITE(' ILLEGAL OPCODE');CRLF;STOP:=1 END
 867  END (CASE OF F)
 868 END (EXEC);
 869
 869 PROC CODE(PC); (PRINT CODE)
 869  VAR X,N,IDX:INTEGER;
 870  BEGIN X:=PC SHL 2 +Z;N:=MEM[X]*3;
 882   IF N<=24 TNEN IDX:=' '
 887   ELSE BEGIN N:=N-48;IDX:='X' END;
 895   WRITE('  ',PC#,'  ',MN[N],MN[N+1],MN[N+2],IDX,'  ',
 924    MEM[X+1]#,',',MEM[X+3] SHL 8 +MEM[X+2]#);CRLF
 944  END (CODE),
 945
 945 PROC CKBP; (CHECK BREAK POINT)
 945  VAR I:INTEGER;
 946  BEGIN IF P<0 THEN STOP:=1
 952   ELSE BEGIN
 954   FOR I:=1 TO BP DO
 961    IF BREAK[I]=P THEN BEGIN
 966     WRITE(' BREAK:');CODE(P);
 978      STOP:=1 END END
 985  END (CKBP);
 986
 986 BEGIN (MAIN)
 986  FOR I:=0 TO 26 DO
 994   MN[I]:=MEM[I+%1E80]; (MNEMONICS ARE IN MEMORY)
1805  WRITE('ADDR?');READ(Z%);CRLF;
1015  INIT; CODE(P);BP:=0;
1021  REPEAT WRITE('>');READ(CMD);
1825   CASE CMD OF
1026 'R':BEGIN STOP:=0;REPEAT EXEC;CKBP UNTIL STOP END;
1837 'S':BEGIN EXEC; CODE(P) END;
1046 'X':BEGIN
1050      WRITE('  P=',P#,' B=',B#,' T=',T#,
1072           ' S[T]=',S[T]#,' S[T-1]=',S[T-1]#);CRLF
1899     END;
1100 'G':BEGIN INIT;REPEAT EXEC;CKBP UNTIL STOP END;
1110 'T':BEGIN WRITE(' *TRACE*');CRLF;
1125      FOR I:=0 TO U DO BEGIN
1132       TP:=TP+1;IF TP>U THEN TP:=0;
1142       IF TRACE[TP]>=0 THEN CODE(TRACE[TP]) END
1151     ENO;
1157 'K':BEGIN READ(I#);
1163      FOR J:=I TO I+6 DO
1172       WRITE('  ',S[J]#);CRLF
1185     END;
1186 'B':IF BP<BPLIM THEN BEGIN
1194      8P:=BP+1;WRITE(BP#,':');
1282      READ(BREAK[BP]#);CRLF END;
1207 'C':BEGIN (CLEAR BP)
1211      BP:=0;CRLF END;
1215 'Y':8EGIN FOR I:=1 TO BP DO
1226      WRITE('  ',BREAK[I]#);CRLF ENO;
1240 'E':8EGIN READ(P0#);CODE(P0) END;
1250 'U':IF P0>0 THEN BEGIN
1258      P0:=P0-1;CODE(P0) END;
1266 'N':BEGIN P0:=P0+1;CODE(P0) END;
1278 'Q':P:=-1
1283     ELSE BEGIN WRITE('??');CRLF END
1291  END (CASE OF CMD)
1292  UNTIL P<0;
1296  CRLF; WRITE(K#,' INSTR. EXECUTED.');CRLF
1319 END (MAIN).
INTERPRET(I), OR TRANSLATE(T)?
```

# A "Tiny" Pascal Compiler

## Part 2: The P-Compiler

**Kin-Man Chung**
**Herbert Yuen**

When Niklaus Wirth introduced Pascal in 1971, one of the design objectives was to allow efficient program compilation. As far as we know, all existing Pascal compilers use the one pass compilation technique.

Newcomers to Pascal sometimes criticize features of the language such as declaring variables before use, and having constant and type declarations precede variable declarations. But such features are necessary to make a one pass compiler work (aside from the fact that it is also good programming practice to declare identifiers before use). Compared with multipass compilers, the job of writing a one pass compiler is relatively simple, since there is no need to store the program in its intermediate form.

Figure 1 shows the structure of our one pass Pascal compiler. The main portion is made up of the scanner, syntax analyzer, semantic analyzer and code generator. A brief overview of these functional portions of the compiler follows. Detailed descriptions will be given later.

The syntax analyzer is commonly called the *parser*. Its main function is to detect syntactical errors in the source program. The smallest unit of the source program that the parser looks at is called a *token*. For instance, the reserved word while, the symbol *:=*, or the identifier *idname* would be tokens. The main job of the scanner is to read the source program and output a token when needed by the parser. Irrelevant information such as blanks, comments and line boundaries are ignored.

To further simplify the work of the parser, the values of numeric constants are also evaluated by the scanner. The parser then parses the program according to the rules laid down by the syntax diagrams which were described in part 1 ("A Tiny Pascal Compiler," September 1978 BYTE, page 58[1]) and generates error messages if illegal constructs are found. Identifier names are entered into a symbol table as they are declared. The symbol table is consulted by

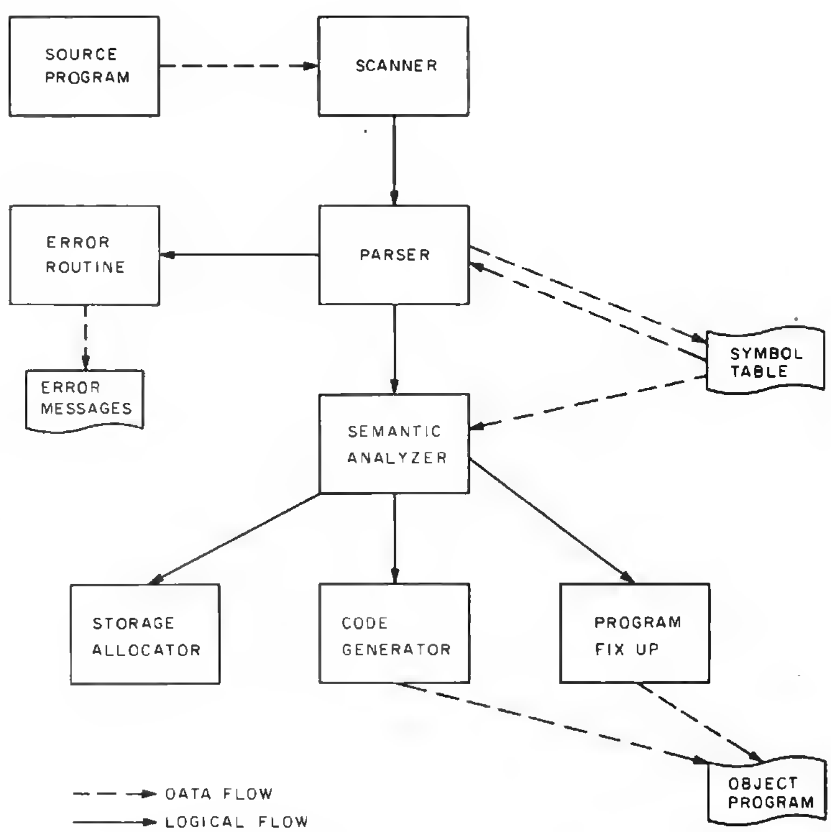


*Figure 1: Logical arrangement and interconnections of the p-compiler modules.*

1. Page 59 of this edition.

*Listing 1: BASIC version of the p-compiler. This program takes the Pascal program and compiles it into p-code. The term p-code stands for pseudocode, an assembler language code for a hypothetical computer which can be converted into an existing assembler language. Listing continues thru page 78.*

```
10REM PASCAL SUBSET COMPILER FOR P-MACHINE
20REM BY KIN-MAN CHUNG
30REM 1/78. LAST VERSION 4/78.
40 N0=32\REM # OF RESERVED WORDS
50 T0=50\REM SYM TABLE SIZE
60 N1=32767\REM LARGEST INT
70 N2=8\REM IDENT LEN
80 DIM W0$(5*N0)\REM RESERVED WORDS
90 DIM T$(T0*N2)\REM SYMBOL TABLE
100 DIM T0$(T0)\REM KIND OF IDENT IN SYM TAB\C,V,P
110 DIM L$(64)\REM LINE BUFFER
120 DIM A$(N2),B$(5)
130 DIM S(100),S$(100)\REM STACKS
140 DIM T1(T0)\REM LEVEL OF ID IN SYM TBL
150 DIM T2(T0)\REM VAL(FOR CONST) OR ADR(FOR INT)OF ID IN S.T
160 DIM T3(T0)\REM ARRAY DIM OR# OF PROC PARAMETERS
170 W0$(1,40)="AND  ARRAYBEGINCALL CASE CONSTDIV  DO   "
180 W0$(41,80)="DOWNTELSE END  FOR  FUNC IF   INTEGMEM  "
190 W0$(81,120)="MOD  NOT  OF   OR   PROC READ REPEASHL  "
200 W0$(121,160)="SHR  THEN TO   TYPE UNTILVAR  WHILEWRITE"
210 DIM M$(27),C$(80)
220 M$="LITOPRLODSTOCALINTJMPJPCDSP"\REM P-CODE MNEMONICS
230 P8=1
240 P7=0\P9=P7\REM START CODE=0000
250 !"P-CODES STARTS AT 0000"
260 Q9=4096*2\REM LAST USABLE MEM
270 F5=-1
280 INPUT "WANT CODE PRINTED?",Y$
290 IF Y$="Y" THEN Y9=0 ELSE Y9=1
300 X$=" "\GOSUB 1240\REM GET A TOKEN
310 GOSUB 5340\REM BLOCK
320 Z=FNE1(".",9)
330 FILL P9,255\FILL P9+1,255\REM FILL IN EOF MARK
340 INPUT"INTERPRET(I), OR TRANSLATE(T)?",Y$
350 IF Y$="" THEN END
360 IF Y$="I" THEN CHAIN "INTERP"
370 IF Y$="T" THEN CHAIN "TRANS"
300 END
390REM **********
400REM ERROR ROUTINES
410REM ***
420REM FNE1..IF CURRENT TOKEN<>K$ THEN ERROR #E
430 DEF FNE1(K$,E)
440 IF S0$<>K$ THEN Z=FNE(E)
450 RETURN 0
460 FNEND
470REM ***
480REM FNE2..IF NEXT TOKEN<>K$ THEN ERROR #E
490 DEF FNE2(K$,E)
500 GOSUB 1240
510 IF S0$<>K$ THEN Z=FNE(E)
520 RETURN 0
530 FNEND
540REM ***
550REM PRINT ERROR MSG
560 DEF FNE(E9)
570 !TAB(C0+4),"↑",E9
500 GOSUB 610
590 STOP
600 RETURN 0\FNEND
610REM ERROR MSGS
620 ON INT((E9-1)/5)+1 GOTO 630,640,650,660,670,680,690,700
630 ON E9 GOTO 710,720,730,740,750
640 ON E9-5 GOTO 990,990,990,760,770
650 ON E9-10 GOTO 780,790,800,990,990
660 ON E9-15 GOTO 810,820,830,840,850
670 ON E9-20 GOTO 860,870,880,990,890
680 ON E9-25 GOTO 900,910,920,990,930
690 ON E9-30 GOTO 940,990,950,960,970
700 ON E9-35 GOTO 980
710 !"MEM FULL"\RETURN
720 !"CONST EXPECTED"\RETURN
730 !"'=' EXPECTED"\RETURN
740 !"IDENTIFIER EXPECTED"\RETURN
750 !"';' OR ':' MISSING"\RETURN
760 !"'.' EXPECTED"\RETURN
770 !"';' MISSING"\RETURN
780 !"UNDECLARED IDENT"\RETURN
790 !"ILLEGAL IDENT"\RETURN
800 !"':=' EXPECTED"\RETURN
810 !"'THEN' EXPECTED"\RETURN
820 !"';' OR 'END' EXPECTED"\RETURN
830 !"'DO' EXPEXTED"\RETURN
840 !"INCORRECT SYMBOL"\RETURN
850 !"RELATIONAL OPERATOR EXPECTED"\RETURN
860 !"USE OF PROC IDENT IN EXPR"\RETURN
870 !"')' EXPECTED"\RETURN
880 !"ILLEGAL FACTOR"\RETURN
```

the parser as well as the semantic analyzer. After a Pascal construct is recognized, its meaning is analyzed by the semantic analyzer and appropriate p-codes are generated. Occasionally, there are forward references whose addresses cannot be determined at the time the codes are generated, but have to be resolved at a later time. Thus updates to the object program have to be done at the appropriate time.

This may sound complicated, but in fact a one pass compiler is actually the simplest compiler imaginable. The technique used by our parser is usually referred to as *top-down* parsing or goal oriented parsing. The top-down parsing algorithm assumes a general goal at the beginning. This goal is then broken down into one or more subgoals, depending on input strings and the rules in the syntax diagrams. The subgoals are realized by breaking them down into finer subgoals.

This is usually not a very efficient algorithm if backups are needed. The need for backups occurs if at some point we choose one subgoal from several others and find after some processing that we have made the wrong choice. We would then have to undo what had been done by the wrong choice and back up to the point where we could try other alternatives. This is usually a messy business and involves a lot of bookkeeping. Fortunately, in the parsing of Pascal, no backup is necessary. A keyword is present at each decision point, and it determines what subgoal we should choose. An example will make this clear.

Suppose our goal is to recognize a *statement*. A statement can be a number of basic constructs: it can be an assignment statement, an if statement, a case statement or any other construct defined by the syntax diagram. The Pascal grammar is so designed that we know which type of statement we should choose by just looking at the next token. If the token is if, then we know it is going to be an if statement; if the token is case, it is going to be a case statement, etc. There would seem to be a problem if the token is an identifier, since the statement can be the beginning of an assignment statement or a procedure call. But this can be easily resolved by consulting the symbol table, where we also keep the attributes (data types, addresses, etc) of the identifiers. This is one of the reasons why identifiers and procedures must be declared before use: it makes compiler writing easier.

A top-down parser without backup can be implemented by using a technique called *recursive descent*. Such a parser uses a recursive procedure for each nonterminal

| Line Number | Remark |
|---|---|
| 400 | Error routines – FNE, FNE1, FNE2 |
| 1030 | Get a character |
| 1090 | Input a line |
| 1240 | Get a token |
| 1950 | Enter entry into symbol table |
| 2060 | Search symbol table |
| 2170 | Constant declaration |
| 2240 | Get constant |
| 2340 | Variable declaration |
| 2380 | Simple expression |
| 2610 | Term |
| 2850 | Factor |
| 3290 | Expression |
| 3490 | Statement |
| 5340 | Block |
| 6120 | Push numeric |
| 6150 | Pop numeric |
| 6180 | Push string |
| 6240 | Pop string |
| 6310 | Code Generation – FNG |
| 6520 | Fixup forward references |

*Table 1: For easy reference the main subroutines of the p-compiler are listed here along with remarks regarding their uses.*

in the syntax diagrams. A call is made to this procedure whenever a parse for such a nonterminal is required. It is easy to see why such a scheme would work. The stacking mechanism of the run time procedures ensures that we get back to the correct position in the syntax diagram after completing the parse of the nonterminal.

If you look at the syntax diagrams carefully, you will see that diagrams for certain nonterminals actually contain the nonterminal itself, either immediately or after several expansions. In terms of compiler writing this means that the procedures corresponding to these nonterminals would call themselves recursively.

One important part missing from our compiler is the ability to recover from errors. Of course all syntactical errors are caught by our compiler and somewhat meaningful messages are printed to indicate errors. However, if an error is found, the compiler is aborted prematurely and will not resume compiling. Such a compiler is, of course, not acceptable in practice. But with the understanding that this compiler will be used as a bootstrap compiler, as discussed in part 1, it is tolerable. A compiler with simple error recoveries would not be particularly difficult to implement but would involve a lot of programming codes and processing time. We hesitate to add things to an already big and slow program.

It is generally difficult to implement a compiler with sophisticated error recovery features. Such a compiler would not only detect errors, but would also try to repair the damages caused by such errors. The com-

```
890 !"'BEGIN' EXPECTED"\RETURN
900 !"'OF' EXPECTED"\RETURN
910 !"ILLEGAL HEX CONST"\RETURN
920 !"'TO' OR 'DOWNTO' EXPECTED"\RETURN
930 !"NUMBER OUT OF RANGE"\RETURN
940 !"'(' EXPECTED"\RETURN
950 !"'[' EXPECTED"\RETURN
960 !"']' EXPECTED"\RETURN
970 !"PARAMETERS MISMATCHED"\RETURN
980 !"DATA TYPE NOT RECOGNIZED"\RETURN
990 !"BUG"\RETURN
1000REM ******************
1010REM SCANNER
1020REM ******************
1030REM GETCHAR
1040 IF C0<L0 THEN 1060
1050 GOSUB 1090\GOTO 1040
1060 C0=C0+1\X$=L$(C0,C0)
1070 RETURN
1080REM *********
1090REM INPUT A LINE
1100 !%4I,C1," ",
1110 IF F5<0 THEN INPUT L$ ELSE 1160
1120 IF L$="" THEN 1100
1130 IF L$(1,1)="$" THEN 1210\REM MACRO FILE?
1140 L$=L$+" "\C0=0
1150 L0=LEN(L$)\RETURN
1160 IF TYP(F5)<>0 THEN 1190\REM EOF IF TYP=0
1170 CLOSE #F5\F5=F5-1\REM RETURN TO LAST ACTIVE FILE
1180 GOTO 1110
1190 READ #F5,L$\!L$
1200 GOTO 1130
1210 F5=F5+1\OPEN #F5,L$(2,LEN(L$))
1220 GOTO 1090
1230REM *********
1240REM GET A TOKEN
1250REM RETURN S0$=TOKEN, A$=STRING, N3=NUMERIC
1260 IF X$<>" " THEN 1280
1270 GOSUB 1030\GOTO 1260\REM FLUSH BLANKS
1280 IF X$<"A" THEN1460\REM INDENTIFIER?
1290 IF X$>"Z" THEN1460
1300 K=0\A$="          "
1310 IF K>=N2 THEN 1330\REM ONLY 1ST N2 LETTERS ARE USED
1320 K=K+1\A$(K,K)=X$
1330 GOSUB 1030
1340 T=ASC(X$)
1350 IF T>47 AND T<58 OR T>64 AND T<91 THEN 1310\REM DGT OR LTTR
1360REM BIN SERACH FOR RES WORDS
1370 I=1\J=N0*5-4
1380 B$=A$
1390 K=INT((I+J)/10)*5+1
1400 Z$=W0$(K,K+4)
1410 IF B$<=Z$ THEN J=K-5
1420 IF B$>=Z$ THEN I=K+5
1430 IF I<=J THEN 1390
1440 IF I-5>J THEN S0$=B$ ELSE S0$="IDENT"
1450 RETURN
1460 Z$=""
1470 IF X$<"0" THEN 1580\REM AN INTEGER?
1480 IF X$>"9" THEN 1580
1490 S0$="NUM"
1500 Z$=Z$+X$
1510 GOSUB 1030
1520 IF ASC(X$)>=48 AND ASC(X$)<=57 THEN 1500
1530 N3=VAL(Z$)
1540 IF N3<=N1 THEN RETURN
1550 E9=30\GOSUB 550
1560 N3=N1\RETURN
1570REM CHECK FOR SPECIAL SYMBOL
1580 IF X$<>":" THEN 1640
1590 GOSUB 1030
1600 IF X$="=" THEN 1620
1610 S0$=":"\RETURN
1620 S0$=":="
1630 GOSUB 1030\RETURN
1640 IF X$<>"<" THEN 1710
1650 GOSUB 1030
1660 IF X$=">" THEN 1690
1670 IF X$="=" THEN 1700
1680 S0$="<"\RETURN
1690 S0$="<>"\GOSUB 1030\RETURN
1700 S0$="<="\GOSUB 1030\RETURN
1710 IF X$<>">" THEN 1750
1720 GOSUB 1030\S0$=">"
1730 IF X$<>"=" THEN RETURN
1740 S0$=">="\GOSUB 1030\RETURN
1750 IF X$<>"'" THEN 1790
1760 S0$="STR"\C$=""
1770 GOSUB 1030\IF X$="'" THEN 1030
1780 C$=C$+X$\GOTO 1770
1790 IF X$<>"{" THEN 1820\REM IGNORE COMMENTS
1800 GOSUB 1030\IF X$<>"}" THEN 1800
1810 GOSUB 1030\GOTO 1240
1820 IF X$<>"%" THEN 1930\REM HEX CONSTANT
1830 GOSUB 1030\S0$="NUM"\N3=0
1840 FOR I=1 TO 4
```

```
1050 T=ASC(X$)
1860 IF T>=48 AND T<=57 THEN 1880
1870 IF T>=65 AND T<=70 THEN T=T-7 ELSE 1910
1880 T=T-48
1890 N3=N3*16+T\GOSUB 1030\NEXT
1900 RETURN
1910 IF I>1 THEN Z=FNE(27)
1920 S0$="%"\RETURN
1930 S0$=X$\GOTO 1030
1940REM **********
1950REM ENTER SYMBOL INTO TABLE
1960 T1=T1+1
1970 T$((T1-1)*N2+1,T1*N2)=A$
1980 T0$(T1,T1)=K$\REM STORE TYPE
1990 IF K$<>"C" THEN 2010
2000 T2(T1)=N3\RETURN\REM STORE VALUE
2010 T1(T1)=L1\REM STORE LEVEL OF IDENT
2020 IF K$<>"V" THEN RETURN
2030 IF NOT F9 THEN RETURN\REM SP WAS ALLOCATED FOR PROC PARS
2040 T2(T1)=D0\D0=D0+1\RETURN\REM STORE OFFSET
2050REM **********
2060REM FIND IDENT A$ IN T$,STARTING FROM T1 AND UP
2070REM RETURN POINTER TO TABLE IF FOUND, ELSE RETURN 0
2080 J=(T1-1)*N2+1
2090 FOR I=T1 TO 1 STEP -1
2100 IF A$=T$(J,J+N2-1) THEN EXIT 2130
2110 J=J-N2\NEXT
2120 I=0
2130 RETURN
2140REM ********************
2150REM PARSER AND CODER
2160REM ********************
2170REM CONSTANT DECLARATION
2180 Z=FNE1("IDENT",4)
2190 Z=FNE2("=",3)
2200 GOSUB 1240\GOSUB 2240
2210 K$="C"\GOSUB 1950
2220 GOTO 1240
2230REM **********
2240REM CONSTANT
2250 IF S0$="NUM" THEN RETURN
2260 IF S0$="IDENT" THEN 2290\REM CONST?
2270 Z=FNE1("STR",2)
2280 N3=ASC(C$)\RETURN\REM TAKE 1ST CHAR
2290 GOSUB 2060\IF I=0 THEN FNE(2)
2300 IF T0$(I,I)<>"C" THEN FNE(2)
2310 N3=T2(I)\RETURN
2320 GOTO 1240
2330REM **********
2340REM VARIABLE DECLARATION
2350 Z=FNE1("IDENT",4)
2360 K$="V"\GOSUB 1950\GOTO 1240
2370REM **********
2380REM SIMPLE EXPRESSION
2390 IF S0$="+" THEN 2420
2400 IF S0$<>"-" THEN 2590
2410 Y$=S0$\GOSUB 6180
2420 GOSUB 1240
2430 GOSUB 2610
2440 GOSUB 6240
2450 IF Y$="-" THEN Z=FNG(1,0,1)
2460 IF S0$="+" THEN 2500
2470 IF S0$="-" THEN 2500
2480 IF S0$="OR   " THEN 2500
2490 RETURN
2500 Y$=S0$\GOSUB 6180
2510 GOSUB 1240
2520 GOSUB 2610
2530 GOSUB 6240
2540 IF Y$="-" THEN 2570
2550 IF Y$="+" THEN 2580
2560 Z=FNG(1,0,14)\GOTO 2460
2570 Z=FNG(1,0,3)\GOTO 2460
2580 Z=FNG(1,0,2)\GOTO 2460
2590 GOSUB 2610\GOTO 2460
2600REM **********
2610REM TERM
2620 GOSUB 2850
2630 IF S0$="*" THEN 2700
2640 IF S0$="DIV  " THEN 2700
2650 IF S0$="AND  " THEN 2700
2660 IF S0$="MOD  " THEN 2700
2670 IF S0$="SHL  " THEN 2700
2680 IF S0$="SHR  " THEN 2700
2690 RETURN
2700 Y$=S0$\GOSUB 6180\REM PUSH
2710 GOSUB 1240\GOSUB 2650
2720 GOSUB 6240
2730 IF Y$="DIV  " THEN 2790
2740 IF Y$="MOD  " THEN 2800
2750 IF Y$="*" THEN 2810
2760 IF Y$="SHL  " THEN 2820
2770 IF Y$="SHR  " THEN 2830
2780 Z=FNG(1,0,15)\GOTO 2630\REM "AND"
2790 Z=FNG(1,0,5)\GOTO 2630
2800 Z=FNG(1,0,7)\GOTO 2630
```

piler has to make some assumptions about the nature of the errors and the intention of the author. This is usually difficult.

If our concern is solely that of locating all errors in a single parse of the source program, there are simple ways of doing it. Upon detecting an error, the compiler simply skips the input text until it can safely resume the compilation process. To do this the compiler looks for certain keywords or *stopping* symbols for hints to resume the parsing process. For instance, if we find an error while parsing a conditional expression, we skip the input tokens and search for

### BASIC Recursive Subroutines

*Most versions of BASIC do not adequately support recursive subroutine calls. In North Star BASIC, the multiline function call can be invoked recursively, in a limited fashion. This is because the function parameters are local within the function definition and are pushed onto a stack when making a call.*

*The surprising fact is that most BASICs do not forbid a recursive call if one is made. For instance, the following BASIC subroutine, which is an inefficient way of printing the first N integers in descending order, is probably permitted in most BASICs:*

```
100 PRINT N
200 IF N=0 THEN RETURN
300 N=N-1
400 GOSUB 100
500 RETURN
```

*The problem of doing recursive calls in BASIC is that of preserving the values of the identifiers in the subroutines. This can be done by using a stack. The values of the identifiers are pushed onto the stack before a recursive call, and popped out of the stack in the reverse order when returning from the call. In BASIC, the stack can be simulated by an array:*

```
10 DIM S(100)
11 P=0
12 REM INITIALIZE STACK POINTER
.
.
.
1000REM PUSH X INTO STACK
1010 S(P)=X
1020 P=P+1
1030 RETURN
2000REM POP X FROM STACK
2010 P=P-1
2020 X=S(P)
2030 RETURN
```

symbols, such as =, > =, etc, and keywords such as then and do or perhaps begin. If we do this for all the parts of the language constructs, we will at least have a compiler that would resume compilation after an error is encountered in the hope of finding all syntactic errors in one pass, and which would give meaningful diagnostics for most errors.

To reduce the size of the program shown in listing 1, comments are kept to a minimum. Each module or subroutine is clearly identified. To facilitate easy reference, the important subroutines and variables are shown in table 1 and table 2, respectively.

### Scanner and Symbol Table Management

Each time the p-compiler calls the scanner (line 1260, listing 1), the input text is scanned and a new token is produced. This is done by calling a subroutine (line 1040) that returns a character from the input string. Since the input/output (IO) routines are line oriented instead of character oriented, a line buffer (L$) is used to hold a line, and a counter (C0) is used to indicate the character just read. When the end of a line is reached, the line input routine (line 1100) is called to read in a new line.

In our compiler we also provide the capability of invoking or recalling a file of Pascal text from disk. This is initiated by a command that starts with a dollar sign ($) in the first column followed immediately by the name of the disk file to be inserted and compiled. Since North Star BASIC allows four disk files to be open at the same time, there can be four levels of file nesting. The variable F5 is used to indicate this level. If it is equal to −1, then input is taken from the keyboard. The initial input is from the keyboard. This feature is quite useful, since we can store procedures that are commonly used in a disk library, and have them recalled when needed.

Usually, the token that the scanner returns is a number that represents the token class the symbol is in. To make the program more readable, we use string variable S0$. Possible values returned by the scanner are: ; , :=, BEGIN, IDENT, and NUM. The last two tokens, which are tokens for identifiers and numbers, require some further information. A$ and N3 are also used to store the textual representation of the identifier and the value of the number, respectively.

The recognition of a valid token is a straightforward process and will not be detailed here. Since : and := are both valid tokens, the scanner, after seeing the : , must also look at the next character to

```
2810 Z=FNG(1,0,4)\GOTO 2630
2820 Z=FNG(1,0,17)\GOTO 2630
2830 Z=FNG(1,0,18)\GOTO 2630
2840REM **********
2850REM FACTOR
2860 IF S0$="IDENT" THEN 2940
2870 IF S0$="NUM" THEN 3060
2880 IF S0$="STR" THEN 3080
2890 IF S0$="(" THEN 3100
2900 IF S0$="MEM  " THEN 3140
2910 IF S0$="NOT  " THEN 3260
2920 Z=FNE(23)
2930REM *** IDENTIFIER
2940 GOSUB 2060
2950 IF I=0 THEN Z=FNE(11)
2960 IF T0$(I,I)="P" THEN Z=FNE(21)\REM PROC NAME
2970 IF T0$(I,I)<>"Y" THEN 3000
2980 Z=FNG(5,0,1)\REM FUNC
2990 I=I-1\GOTO 4290\REM T2(I)=ADD OF FUNC
3000 IF T0$(I,I)="A" THEN 3190\REM ARRAY
3010 IF T0$(I,I)<>"C" THEN 3030
3020 Z=FNG(0,0,T2(I))\GOTO 1240\REM CONST
3030 Z=FNG(2,L1-T1(I),T2(I))\REM ID
3040 GOTO 1240
3050REM *** NUMERIC CONST
3060 Z=FNG(0,0,N3)\GOTO 1240
3070REM *** STRNG CONST
3080 Z=FNG(0,0,ASC(C$))\GOTO 1240
3090REM *** PAREN EXPR
3100 GOSUB 1240\GOSUB 3290
3110 IF S0$=")" THEN 1240
3120 Z=FNE(22)\RETURN
3130REM *** READ MEMORY
3140 Z=FNE2("[",33)
3150 GOSUB 1240\GOSUB 3290
3160 Z=FNE1("]",34)
3170 GOSUB 1240
3180 Z=FNG(2,255,0)\RETURN
3190 X=I\GOSUB 6120
3200 Z=FNE2("[",33)
3210 GOSUB 1240\GOSUB 3290
3220 Z=FNE1("]",34)
3230 GOSUB 6150\Z=FNG(18,L1-T1(X),T2(X))
3240 GOTO 1240
3250REN *** NEGATE
3260 GOSUB 1240\GOSUB 2850
3270 Z=FNG(1,0,16)\RETURN
3280REM **********
3290REM EXPRESSION
3300 GOSUB 2390\REM SIMPLE EXP
3310 IF S0$="=" THEN 3380
3320 IF S0$="<>" THEN 3380
3330 IF S0$="<" THEN 3380
3340 IF S0$="<=" THEN 3380
3350 IF S0$=">" THEN 3380
3360 IF S0$=">=" THEN 3380
3370 RETURN
3380 Y$=S0$\GOSUB 6180\REM PUSH
3390 GOSUB 1240\GOSUB 2390
3400 GOSUB 6240\REM POP
3410 IF Y$="=" THEN Z=FNG(1,0,8)
3420 IF Y$="<>" THEN Z=FNG(1,0,9)
3430 IF Y$="<" THEN Z=FNG(1,0,10)
3440 IF Y$=">=" THEN Z=FNG(1,0,11)
3450 IF Y$=">" THEN Z=FNG(1,0,12)
3460 IF Y$="<=" THEN Z=FNG(1,0,13)
3470 RETURN
3480REM **********
3490REM STATEMEMT
3500 IF S0$="IDENT" THEN 3630
3510 IF S0$="IF   " THEN 4440
3520 IF S0$="FOR  " THEN 5170
3530 IF S0$="WHILE" THEN 4800
3540 IF S0$="CASE " THEN 4890
3550 IF SO$="REPEA" THEN 4730
3560 IF S0$="BEGIN" THEN 4590
3570 IF S0$="READ " THEN 4040
3580 IF S0$="WRITE" THEN 3870
3590 IF S0$="MEM  " THEN 4650
3600 IF S0$="CALL " THEN 4240
3610 RETURN
3620REM *** ASSIGNMNT
3630 GOSUB 2060
3640 IF I=0 THEN Z=FNE(11)
3650 IF T0$(I,I)="A" THEN 3700\REM ARRAY
3660 IF T0$(I,I)="V" THEN 3760\REM INT VAR
3670 IF T0$(I,I)="Y" THEN 3760\REM FUNC RETURN VALUE
3680 IF T0$(I,I)="P" THEN 4290\REM PROC CALL
3690 Z=FNE(12)
3700 X=I\GOSUB 6120\REM PUSH TBL ADD
3710 X=16\GOSUB 6120\REM INDEX ADD MODE
3720 Z=FNE2("[",33)
3730 GOSUB 1240\GOSUB 3290
3740 Z=FNE1("]",34)
3750 GOTO 3780
3760 X=I\GOSUB 6120
```

```
3770 X=0\GOSUB 6120
3780 GOSUB 1240
3790 IF S0$=":=" THEN 3810
3800 Z=FNE(13)\GOTO 3820
3810 GOSUB 1240
3820 GOSUB 3290\GOSUB 6150
3830 K=X\GOSUB 6150
3840 Z=FNG(3+K,L1-T1(X),T2(X))
3850 RETURN
3860REM *** WRITE
3870 Z=FNE2("(",31)
3880 GOSUB 1240\IF S0$<>"STR" THEN 3950
3890 L=LEN(C$)\IF L>1 THEN 3910
3980 Z=FNG(0,0,ASC(C$))\Z=FNG(8,0,1)\GOTO 3940
3910 FOR I=1 TO L
3920 Z=FNG(0,0,ASC(C$(I,I)))\NEXT
3930 Z=FNG(0,0,L)\Z=FNG(8,0,8)
3940 GOSUB 1240\GOTO 4000
3950 GOSUB 3290\K=1
3960 IF S0$="#" THEN K=3\REM DEC
3970 IF S0$="%" THEN K=5\REM HEX
3980 IF K>1 THEN GOSUB 1240
3990 Z=FNG(8,0,K)
4000 IF S0$="," THEN 3880
4010 Z=FNE1(")",22)
4020 GOTO 1240
4030REM *** READ
4040 Z=FNE2("(",31)
4050 Z=FNE2("IDENT",4)
4060 GOSUB 2060\IF I=0 THEN Z=FNE(11)
4070 X=I\GOSUB 6120
4080 IF T0$(I,I)="A" THEN 4190
4090 IF T0$(I,I)="V" THEN L=0 ELSE Z=FNE(4)
4100 GOSUB 1240\K=0
4110 IF S0$="#" THEN K=2\REM DEC
4120 IF S0$="%" THEN K=4\REM HEX
4130 Z=FNG(8,0,K)
4140 IF K>0 THEN GOSUB 1240
4150 GOSUB 6150\Z=FNG(L+3,L1-T1(X),T2(X))
4160 IF S0$="," THEN 4050
4170 Z=FNE1(")",31)
4180 GOTO 1240
4190 Z=FNE2("[",33)
4280 GOSUB 1240\GOSUB 3290
4210 Z=FNE1("]",34)
4220 L=16\GOTO 4100
4230REM *** ABSOLUTE MEM CALL
4240 Z=FNE2("(",31)
4250 GOSUB 1240\GOSUB 3290
4260 Z=FNE1(")",22)
4270 Z=FNG(4,255,0)\GOTO 1240
4280REM *** PROC OR FUNC CALL
4290 K2=0\K3=I
4380 IF T3(I)=0 THEN 4400\REM NO PARAMETER
4310 Z=FNE2("(",31)
4320 X=K2\GOSUB 6120
4330 X=K3\GOSUB 6120
4340 GOSUB 1240\GOSUB 3290
4350 GOSUB 6150\K3=X
4360 GOSUB 6150\K2=X\K2=K2+1
4370 IF S0$="," THEN 4320
4380 IF K2<>T3(K3) THEN Z=FNE(35)
4390 Z=FNE1(")",22)
4400 Z=FNG(4,L1-T1(K3),T2(K3))
4410 IF K2 <>0 THEN Z=FNG(5,0,-K2)
4420 GOTO 1240
4430REM *** IF
4440 GOSUB 1240
4450 GOSUB 3290
4460 Z=FNE1("THEN ",16)
4470 GOSUB 1240
4480 X=C1\GOSUB 6120\REM FORWARD REF POINT
4490 Z=FNG(7,0,0)\REM JPC
4500 GOSUB 3490
4510 IF S0$<>"ELSE " THEN 6520
4520 GOSUB 6150\K=X
4530 X=C1\GOSUB 6120
4540 Z=FNG(6,0,0)\REM JMP
4550 X=K\GOSUB 6540\REM FIXUP FORWD REF
4560 GOSUB 1240\GOSUB 3490
4570 GOTO 6520
4580REM *** COMPOUND STTMNT
4590 GOSUB 1240
4600 GOSUB 3490
4610 IF S0$=";" THEN 4590
4620 IF S0$="END  " THEN 1240
4630 Z=FNE(17)\RETURN
4640REM *** WRITE MEM
4650 Z=FNE2("[",33)
4660 GOSUB 1240\GOSUB 3290
4670 IF S0$<>"]" THEN Z=FNE(34)
4680 Z=FNE2(":=",13)
4690 GOSUB 1240\GOSUB 3290
4700 Z=FNG(3,255,0)
4710 RETURN
4720REM *** REPEAT .. UNTIL
```

determine the correct token. This can be done by using a one character look ahead. When the scanner is entered, a character is assumed to have been read, and upon exit from the scanner, a character beyond the current token is read.

Another problem that the scanner may have is that of recognizing reserved words. The reserved words are stored in a table in sorted order. When an identifier is found, it is compared with the entries in the table, by performing a binary search. If it is not in the table, it is assumed to be a user defined identifier.

In Pascal programs, identifiers are declared at the beginning of each procedure block. The scope of an identifier covers the entire block containing it (and any of the blocks inside that block). A simple symbol management scheme that reflects such scope rules makes use of a stack. When the compiler enters a procedure block, a segment of the stack is used to store identifiers for the block. If the procedure block contains another procedure block, then another segment of the stack on top of the existing segments is used for identifiers of this block. After successful compilation of a procedure, its segment of the stack can be discarded, since there is no further use for this part of the symbol table. In this way, we can also eliminate possible interference with identifiers in some other blocks. We also see that since the block delimiting mechanism is hierarchical, use of stack is also appropriate. Figure 2 illustrates two-level block nesting.

Readers may have noticed the similarities between this symbol table stacking scheme and the run time storage allocation scheme discussed in part 1. Since the symbol table deals with a static structure, it is much simpler.

Within the segment of the symbol table for a procedure block, further data structures can be set up for storing the identifiers. We chose to use what we feel is the simplest method: store the identifiers sequentially, in their order of appearance. This means that search also has to be done sequentially. Since most procedures have only a small number of identifiers, this should work well in most cases. Other more sophisticated structures such as a balanced binary tree or hashed table are commonly used in larger compilers.

The symbol table also contains some information about the identifiers. The identifier type has to be kept with the symbol table. Specific information is needed for each type of identifier. For constants, the information is the values of the constants; for program variables, the information is the address pair (level, offset from

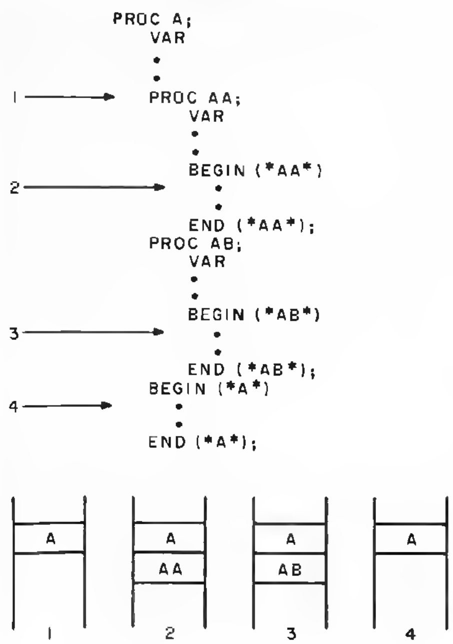


*Figure 2: Example symbol table at various points of compilation.*

| Variable Name | Remark |
|---|---|
| A$ | String of the token returned by the scanner |
| C0 | Input buffer pointer |
| C1 | P-code address pointer |
| D0 | Run time storage counter |
| E9 | Error code |
| F5 | Active input file unit number; keyboard=–1 |
| K1 | Number of parameter in the previous block |
| L0 | Length of the input line |
| L1 | Static level of procedure |
| L$ | Input line buffer |
| M$ | P-code mnemonics |
| N0 | Reserved word table size |
| N1 | Largest integer |
| N2 | Length of identifier name |
| N3 | Numeric value of token (token = "NUM") or ASCII value of string (token = "STR") |
| P8 | Stack pointer for S$ |
| P9 | P-code absolute memory address counter |
| S | Stack for numeric values |
| S9 | Stack pointer for S |
| S$ | Stack for strings |
| S0$ | Next token |
| T0 | Symbol table size |
| T1 | Symbol table pointer |
| T$ | Symbol table: identifier |
| T0$ | Symbol table: type of identifier<br>V: variable  A: array  C: constant<br>P: procedure  F: function  Y: parameter |
| T1( ) | Symbol table: level |
| T2( ) | Symbol table: value (constant)<br>or displacement (variable)<br>or address (proc or func) |
| T3( ) | Symbol table: array size (array)<br>or number of parameter (proc or func) |
| X | Value to be pushed or popped |
| X$ | Next character to be read by the scanner |
| Y$ | String to be pushed or popped |
| W0$ | Table for reserved words |

*Table 2: Important variables used in the p-compiler.*

base address); for procedures and functions, it is the address pairs and the number of parameters; and, lastly, for array variables, the information is the address pair as well as array sizes. See table 2 for actual variables that are used to store these quantities.

```
4730 X=C1\GOSUB 6120
4740 GOSUB 1240\GOSUB 3490
4750 IF S0$=";" THEN 4740
4760 Z=FNE1("UNTIL",10)
4770 GOSUB 1240\GOSUB 3290
4780 GOSUB 6150\Z=FNG(7,0,X)\RETURN
4790REM *** WNILE .. DO
4800 GOSUB 1240\X=C1\GOSUB 6120
4810 GOSUB 3290\X=C1\GOSUB 6120
4820 Z=FNG(7,0,0)
4830 Z=FNE1("DO   ",18)
4840 GOSUB 1240\GOSUB 3490
4850 GOSUB 6150\K=X\GOSUB 6150
4860 Z=FNG(6,0,X)
4870 X=K\GOTO 6540
4880REM *** CASE .. OF
4890 GOSUB 1240\GOSUB 3290
4900 Z=FNE1("OF   ",25)
4910 I2=1\REM # OF CASE STATMNTS
4920 I1=0\REM # OF CASE LABELS
4930 GOSUB 1240\GOSUB 2240
4940 Z=FNG(1,0,21)\Z=FNG(0,0,N3)\Z=FNG(1,0,8)
4950 GOSUB 1240\IF S0$=":" THEN 4990
4960 Z=FNE1(",",5)
4970 X=C1\GOSUB 6120\Z=FNG(7,1,0)\REM A MATCN FOUND?
4980 I1=I1+1\GOTO 4930
4990 K=C1\Z=FNG(7,0,0)\REM GOTO NEXT CASE STMNT IF NO MATCN
5000 FOR I=1 TO I1\GOSUB 6520\NEXT\REM FIXUP FORWD REFS
5010 X=K\GOSUB 6120
5020 GOSUB 1240\X=I2\GOSUB 6120
5030 GOSUB 3490\GOSUB 6150\I2=X
5040 IF S0$="ELSE " THEN 5090
5050 IF S0$<>";" THEN 5130
5060 K=C1\Z=FNG(6,0,0)\REM EXIT AFTER A CASE STMNT
5070 GOSUB 6520
5080 X=K\GOSUB 6120\I2=I2+1\GOTO 4920
5090 K=C1\Z=FNG(6,0,0)\GOSUB 6520
5100 X=K\GOSUB 6120
5110 GOSUB 1240\X=I2\GOSUB 6120
5120 GOSUB 3490\GOSUB 6150\I2=X
5130 Z=FNE1("END  ",17)
5140 FOR I=1 TO I2\GOSUB 6520\NEXT\REM FIXUP FORWD REFS
5150 Z=FNG(5,0,-1)\GOTO 1240\REM POP VAL OF CASE EXP
5160REM *** FOR
5170 Z=FNE2("IDENT",4)
5180 GOSUB 3630\GOSUB 6120
5190 F9=1\IF S0$="TO   " THEN 5210\REM REMEMBER UP OR DOWN
5200 Z=FNE1("OOWNT",28)\F9=0
5210 GOSUB 1240\GOSUB 3290
5220 GOSUB 6150\K=X\X=C1\GOSUB 6120
5230 Z=FNG(1,0,21)\Z=FNG(2,L1-T1(K),T2(K))
5240 Z=FNG(1,0,13-F9-F9)\X=C1\GOSUB 6120\Z=FNG(7,0,0)
5250 X=F9\GOSUB 6120\X=K\GOSUB 6120
5260 Z=FNE1("DO   ",18)\GOSUB 1240
5270 GOSUB 3490\GOSUB 6150\Z=FNG(2,L1-T1(X),T2(X))
5280 K=X\GOSUB 6150\Z=FNG(1,0,20-X)
5290 Z=FNG(3,L1-T1(K),T2(K))
5300 GOSUB 6150\K=X\GOSUB 6150\Z=FNG(6,0,X)
5310 X=K\GOSUB 6540
5320 Z=FNG(5,0,-1)\RETURN\REM POP OFF VAL OF LOOP CNTRL VAR
5330REM **********
5340REM BLOCK
5350 D0=3\REM RESERVED FOR STATIC LINK,DYNAMIC LINK & RETN ADD
5360 T2(T1-K1)=C1\REM INIT ADD OF THE PROC BLOCK
5370 Z=FNG(6,0,0)\REM JMP TO STARTING BLK ADD
5380 X=T1-K1\GOSUB 6120
5390 IF S0$="CONST" TNEN 5460
5400 IF S0$="VAR  " THEN 5550
5410 IF S0$="PROC " TNEN 5730
5420 IF S0$="FUNC " THEN 5770
5430 IF S0$="BEGIN" TNEN 5980
5440 Z=FNE(25)
5450REM *** CONST DCL
5460 GOSUB 1240
5470 GOSUB 2170
5480 Z=FNE1(";",5)\GOSUB 1240
5490 IF S0$="VAR  " THEN 5550
5500 IF S0$="PROC " TNEN 5730
5510 IF S0$="FUNC " TNEN 5770
5520 IF S0$="BEGIN" THEN 5980
5530 GOTO 5470
5540REM *** VARIABLE DCL
5550 L=0\F9=1
5560 GOSUB 1240\GOSUB 2340
5570 L=L+1\IF S0$="," THEN 5560
5580 Z=FNE1(":",5)
5590 GOSUB 1240\IF S0$="ARRAY" THEN 5610
5600 Z=FNE1("INTEG",36)\GOTO 5670
5610 Z=FNE2("[",33)\GOSUB 1240\GOSUB 2240
5620 Z=FNE2("]",34)\Z=FNE2("OF   ",26)\Z=FNE2("INTEG",36)
5630 D0=D0-L
5640 FOR I=T1-L+1 TO T1
5650 T0$(I,I)="A"\T3(I)=N3+1
5660 T2(I)=D0\D0=D0+N3+1\NEXT
5670 Z=FNE2(";",5)
5680 GOSUB 1240\IF S0$="PROC " TNEN 5730
```

```
5690 IF S0$="FUNC " THEN 5770
5700 IF S0$="BEGIN" THEN 5980
5710 L=0\F9=1\GOSUB 2340\GOTO 5570
5720REM *** PROC DCL
5730 Z=FNE2("IDENT",4)
5740 K1=0\K$="P"\GOSUB 1950
5750 L1=L1+1\GOTO 5810
5760REM *** FUNC DCL
5770 Z=FNE2("IDENT",4)
5780 K$="F"\GOSUB 1950\REM FUNC ADDRSS
5790 L1=L1+1\K1=1
5800 K$="Y"\GOSUB 1950\REM FUNC VALUE
5010 K2=K1\GOSUB 1240
5020 X=T1\GOSUB 6120
5030 X=D0\GOSUB 6120
5840 IF S0$<>"(" THEN 5890
5850 GOSUB 1240\F9=0\GOSUB 2340\K1=K1+1
5860 IF S0$="," THEN 5850
5870 Z=FNE1(")",22)
5800 GOSUB 1240\T3(T1-K1)=K1-K2
5890 Z=FNE1(";",5)
5900 FOR I=1 TO K1\REM FUNC VALUE & PARS HAVE - OFFSET
5910 T2(T1-I+1)=-I\NEXT
5920 GOSUB 1240\GOSUB 5340\L1=L1-1
5930 GOSUB 6150\D0=X
5940 GOSUB 6150\T1=X
5950 Z=FNE1(";",5)
5960 GOSUB 1240\GOTO 5410
5970REM *** START OF EXECUTIBLE STTMNTS
5980 GOSUB 1240\GOSUB 6150\K=X
5990 X=T2(K)\GOSUB 6540
6000 T2(K)=C1\REM START BLOCK ADDR
6010 Z=FNG(5,0,D0)
6020 GOSUB 3490
6030 IF S0$<>";" THEN 6050
6040 GOSUB 1240\GOTO 6020
6050 IF S0$<>"END  " THEN Z=FNE(17)
6060 GOSUB 1240
6070 Z=FNG(1,0,0)
6080 RETURN
6090REM **********
6100REM END PARSER AND CODER
6110REM **********
6120REM PUSH X INTO STACK
6130 S(S9)=X\S9=S9+1\RETURN
6140REM **********
6150REM POP X FROM STACK
6160 S9=S9-1\X=S(S9)\RETURN
6170REM **********
6180REM PUSH Y$ INTO STACK
6190 L=LEN(Y$)
6200 S$(P8,P8+L-1)=Y$
6210 X=P8\GOSUB 6120\REM PUSH START & END STRNG POS
6220 X=P8+L-1\GOSUB 6120
6230 PS=P8+L\RETURN
6240REM POP Y$ FROM STACK
6250 GOSUB 6150
6260 L=X\GOSUB 6150
6270 Y$=S$(X,L)
6280 P8=P8-L+X-1
6290 RETURN
6300REM **********
6310REM GENERATE CODES
6320 DEF FNG(X1,X2,X3)
6330 B$="   "
6340 FILL P9,X1\FILL P9+1,X2
6350 FILL P9+2,FNA(X3)\FILL P9+3,FNB(X3)
6360 IF Y9 THEN 6400\REM IF INPUT FROM KEYBOARD THEN DONT ECHO
6370 IF X1<16 THEN 6390
6380 B$(1,1)="X"\X1=X1-16\REM INDEX
6390 !%4I,C1,"  ",M$(X1*3+1,X1*3+3),B$,%3I,X2,%6I,X3
6400 C1=C1+1\P9=P9+4
6410 IF P9>=Q9 THEN Z=FNE(1)
6420 RETURN 0
6430 FNEND
6440REM **********
6450 DEF FNB(Z)
6460 N=INT(Z/256)
6470 IF N<0 THEN N=256+N
6480 RETURN N
6490 FNEND
6500 DEF FNA(Z)=Z-INT(Z/256)*256
6510REM **********
6520REM FIXUP FORWORD REF
6530 GOSUB 6150
6540 N=P7+X*4
6550 FILL N+2,FNA(C1)\FILL N+3,FNB(C1)
6560 IF Y9 THEN RETURN
6570 !"ADD AT",X," CHANGED TO",C1
6580 RETURN
READY
```

The symbol table is used by both the parser and the semantic analyzer. The information in the symbol table is used in a number of ways. The type of identifier is used, for instance, to check the type consistency in an expression. When a variable is referenced or a procedure or function called, the symbol table is searched to obtain the level and relative address from the base address. The number of parameters in a procedure or function is used to check the correct matching of parameters in actual procedure or function calls.

An identifier is searched for by starting from the end of the symbol table and working towards the beginning. (Viewing the table as a stack, we say that we search from the *top* of the stack down to the *bottom*.) There are two reasons for this searching direction. First, identifiers in the current block are more likely to be referenced and should be searched first. Secondly, suppose that a variable X is declared in both an outer and an inner block: by searching for X from top to bottom of the stack, we can be sure that we will find X of the inner block first, in accordance with the scope rule.

## Parser, Semantic Analyzer, and Coder

The parser, the semantic analyzer and the coder are not separate routines, but are intermixed in a large routine. In most cases, after the successful parsing of a statement, its meaning is also understood by the compiler. Thus the semantic analyzer either requires minimal extra processing or is implicit in the parser and disappears altogether.

The parser, as we have mentioned before, uses a top-down technique called recursive descent. Since there is a close correspondence between the parser and the syntax diagrams of the Pascal grammar, there should be no difficulties in understanding the parsing process. The parser adopts the convention of one token look ahead which is similar to the one character look ahead convention used by the scanner. The variable S0$ is used to hold the next token to be read by the parser.

There is a part of the Pascal grammar, commonly referred to as the dangling else, that is ambiguous. The statement:

**if** *cond1* **then if** *cond2* **then** *stat1* **else** *stat2;*

can be parsed in two ways. The else statement can be associated with the first if or with the second if, producing entirely different results.

We resolve this difficulty by always associating the else statement with the most recent if. If an else statement with the first if is desired, one of these two methods should be used:

```
if cond1 then
    if cond2 then stat1 else
else stat2;
```

or:

```
if cond1 then begin
    if cond2 then stat1
    end
else stat2;
```

The situation is similar to the case statement with the added feature of an optional else statement. If the statement for the last case label is an if statement, we then have the dangling else problem. This is resolved in the same manner.

There are three functions used to print messages when errors are detected. The function FNE(X) prints the error message corresponding to error code X. FNE1(A$,X) checks to see if the current token is equal to A$, and prints the error message corresponding to error code X if not. FNE2 is similar to FNE1 except that the scanner is first called to get a new token. As we mentioned earlier, the compiler aborts as soon as an error is found. Therefore these error routines do not return to the calling procedure.

The code generator requires more work: care must be taken to store important values in stacks due to the inability of BASIC to fully support recursive subroutine calls. Otherwise the coder is more or less straightforward, since the p-codes are so designed (see part 1) that there is a direct correspondence between simple Pascal statements and p-codes. Table 3 shows the almost direct translation of Pascal statements into p-codes.

The declarative statements (const, var, proc, and func) do not produce any executable statements; they merely provide information about declared identifiers. The first executable code encountered when entering a procedure or function block is a forward jump instruction to the main body of the block. This jump is necessary since in general there may be procedures and functions whose codes take up space. The second executable code of the block increments the stack pointer (INT). This allocates space for the triplet (static link, dynamic link and return address) plus any variables declared. The number of spaces for the variables is already known from the declaration portion of the procedure block. The variable D0 is used to keep track of the space to be allocated at the activation of the block.

Note that no space is allocated for constants. If a constant is referenced, a load literal (LIT) instruction is generated instead of a load (LOD) instruction. Also note that the procedure or function parameters and the function return value do not reserve any space in the procedure or function block called. Space is reserved before the call is made. Therefore, these values have negative displacement from the base address of the called procedure or function.

When a call is made to a function, the space for function return value is allocated by incrementing the stack pointer (line 2980 in listing 1) (this step is skipped for a procedure call). The parameter expression is then evaluated (line 4250), putting

| Pascal source | | p-codes | |
|---|---|---|---|
| *x+10*y[5]* | | LOD | X |
| | | LIT | 10 |
| | | LIT | 5 |
| | | LODX | Y |
| | | OPR | * |
| | | OPR | + |
| *a:=exp;* | | (exp) | |
| | | STO | A |
| **if** *exp* **then** *stm1* **else** *stm2;* | | (exp) | |
| | | JPC | 0,1b1 |
| | | (stm1) | |
| | | JMP | 1b2 |
| | 1b1 | (stm2) | |
| | 1b2 | . . . | |
| **for** *i:=exp1* **to** *exp2* **do** *stm;* | | (exp1) | |
| | | STO | I |
| | | (exp2) | |
| | 1b1 | OPR | CPY |
| | | LOD | I |
| | | OPR | >= |
| | | JPC | 0,1b2 |
| | | (stm) | |
| | | LOD | I |
| | | OPR | INC |
| | | STO | I |
| | | JMP | 1b1 |
| | 1b2 | INT | –1 |
| **while** *exp* **do** *stm;* | 1b1 | (exp) | |
| | | JPC | 0,1b2 |
| | | (stm) | |
| | | JMP | 1b1 |
| | 1b2 | . . . | |
| **case** *exp* **of** | | (exp) | |
| *c1b1,c1b2:stm1;* | | OPR | CPY |
| *c1b3 :stm2;* | | LIT | c1b1 |
| **else** *stm3* | | OPR | = |
| **end;** | | JPC | 1,1b1 |
| | | OPR | CPY |
| | | LIT | c1b2 |
| | | OPR | = |
| | | JPC | 0,1b2 |
| | 1b1 | (stm1) | |
| | | JMP | 1b4 |
| | 1b2 | OPR | CPY |
| | | LIT | c1b3 |
| | | OPR | = |
| | | JPC | 0,1b3 |
| | | (stm2) | |
| | | JMP | 1b4 |
| | 1b3 | (stm3) | |
| | 1b4 | INT | –1 |
| **repeat** *stm* **until** *exp;* | 1b1 | (stm) | |
| | | (exp) | |
| | | JPC | 0,1b1 |
| *i:=funca(exp1,exp2);* | | INT | 1 |
| | | (exp1) | |
| | | (exp2) | |
| | | CAL | funca |
| | | INT | –2 |

*Table 3: Code generation for various Pascal constructs. For readability, the p-codes are given in assembly form. The italic identifiers in the Pascal statements are nonterminals that can be substituted by any valid expansion. The codes for these quantities are represented by parenthesized identifiers.*

```
P-CODES START AT 0000
WANT CODE PRINTED?N
   0 ?$LST2.2
   0 CONST CR=13;LF=10;
   1 VAR A,B,C,D:INTEGER;
   1 FUNC MAX4(X1,X2,X3,X4); {LARGEST OF 4 NUMBERS}
   1     FUNC MAX2(X1,X2); {LARGEST OF 2 NUMBERS}
   2         BEGIN
   3             IF X1>X2 THEN MAX2:=X1
   9             ELSE MAX2:=X2
  12             END;
  14     BEGIN
  14         MAX4:=MAX2(MAX2(X1,X2),MAX2(X3,X4))
  28         END;
  30 BEGIN
  30     REPEAT
  31         READ (A#,B#,C#,D#);
  39         WRITE ('THE LARGEST IS',MAX4(A,B,C,D)#,CR,LF)
  67         UNTIL A<0
  69     END.
INTERPRET(I), OR TRANSLATE(T)?N
READY
LOAD DECODE
READY
RUN
   0  JMP   0      30  JMP   0      14  JMP   0       3  INT   0      3
   4  LOD   0      -2  LOD   0      -1  OPR   0       >  JPC   0     11
   8  LOD   0      -2  STO   0      -3  JMP   0      13  LOD   0     -1
  12  STO   0      -3  OPR   0     RET  INT   0       3  INT   0      1
  16  INT   0       1  LOD   0      -4  LOD   0      -3  CAL   0      3
  20  INT   0      -2  INT   0       1  LOD   0      -2  LOD   0     -1
  24  CAL   0       3  INT   0      -2  CAL   0       3  INT   0     -2
  28  STO   0      -5  OPR   0     RET  INT   0       7  CSP   0  INNUM
  32  STO   0       3  CSP   0   INNUM  STO   0       4  CSP   0  INNUM
  36  STO   0       5  CSP   0   INNUM  STO   0       6  LIT   0     84
  40  LIT   0      72  LIT   0      69  LIT   0      32  LIT   0     76
  44  LIT   0      65  LIT   0      82  LIT   0      71  LIT   0     69
  48  LIT   0      83  LIT   0      84  LIT   0      32  LIT   0     73
  52  LIT   0      83  LIT   0      14  CSP   0   OUTST  INT   0      1
  56  LOD   0       3  LOD   0       4  LOD   0       5  LOD   0      6
  60  CAL   0      14  INT   0      -4  CSP   0   OUTNM  LIT   0     13
  64  CSP   0   OUTCH  LIT   0      10  CSP   0   OUTCH  LOD   0      3
  68  LIT   0       0  OPR   0       <  JPC   0      31  OPR   0    RET
```

*Listing 2: Sample Pascal program with compiled p-code. The number at the beginning of each source line is the offset of the corresponding p-code from the base address.*

the resultant value on the stack. Thus, space is allocated for each parameter and initialized with the value of the parameter expression. Upon return from a procedure, the stack pointer is decremented by an amount equal to the space allocated for the parameters, getting back to the state before the procedure call. Upon returning from a function call, the stack pointer is also decremented by the same amount, but since a space has been allocated before the function call, the function return value is now on top of the stack, ready for further processing. This simple scheme works very efficiently and should lower the overhead usually associated with procedure or subroutine calls.

Listing 2 gives an output from the compiler for a Pascal program that prints out the maximum of four numbers. There are of course better ways of writing the program, but it does illustrate some ideas of the compiler discussed so far.

There is no optimization of the p-codes produced. Limited optimization can be done on the local level, and some optimization is actually done in the p-code to machine code translator. The problem of producing efficient codes is a difficult one, and is not addressed properly in our project. Given the simplicity of the p-machine and p-code, the p-compiler is efficient. But whether the combination of p-compiler and translator produces efficient 8080 code is uncertain.

This completes our discussion of the p-compiler. In part 3 we give a detailed discussion of a translator for converting the p-code into executable 8080 machine code. ■

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# A "Tiny" Pascal Compiler

## Part 3: P-Code to 8080 Conversion

**Kin-Man Chung**
**Herbert Yuen**

In part 1 of this series (September 1978 BYTE, page 58[1]) we defined a Pascal subset language in terms of syntax diagrams. The p-machine and its instruction set and a p-code interpreter were also described. In part 2 (October 1978 BYTE, page 34[2]) we presented the design and implementation of the p-compiler. The subject matter for this part is the translation of p-codes to executable 8080 machine codes. We will also discuss the implementation of run time support routines and code optimization.

### Compiler-Interpreter Systems

To understand why we need a p-code to 8080 translator, we should first take a brief look at the different structures of compiler-interpreter systems. The most widely used structure for microcomputers is the *interpreter.* Since interpreters are written in the target computer's assembly language, their memory size is small. They are self-contained in the sense that they include an editor for creating source programs and run time routines to do all computations. Memory storage for source programs is also small. The only disadvantage is speed. Execution time for a typical BASIC program is estimated to be about 300 to 1000 times the execution time of the same program written in assembly language. Interpreters may spend more than 70 percent of their time scanning source symbols character by character, parsing the syntax and checking errors. No matter how many times a program statement is executed, the parsing procedure is repeated every time.

This problem can be readily solved by separating the parsing and execution steps. Before execution, the source program is compiled and intermediate code is generated. Thus scanning and parsing are done only once for each program statement. This is the so-called *compiler-interpreter* scheme used in some BASIC compilers. Execution of the intermediate codes is by interpretation. The gain in speed over a pure interpreter is a factor of approximately 2 to 10. However, the gain in speed is paid for by extra memory storage needed for intermediate codes.

The *compile-go* and *compile-link-go* approaches are commonly used for many high level language compilers in mainframe computer systems. These compilers generate relocatable binary codes. The compile-link-go approach has the advantage of linking together different modules of programs that are compiled separately, such as those in a subroutine library. This is done by a linking loader. However, due to limited system resources like memory and peripheral devices in microcomputers, these two structures are rarely used. Further, since Pascal is designed for fast compilation, linkage of program modules may be done at the source language level.

Among those four structures just mentioned, the compiler-interpreter seems to be most appropriate for implementation on microcomputers. However, execution speed is still slow because intermediate codes are interpreted rather than executed directly by the computer. An obvious solution to this problem is to translate the intermediate codes into executable machine codes. Thus,

1. Page 59 of this edition.
2. Page 71 of this edition.

each intermediate code is decoded once by a program which we call a *translator.* The translated machine code can be expected to run about two to five times faster than interpreted intermediate codes. Therefore, the overall gain in speed, compared with a pure interpreter, is a factor of approximately 10 to 50. (Preliminary test runs in our system show that Pascal programs run about 15 times faster than the same program written in BASIC.) We call this structure *compile-translate-go.*

The five compiler-interpreter structures we discussed above are summarized in table 1. The compile-go and compile-translate-go are rather similar in structure. Compile-go actually combines the process of compiling and generating executable codes into one step. The binary codes are generated by straightforward algorithms without optimization, because code optimization would require more complex program logic and make the compiler even larger. Separating compilation and translation into two steps significantly reduces the size of the compiler. Local optimization techniques can also be applied during translation. Code optimization will be discussed later. Since p-codes are designed to be machine independent to make the compiler portable, the translator is responsible for producing efficient codes for a target computer.

### Designing the Run Time Routines

Run time routines form an essential part of all compiler-interpreter systems in microcomputers. Large computers can do fixed point, floating point and decimal arithmetic with 32 bit or larger word sizes in single instructions. Many microcomputers, on the other hand, can do only basic integer arithmetic with 8 bit words (bytes). Therefore, multiple instructions are needed to implement 16 bit operations like multiply, divide, subtract, logical operations and multibit shifts. The run time routines, sometimes referred to as *run time support package*, are a collection of subroutines written in assembly language that can be called by an interpreter or any program to perform various arithmetic and logical operations. Usually they include subroutines for IO conversion between ASCII and binary data.

The design of run time routines for our compiler system is based on three principles:

- Fast implementation and clarity: A straightforward approach is followed so that the overall package can be debugged and tested quickly and modified easily.
- Speed: The best known algorithms are used for computer arithmetic to achieve fastest execution speed possible. However, tricks such as self-modifying code are not used.
- Memory storage: The package is expected to be fairly compact. Since p-codes are translated mostly into subroutine calls, the number of instructions to set up arguments to be passed to the subroutine should also be minimal.

As described in part 1, the p-machine has a data stack and four registers: stack pointer T, base register B, program counter P, instruction register I. Since the translator takes care of the program counter and p-code instructions are not needed after translation, all we need are the stack pointer and base register. In the current version of our run time routines, contiguous memory storage is used to represent the data stack. For the sake of program clarity and easy debugging, the 8080 machine stack is not used, although using it for dual purposes as a data

*Table 1: Summary of different structures of compiler-interpreter systems.*

| Structure | Example | Step | Input | System software | Output | Remarks |
|---|---|---|---|---|---|---|
| interpreter | BASIC, APL interpreter | 1 | source program | interpreter (execution) | | Most popular for microcomputers. Advantage: conserves memory space. Disadvantage: very slow execution speed. |
| compiler-interpreter | BASIC-E, Pascal compiler | 1<br>2 | source program<br>intermediate code | compiler<br>interpreter (execution) | intermediate code | The interpreter may overlay the compiler to save memory space. Advantage: faster execution speed. |
| compile-go | WATFIV,PL/C compiler | 1 | source program | compiler | executable code | Only used in large computers. Disadvantage: size is too big for microcomputers. |
| compile-link-go | FORTRAN IV, PL/I, COBOL compiler | 1<br>2 | source program<br>binary code | compiler<br>linking loader | binary code<br>executable code | Widely used in large computers. Advantage: fast execution speed. Disadvantage: requires more system resources. |
| compile-translate-go | Pascal compiler (by authors) | 1<br>2 | source program<br>p-code | compiler<br>translator | p-code<br>executable 8080 code | Advantage: size of compiler is reduced, fast execution speed, increased portability, easy implementation. |

stack and temporary storage for normal program logic is possible and probably more efficient.

Figure 1 shows the structural differences between the p-machine stack which we implement and the 8080 machine stack. Since integer data is stored as pairs of 8 bit bytes (character strings are stored as single dimensional arrays, two bytes to each element and only the low order byte is used; see descriptions in part 1), each load instruction increments the stack pointer by 2. The order of the byte pair is arranged as high-low because it is more convenient to use than low-high. The stack pointer always points to the low order byte of the 16 bit integer, which is on top of the stack.

Register pair D,E is dedicated for use as the stack pointer, while registers H and L are mainly used for 16 bit operations such as DAD, LHLD, SHLD and PCHL. When needed, register pairs D,E and H,L can be easily exchanged using the XCHG instruction. Since the base address remains unchanged within a procedure block, a 2 byte fixed memory location (with symbolic name BB) is used to represent the base register. The LHLD and SHLD instructions are used to retrieve and update the base address value. A summary of register assignments for implementation of the p-machine is shown in table 2.

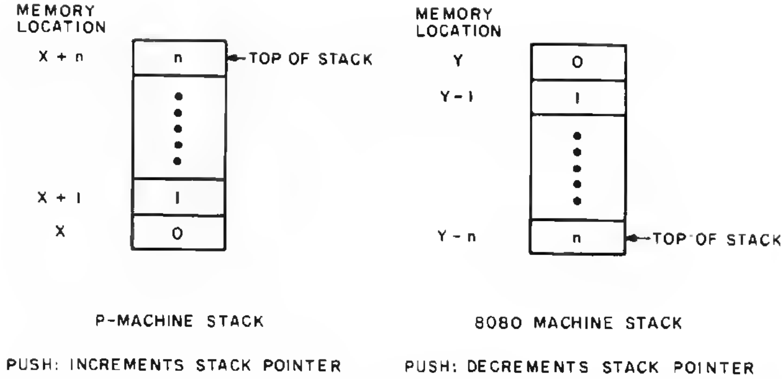



*Figure 1. Differences between p-machine and 8080 stacks. This figure shows n+1 entries on each of the stacks.*

| P-machine | 8080 run time routines |
|---|---|
| P: program counter | PC |
| T: stack pointer | D,E register pair |
| B: base register | memory location BB (16 bits) |
| I: instruction register | — |
| data stack | memory storage |

*Table 2: Register and storage assignment for runtime routines.*

## Coding the Run Time Routines

Most of the subroutines are easily understandable. The routines for load, store, call and load constant are coded by direct translation from the interpreter program to 8080 assembly language, keeping in mind that each stack element (one data item) occupies two bytes. The routines for arithmetic and logical operations and IO conversions require more programming effort. In general, single operand functions such as negate, logical not and increment are performed one byte at a time in register A. Double operand operations such as add, divide and logical or are performed with register pairs H,L and B,C. The entire runtime package occupies about 1 K bytes of memory. The following are remarks on coding some of the not-so-trivial subroutines.

PUSH and POP: for most double operand functions, subroutine POP is called first to get the two operands from the stack (memory) and put in register pairs H,L (first operand) and B,C (second operand). After the operations, subroutine PUSH is called to put the result from H,L back onto the stack.

Add and subtract: since DAD (double precision add) is the only 8080 instruction for double operand 16 bit operation, subtraction is done by adding the 2's complement of the second operand to the first. A message will be issued if overflow occurs and execution continues without any corrective action. The condition for overflow is detected by the rule:

> if [sign(arg.1) ⊕ sign(arg.2) ⊕ carry ⊕ sign (result)] = 1, then overflow; otherwise nothing.

MULT16: 16 bit signed multiplication is done in two stages using an 8 bit multiplication routine. First, multiply the second operand by the high order byte of the first operand; the result is in register pair H,L. Second, continue the multiplication (left shift and double add) with the low order byte of the first operand; the result is in register pair H,L. This method is very efficient. In comparison, conventional 16 bit multiplication routines require more PUSH, POP and XCHG instructions because there are not enough registers to shift two 16 bit words and also update a loop counter. Overflows are ignored, as this is the usual practice for integer multiplication.

DIV16: 16 bit signed division is one of the most difficult routines to implement. First the signs of both operands are saved on a stack and are then converted to positive integers (actually the divisor is made negative in 2's complement because subtraction is done with a double add instruction). The divisor is also checked for zero value, and if so, a DIVIDE CHECK message is issued and the routine returns. Division is carried out as a sequence of subtraction and shifts. At the end, the signs of the quotient and remainder are corrected according to the original signs of the operands. The same routine is also used for calculation of the MOD function.

**Relational operations**: are done by comparing the high order and then the low order bytes of the operands. For testing less than, less than or equal, greater than, greater than or equal conditions, a common subroutine for testing less than is used. Register pair B,C is used as a flag to indicate whether the opposite of less than and equal to is wanted.

**SHL and SHR**: the logical left shift and right shift routines are symmetric in the sense that a negative argument (second operand) for the number of bits to be shifted will cause one routine to jump to the other, resulting in shifts in reverse direction.

**INNUM**: the conversion subroutine for input integers allows leading zeros and blanks and may optionally be preceded by a plus or minus sign (+ or –). It also checks for the absolute magnitude of the integer, which must be less than 32,768.

**OUTNUM**: conversion of binary integers to ASCII is done by repeated division by 10. The 16 bit divide routine is utilized.

### P-code Translation

In general, p-codes are translated to subroutine call instructions which jump to the appropriate entry points in the run time routines. Output from the translator is an 8080 machine language program containing mostly subroutine call instructions. Some p-codes, such as load and store, require additional instructions to set up the arguments to be passed. Address offsets are always placed in register pair B,C and the static level difference is placed in register A. The jump instruction in p-code simply becomes a JMP instruction in 8080 with the correct address determined by the translator. The p-code addresses in CAL and JPC instruc-

| Hexadecimal Op code | P-code | 8080 Mnemonic | Commentary |
|---|---|---|---|
| 00 | LIT 0,n | LXI B,n<br>CALL LIT | |
| 01 | OPR 0,0 | JMP P00; | procedure return routine |
| | OPR 0,n | CALL Pn ; | one of the 21 arithmetic/logical routines |
| 02 | LOD v,d | | |
| | a) v=0 | LXI B,2d<br>CALL LOD | |
| | b) v>0 | LXI B,2d<br>MVI A,v<br>CALL LOD1 | |
| | c) v=255 | CALL LODA; | load absolute address |
| 12 | LODX v,d | | |
| | a) v=0 | LXI B,2d<br>CALL LODX | |
| | b) v>0 | LXI B,2d<br>MVI A,v<br>CALL LODX1 | |
| 03 | STO v,d | | |
| | a) v=0 | LXI B,2d<br>CALL STO | |
| | b) v>0 | LXI B,2d<br>MVI A,v<br>CALL STO1 | |
| | c) v=255 | CALL STOA; | store absolute address |
| 13 | STOX v,d | | |
| | a) v=0 | LXI B,2d<br>CALL STOX | |
| | b) v>0 | LXI B,2d<br>MVI A,v<br>CALL STOX1 | |

| Hexadecimal Op code | P-code | 8080 Mnemonic | Commentary |
|---|---|---|---|
| 04 | CAL v,a | | |
| | a) v=0 | CALL CAL<br>JMP x | |
| | b) v>0 | MVI A,v<br>CALL CAL1<br>JMP x | |
| | c) v=255 | CALL CALA; | machine language subroutine interface |
| 05 | INT 0,n | LXI H,2n<br>CALL INT | |
| 06 | JMP 0,a | JMP x | |
| 07 | JPC 0,a | LDAX D;<br>DCX D<br>DCX D;<br>RAR ;<br>JNC x | get conditional code<br>decrement stack pointer test conditional code |
| | JPC 1,a | | (same as JPC 0,a except JC x) |
| 0B | CSP 0,n (n=0...5) | CALL SYSn; | one of the 6 conversion routines |
| | for n=8: | | (output a string) |
| | LIT 0,$c_1$<br>LIT 0,$c_2$<br>.<br>.<br>.<br>LIT 0,$c_n$<br>LIT 0,n<br>CSP 0,8 | MVI C,n;<br>CALL SYS8<br>DB $c_1$<br>DB $c_2$<br>.<br>.<br>.<br>DB $c_n$ | # of char. |

*Table 3: P-code to 8080 translation. LIT, LOS, STOX1, INT, LODA, etc, are used as symbolic entry points in the run time routines. There are 22 routines for the OPR instructions: P00, P01, . . ., P21. There are seven standard routines for IO conversion: SYS0, SYS1, . . ., SYS5 and SYS8. The variable* x *is used as the memory address in the translated 8080 code corresponding to p-code address* a *in a call and jump instruction.*

tions are similarly taken care of by the translator. The complete list of 8080 code corresponding to each p-code is shown in table 3.

## The 2 Pass Translator

The structure of the translator is similar to that of the interpreter. Both programs

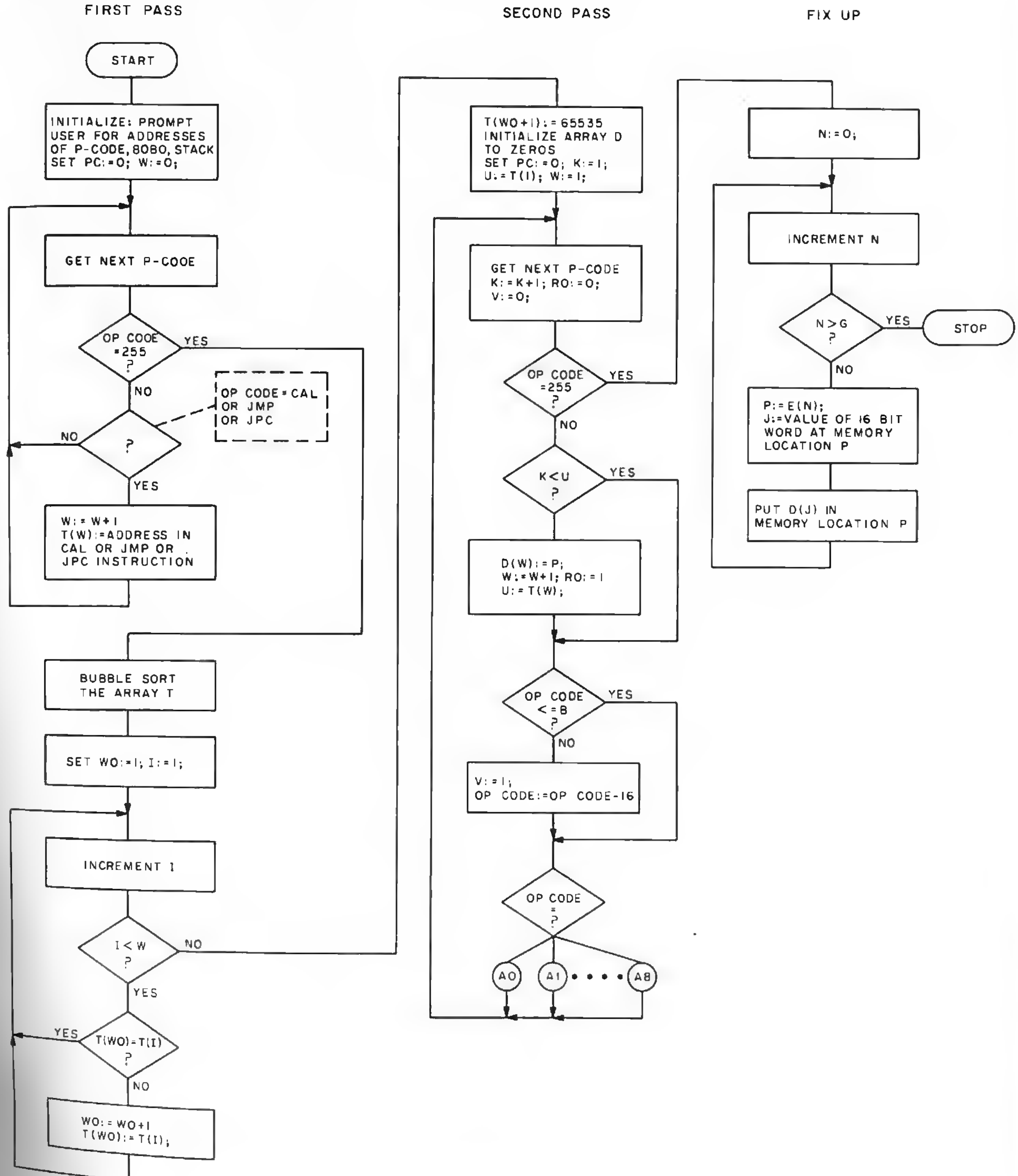



*Figure 2: A simplified flowchart of the translator. A0, A1, . . .A8 are program segments for generating 8080 code for the p-code with peephole optimization as illustrated by the rules in table 4. Refer to table 5 for a description of the variables.*

read p-codes from memory and decode them. The interpreter calls a simulator to execute the p-codes. The translator writes translated 8080 code in memory. The major difference between them is that the translator needs three additional tables to keep track of p-code and 8080 addresses. Since all p-code addresses are relative to the starting p-code of the program, the program is relocatable. The memory address corresponding to p-code address for any backward and forward referenced jumps can be calculated easily because all p-codes are four bytes long. The number of 8080 instructions generated per p-code is also not constant as shown in table 3. Therefore, it is necessary to build a table of 8080 addresses corresponding to p-code addresses to be used in jump and call instructions. However, it is not practical to build a table of 8080 addresses for every p-code because it will take too much memory storage for large programs. Only the addresses of those p-codes that are being referenced need be entered into the table.

P-code to 8080 machine code translation is done in two passes. During the first pass, p-code addresses in CAL, JMP and JPC instructions are entered into a table. The table is sorted after the completion of the first pass. Actual translation is carried out in the second pass. P-codes are fetched one by one from memory and decoded. The address of each p-code is checked with those in the address table. If it indicates that the current p-code is being referenced, the current 8080 address is entered to the corresponding 8080 address table. Then 8080 machine codes are produced according to the translation rules shown in table 3.

For CAL, JMP and JPC instructions, the p-code address in the instruction is looked up in the address table using a binary search. If the corresponding 8080 address has already been entered, it is output in the translated code; otherwise it is a forward referenced address. When the latter case occurs, it is necessary to record the current 8080 address in a *forward reference* table. Then, instead of the 8080 address (which is not yet known), its position in the table is output in the translated code. At the end of the second pass the forward referenced addresses are fixed up by the following procedure:

a) Get the 8080 address from the forward reference table (call it P).
b) Get the table entry (call it J) at address P in the translated program.
c) Get the updated 8080 address (call it A) at table entry J.
d) Write the correct address A back to memory location P.

Figure 2 is a simplified flowchart of the translator. The part for code generation is not shown, but it can be easily understood by referring to tables 3 and 4. Table lookup is done by binary search through the sorted table. The table elements are entered sequentially during the first pass. A simple bubble sort algorithm is used to sort the table. This method works fine for small Pascal programs. For larger programs, and thus more referenced addresses, the bubble sort algorithm is too slow because the number of comparisons is of order $n^2$ for $n$ elements. A binary tree sorting algorithm with order $n \log n$ will be used for our next version of the translator.

The various entry points in the runtime routines are initialized in the translator as a series of string constants. These hexadecimal addresses are converted to integers and placed in arrays so they can be accessed very easily later on.

When execution begins, the program prompts the user for starting addresses of the p-code program, the output 8080 code, and starting and ending addresses of the data stack. The following three instructions are generated to initialize the data stack and pointer:

| | |
|---|---|
| LXI H,STK1 | starting address of data stack. |
| LXI D,STK2 | 2's complement of stack ending address. |
| CALL #1A00 | run time routine (initialization. |

The program then begins its first pass. The number of address references and actual number of referenced addresses are displayed at the end of the first pass. During the second pass, cross references of p-code and 8080 addresses, which may be useful for future references, are listed in hexadecimal form. At the end of the translation, sizes of the p-code program and 8080 code are displayed.

### Code Optimization

Code optimization is a technique employed by most compilers to improve the object code produced. Many sophisticated code optimization techniques are known today but are outside the scope of this article. We shall describe only one form of local optimization technique which is being used in our project. Local optimization is done within a straight line block of code with no jumps into or out of the middle of the block. *Peephole* optimization is one form of local optimization which examines only small pieces of object code.

Since most code optimization techniques are difficult to build in a syntax directed code generation algorithm, peephole optimization is particularly useful in improving the intermediate code. Each improvement may lead to opportunities for further improvements. The technique can be applied repeatedly to get maximum optimization. In our translator, peephole optimization is applied only once during the second pass.

The goal of optimization is to minimize the size of the translated 8080 code and to increase execution speed without sacrificing a lot of time during translation. The peephole technique is quite simple. It examines only a single code or two consecutive codes. Some redundant p-codes are obvious and can be easily recognized. For example, the JMP instruction generated at the beginning of a procedure block which does not contain inner blocks is redundant. Similarly, the p-code INT 0,0 (increment stack pointer) generated after a procedure call with no arguments can be eliminated. The biggest benefit comes from optimizing redundant load and store instructions, because they are relatively slow in the current implementation. For example, a LOD instruction immediately following a STO instruction of the same variable can be replaced by an increment stack pointer instruction, because the variable is still on the stack. However, if the LOD instruction has a label, ie: is being referenced somewhere in the program, we cannot be sure that the STO instruction is always executed immediately before the LOD instruction.

Other sources of peephole optimization are the replacement of specific operations by more efficient instructions. Addition and subtraction of small constants (less than 4) occur frequently in array subscripts and loop counters. They can be replaced by repeated increment or decrement instructions. Some p-codes are translated into in line 8080 code instead of a call to run time routines. Table 4 is a summary of peephole optimization used in the translator. Note that the optimized code always takes less memory space than the unoptimized code.

## An Example

The various modules of the compiler system have been described. Now let us look at a complete program example. Listing 1 shows the compilation, translation and execution of a sample Pascal program. The program is stored in a disk file with file name T4. It is a sorting program that uses a binary tree algorithm. As mentioned before, it is more efficient than a bubble sort algorithm. The two subroutines in this program will

*Table 4: Summary of peephole optimization. The goal is to reduce the size of the object program. The optimized code is more efficient than the unoptimized 8080 code. For the redundant store fix, the load instruction cannot be referenced elsewhere in the program.*

| Source of optimization | Example | P-code | 8080 code | Optimized 8080 code |
|---|---|---|---|---|
| Redundant jump instructions | beginning of a procedure without inner procedure | n: JMP 0,n+1 | JMP x | no code generated |
| Redundant loads and stores | J:=J+5; A[J]:=X; | STO v,d<br>* LOD v,d | (as usual)<br>(as usual) | (as usual)<br>INX D; increment stack<br>INX D; pointer |
| Repeated load of the same variable | A[J]:=A[J]+Y; | LOD v,d<br>LOD v,d | (as usual)<br>(as usual) | (as usual)<br>CALL P21; copy |
| INT instruction with small constant | procedure call without parameter<br>procedure call | INT 0,0<br>INT 0,n<br>$(-3 \leq n \leq 2)$ | LXI H,#0000<br>CALL INT<br>LXI H,2n<br>CALL INT | no code generated<br>INX D<br>INX D (repeat n times, n > 0)<br>DCX D<br>DCX D (repeat n times, n < 0) |
| Load negative constants | B:= −20; | LIT 0,n<br>OPR 0,1 | LXI B,n<br>CALL LIT<br>CALL P01 | LXI B,−n<br>CALL LIT |
| Add and subtract small constants $(n \leq 3)$ | array subscripts<br>A[J+2]:=<br>B[K−1]:=<br>L:=L+1; | LIT 0,n<br>OPR 0,2<br>LIT 0,n<br>OPR 0,3 | LXI B,n<br>CALL LIT<br>CALL P02<br>LXI B,n<br>CALL LIT<br>CALL P03 | CALL P19; increment (repeat n times)<br>CALL P20; decrement (repeat n times) |
| Load zeros | P:=0; | LIT 0,0 | LXI B,#0000<br>CALL LIT | XRA A<br>INX D<br>STAX D<br>INX D<br>STAX D |

*Must be an unreferenced p-code

| | | |
|---|---|---|
| T$ | — | table of p-code address labels |
| D$ | — | table of 8080 address corresponding to address labels in array T$ |
| E | — | table of forward references |
| W | — | count of address references |
| WO | — | count of actual labels |
| G | — | count of forward references |
| K | — | p-code instruction counter |
| X | — | memory location of current p-code |
| P | — | 8080 program counter of the translated code |
| F | — | current op code |
| V | — | =1 means indexed load or store |
| RO | — | =1 means current p-code is being referenced |
| U | — | program counter of the next referenced p-code |

*Table 5: Table of important variables and arrays in the translator program shown in flowchart form in figure 2.*

*Listing 1: Compilation and translation of a sample Pascal program. At the end of the translation, the ratio of p-code to 8080 code is determined for reference purposes.*

```
P-CODES STARTS AT 0000
WANT CODE PRINTED?N
   0 ?$T4
   0  ( PGM -- SORTING BY BINARY TREE )
   0 VAR I,J,K,N,NEW:INTEGER;
   1 T,L,R,S:ARRAY[110] OF INTEGER;
   1
   1 PROC ENTER(N);
   1  VAR J:INTEGER;
   2  BEGIN J:=0;
   5   REPEAT
   5    IF N<=T[J] THEN
   9      IF L[J]<>0 THEN J:=L[J]
  17      ELSE BEGIN L[J]:=NEW;J:=0 END
  24    ELSE IF R[J]<>0 THEN J:=R[J]
  32          ELSE BEGIN R[J]:=NEW;J:=0 END
  39   UNTIL J=0;
  43   T[NEW]:=N;NEW:=NEW+1
  48  END;
  51
  51 PROC TRAV(J);  ( TRAVERSE THE TREE )
  51  BEGIN IF L[J]<>0 THEN TRAV(L[J]);
  62   S[K]:=T[J];K:=K+1;
  70   IF R[J]<>0 THEN TRAV(R[J])
  79  END;
  80
  80 BEGIN (MAIN)
  80  T[0]:=255;NEW:=0;
  86  READ(K#);WRITE(13,10);
  92  FOR I:=0 TO K DO BEGIN
  99   L[I]:=0;R[I]:=0; ENTER(MEM[I+%1A00]) END;
 116  K:=0; TRAV(0);
 121  FOR I:=0 TO K-1 DO WRITE(' ',S[I]#);
 140  WRITE(13,10)
 144 END.
INTERPRET(I), OR TRANSLATE(T)?T

*** P-CODE TO 8080 TRANSLATION ***
ADDR (HEX) OF PAS.LIB:1A00
ADDR (HEX) OF P-CODE:0000
ADDR (HEX) OF OUTPUT 8080 PGM:0800
STACK START ADDR (HEX):5000
STACK END ADDR (HEX):7FFF
 20 REFERENCES
 15 ACTUAL LABELS

   0  0809 0C 0C 12 17 1D 23 29 31 34 3B 41 49 4F 51
  15  0858 5E 66 6C 6F 75 7D 85 8A 90 93 99 A1 A6 A9
  30  08B0 B6 BE C4 C7 CD D5 DD E2 E8 EE F3 F6 FD 05
  45  090B 13 1B 21 1E 26 29 29 2F 35 3D 42 45 4C 52
  60  095A 62 64 6C 72 7A 82 8A 90 8D 95 9B A3 A8 A8
  75  09B2 B8 C0 C8 CA CD D3 D8 DE E4 E9 EF F2 F8 FE
  90  0A01 07 0A 0F 15 1B 1E 24 27 2E 34 39 3F 45 4A
 185  0A50 56 5C 5F 62 68 6A 70 73 79 7C 7E 83 89 8E
 120  0A94 96 9B A1 A7 AD AA AD B3 B6 BD C3 C6 CC D2
 135  0AD5 DB DE E4 E7 E9 EF F2 F8 FB FE
   11 FORWARD REFERENCES
P-CODE.. 145 INSTRUCTIONS
8080.. 766 BYTES
P-CODE:8080 = 1.3206897
* END TRANSLATION *
BYE
*LF PAS.LIB 1A00
*JP0800
?7
 29 34 34 35 43 43 235 242
*JP0800
?20
 0 1 5 25 29 29 32 33 34 34 35 35 40 43 43 112 113 201 235 242 244
*JP2A04
READY
!CHR$(129)
```

be used in our next version of the translator (written in Pascal). The main program begins by asking the user to input an integer K (K must be less than 110) for the number of items to be sorted. It then reads the K+1 bytes of data starting from hexadecimal memory location 1A00 (the location where runtime routines are stored). The data items are read one at a time and procedure ENTER is called to build a binary tree with these items. Procedure TRAV is then called to traverse the tree recursively in the "left subtree..root..right subtree" fashion and the data with sorted order is placed in array S. Finally, array S is printed.

The p-compiler generates 145 p-codes (0 to 144) for this program. Afterwards, it uses a CHAIN statement (North Star BASIC) to load the translator program from disk, and overlays the compiler. The translator begins by asking the user to input memory addresses of run time routines, p-code program, output 8080 code and data stack. At the end of the first pass, 20 address references are recorded. After sorting, it is found that there are only 15 actual labels. Output from the second pass of the translator is a cross-reference of p-code program counter and memory addresses of the corresponding translated 8080 code. The leftmost column is the p-code program counter. Hexadecimal memory addresses are printed in groups of 15 per line. With the exception of the first one, only the two low order hexadecimal digits are printed. At the end of the second pass, 11 forward references are recorded. A total of 766 bytes of 8080 code are generated. Compared to the size of the p-code program, the translated code is 1.32 times larger. This ratio usually ranges between 1.05 and 1.35, depending on program structure and the types of statements used.

After translation is completed, control is transferred to the disk operation system (DOS). The run time routines are loaded from the disk file, PAS.LIB, to hexadecimal memory location 1A00. Then execution may begin by typing a JPxxxx command (jump to xxxx), where xxxx is the starting hexadecimal memory address of the translated code. In listing 1, two separate runs are shown: the first one sorts eight numbers (K+1 with K = 7) and the second sorts 21 numbers. The user may get back to BASIC by typing JP2A04, where 2A04 is the entry point of BASIC. (The command !CHR$(129) is an immediate BASIC statement used to turn off the printer.)

## Summary

Compilers for high level languages are large, nontrivial programs. Their implementation usually requires a significant amount of computer system resources and human effort. Although our available system resources were limited, both in hardware and software, we managed to finish the bootstrap compiler within a relatively short time period. The reason is obvious: The Pascal subset we implemented is small. We followed the same approach professionals use for implementing portable Pascal compilers on mainframe computers. Syntax diagrams, which define the subset language, are used to construct the syntax directed, top-down parser of the compiler. The generation of p-code is also syntax directed. P-code is relocatable and portable, and its interpreter can be easily implemented on most microcomputers.

There are several features that are unique to our compiler project. First, the bootstrap compiler was written in BASIC (North Star disk BASIC). Although BASIC is not an appropriate language for compiler writing, it is the only high level language available in our system. Its ability to perform recursive function calls proved essential in simplifying the implementation of the compiler. Secondly, instead of writing a p-code interpreter in assembly language, a p-code to 8080 machine code translator was written in BASIC. The translated code can be expected to run more than twice as fast as interpreting p-codes. A p-code interpreter with debug facilities was also written (in Pascal). It can be used to debug p-code programs. Thirdly, minor extensions to the subset language were implemented. Absolute addressing of memory locations and machine language interface are desirable features for microcomputer systems. The availability of hexadecimal constants and IO conversions provides much user convenience.

Presently, the bootstrap compiler is very slow. It compiles at the rate of about eight lines per minute for a very dense Pascal program (using North Star BASIC with a 2 MHz 8080 processor). With some refinement in the compiler and run time routines, the Pascal version of the compiler can be expected to run 25 times faster, or approximately 200 lines per minute.

Completion of the bootstrap compiler is only a milestone in our compiler project. There are many tasks still to be done. Logically the next step is to write the translator and then the p-compiler in the Pascal subset and compile them using the BASIC version of the compiler. Since the compiler source and p-codes are big, there may be a minor problem in memory management. It may be necessary to write the p-codes onto disk to save memory. After these two programs have been debugged, any further development can be done in Pascal without the BASIC interpreter. It would be quite interesting to have the compiler (in object code) compile itself (in source code) and use the output object code to compile itself again. After each compilation, the object code could be compared with the previous one to provide a means of verification.

More Pascal features or extensions can be implemented one step at a time. They may include character type and pointer type variables, disk IO capabilities, floating point arithmetic, multidimensional arrays and built-in functions. It is also necessary to improve the error diagnosis and recovery scheme of the compiler. Further development should be aimed at user convenience. A dynamic debugging package that can display and alter the values of variables as specified by name at runtime would be desirable. Ultimately, we hope to see a Pascal system that is as convenient and easy to use as an interactive BASIC system.■

*The Pascal run time routines and the p-code to 8080 conversion program are listed in Appendix A, beginning on page 203*...**BWL**

# "Tiny" Pascal in 8080 Assembly Language

**Dr. B. Gregory Louis**

The p-code interpreter, Pascal to p-code compiler, and p-code to 8080 code translator described by Chung and Yuen in the September through November 1978 issues of BYTE magazine have been rewritten in 8080 assembly language. In addition to providing approximately two orders of magnitude increase in speed, the object versions run in far less memory. It is quite feasible to write and run "tiny" Pascal programs in a system havng 12 K bytes of programmable memory with these 8080 object code modules. The Pascal to p-code compiler occupies just under 8 K bytes of memory, while the p-code interpreter needs just under 4 K bytes including run time routines.

The articles by Chung and Yuen are required reading for potential users of this package. Not only do they describe in detail what the package does, they supply documentation without which these assembly listings will be difficult, if not impossible to understand or modify.

It should be noted that these three assembly language programs are essentially direct hand compilations of the high level programs written by Chung and Yuen. They could probably be reduced in length by 25 or 30 percent if rewritten with a view to such optimization. If this were done, a "tiny" Pascal development system including text editor could easily be fitted into a 12 K byte read only memory.

"Tiny" Pascal is a subset of the programming language Pascal. The book *Pascal User Manual and Report*, by Jensen and Wirth (Springer-Verlag, 1974) contains the full definition of standard Pascal. The present implementation is restricted in that there are no data types other than integer and array of integer, and parameters are passed by value only. However, there are several extensions which have been made.

In READ and WRITE statements, format control characters have been provided. If the variable name is followed by a numerical sign (#), the input or output string is taken as a decimal integer. If a percent sign (%) is used, the input or output string is taken as hexadecimal. If no format control character follows a variable name or constant, a single ASCII charcter is written or read. In write statements, quoted strings of up to 79 characters may be used.

In the body of a program, hexadecimal constants are specified by preceding them with a percent sign. ASCII constants may be specified, but only the first character of a quoted string is used. Source code lines may not exceed 63 characters exclusive of line number.

The compiler can accept input from the keyboard or from tape. If a line of input begins with the character $, the next five characters are taken as specifying the name of a file to be loaded from tape. (Such files may be prepared with

*Table 1: Common I/O routines which the user must supply. Routines DEOUT, OSEQ, and MOVE are given in listing 5.*

| | |
|---|---|
| WH0 | get character from console to register A. |
| WH1 | send cherecter to console from register A. |
| BLK1 | send blenk to console. |
| DEOUT (or DEOUT1) | displey hexadecimel contents of DE. |
| OSEQ | send contents of memory to console, stopping et the next carriage return. The pointer is the HL register pair and the carriage return is not sent. Return with the HL register pair pointing et the carriege return. |
| MOVE | copy memory from location pointed by HL to a location pointed by DE, incrementing ell three register pairs (BC, DE, HL) efter eech transfer. Repeat until BC register pair contains zero. |
| CRLF | send a carriage return end line feed to the console. |
| CLEAR | send hexadecimal FF to the console. |

an editor.) The rest of the input line is then ignored. If the file thus loaded does not contain either the end of the program or another line beginning with $, the compiler waits for further input from the keyboard. This is signalled by the appearance of a $ at the beginning of a new line. If the user wishes to continue input via the keyboard, the $ is erased with the rub out key; otherwise another file name is typed.

The words MEM and CALL are reserved and provide the user with access to memory. MEM is an array name that refers to memory space. For example, the statement MEM 0 := MEM 1 would cause the contents of location 1 to be written into location 0. CALL is a way of transferring control to a machine language subroutine. The form is CALL(ADDRESS).

CASE statements may be concluded with ELSE. In any instance of possible ambiguity, ELSE is always taken as referring to the most recent CASE or IF statement encountered.

In this implementation of "tiny" Pascal, there are several changes with respect to Chung and Yuen's version.

Comments in "tiny" Pascal source code are begun and ended with right braces instead of left and right braces so it is teletypewriter compatible.

The single quote may be included in a quoted string by the usual trick of doubling, thus:

'This is how it' s done'.

Hexadecimal constants may be one to four characters long, and may be preceded by a minus sign if desired.

To increase flexibility, single character input is not echoed to the console. Although this necessitates an explicit WRITE statement in many applications, it allows for character mapping and for redefinition of control characters.

The assembly source code for the three modules is virtually devoid of comments, since the high level source already published is intended to act as documentation. Accordingly, the labels in the assembly language programs have been chosen to key to the previously published listings. However, reference is made to several I/O and utility routines external to the programs. These common utilities are already available in most systems. They must be provided by the user, and they perform the functions shown in table 1.

Addresses 5966 through 5A15 of the compiler implement a file input from mass storage. The contents of BOFP are used as the load address for the file, which is assumed to be in the form of a SYS/8 (or Processor Technology SP-1, or Poly 88) listing. That is, the file is broken into lines consisting of a length byte, a 4 digit line number, a space, and the text, ending with a carriage return.

Similarly, hexadecimal locations 6D7E and the following are used to implement the chain to the interpreter or translator.

One other thing to note in the compiler is that if a file has been input and the end of the file (length byte of 1) is encountered before the program ends, keyboard input resumes, but a $ keystroke is simulated. The code that does this is in locations 5921 to 5928. This code assumes a double buffered, interrupt driven keyboard input routine; for use with a polled keyboard, it would need modification.

These programs are relocatable in that all address calculations employ three byte instructions. For the interpreter, the move address space is hexadecimal 5000 to 5ECF, and the block of executable code to be scanned by the relocator runs from hexadecimal 5529 to 5ECF. The compiler move address space is hexadecimal 4F00 to 6DC5 and executable code runs from hexadecimal 57BA to 6DC5. The translator runs from hexadecimal 5A00 to 68FD with code starting at hexadecimal 6130. The run time routines occupy hexadecimal 6946 on. In addition, there are two jump instructions at the beginning of the interpreter, four at the beginning of the compiler, and one each at the start of the translator and run time routines that have to be changed on relocation.

A sample compilation in "tiny" Pascal

appears in listing 1 (Appendix B, page 221). The program is a simple p-code lister that displays p-codes a screenful at a time until control X is typed. An editor listing appears first, followed by the p-code compilation and translation. Then there is a dump of the resulting source code, and finally a disassembly listing.

Listings, 2, 3, 4, and 5 (pages 235 thru 286) are the run time routines, Pascal to p-code compiler, and the p-code interpreter. These programs are copyright 1979 by B Gregory Louis, Ph. D. They may be used or copied for noncommercial purposes only. The author accepts no liability for any damage resulting from the use or malfunction of these programs and no warranty express or implied applies to any of this material.■

# Applications

# WADUZITDO: How to Write a Language in 256 Words or Less

**Larry Kheriaty**

Every computer owner likes to show his or her microcomputer to friends. The first question the friends usually ask is, "What does it do?" The software system presented here demonstrates what a computer can do in a manner simple enough for almost anyone to understand. Even if you have a larger, more capable system, it is often worthwhile to be able to demonstrate something that can be accomplished on a smaller scale. WADUZITDO is small enough to run on almost any microcomputer yet it allows even the novice user to make the computer "do something."

WADUZITDO is a complete high level language processor that fits in less than 256 bytes on either a 6800 or 8080 based system. The only other requirement is some kind of terminal. The system includes a text editor to allow a program to be entered and modified, and an interpreter to execute the program. The only external routines needed are single character input and single character output such as those provided by most system monitors.

The object of WADUZITDO is to run simple conversational programs. There are just five statement types, roughly derived from the PILOT language. To keep it small only the most essential capabilities are available. This also makes programming very easy. In fact, only a few minutes after my unsuspecting spouse had asked, "What does it do?", she had written the interactive dialogue program in listing 1 to help me make out a list of acceptable birthday gifts!

Programming in WADUZITDO is straightforward and uncomplicated. For example, to direct the computer to display a line of text on the terminal you use the *type* statement. The following example shows the format of the *type* statement.

```
T:WHAT COULD BE EASIER
  THAN THIS?
```

The T is the operation code for *type*. A colon always follows the operation code. The text after the colon is displayed exactly as shown.

The *accept* statement allows the program to receive one input character from the terminal keyboard. Normally it is used after a *type* that asks for a response. For example:

```
T:CAN YOU TELL ME WHAT 2 + 3
  EQUALS?

A:
```

The *accept* statement is just the A operation code followed by a colon. When it is encountered execution pauses until the user keys in any single character. Then the input character is saved internally for use in subsequent *match* statements.

The *match* statement is used to test the character entered by the user on the previous *accept. Match* is coded as an M (the operation code), followed by a colon and one character. The character in the statement is compared to the last character entered by the user. The result of the comparison is recorded internally in the match flag: Y if the match is equal, N if it is not equal.

Once set the match flag can be used to conditionally execute or skip any subsequent statement. This is done by placing either a Y (yes) or N (no) immediately before any operation code. If the Y or N is the same as the match flag the statement is executed, otherwise it is skipped. An elaboration of the previous example illustrates the use of *match*.

```
T:WHAT IS 2 + 3?

A:

M:5

YT:FIVE, RIGHT.

NT:NO, THE ANSWER IS 5.
```

*Listing 1: WADUZITDO program written by a non-computer person. Notice the last line of the program, the J:0 command. This instruction will make the program execution jump back to the accept statement to try another input.*

```
T:IT IS BIRTHDAY LIST TIME.
T:THE PURPOSE OF THIS PROGRAM IS TO
T:DETERMINE WHAT GIFTS ARE ACCEPTABLE.
T:TYPE THE CODE LETTER ASSOCIATED WITH
T:THE POTENTIAL GIFT IDEA...
T:  A  HOME APPLIANCE
T:  B  SOMETHING BORING
T:  C  ITEM OF CLOTHING
T:  D  SOMETHING DECORATIVE FOR THE HOUSE
T:  G  GARBAGE DISPOSAL
T:  M  MY OWN COMPUTER
A:
M:A
YT:UNACCEPTABLE.
M:B
YT:NO WAY.
M:C
YT:ACCEPTABLE IF NOT UGLY.
M:D
YT:OKAY IF CHOSEN WITH GOOD TASTE
YT:SO AS NOT TO BE TACKY.
M:G
YT:YEAH !
M:M
YT:THE LAST THING IN THE WORLD
YT:I WOULD EVER WANT.
NM:A
NM:B
NM:C
NM:D
NM:G
NT:CANT YOU READ FOOL, THAT IS NOT
NT:ONE OF THE CHOICES.
NT:TRY A,B,C,D,G OR M
J:0
```

*Listing 2: A NIM playing program. This program demonstrates the jumping capability of the language.*

```
T:LETS PLAY NIM WITH 7 PEBBLES.
T:WE TAKE TURNS TAKING 1,2 OR 3.
T:THE LAST ONE TO TAKE ONE LOSES.
T:THERE ARE 7, HOW MANY ?
A:
M:1
YJ:1
M:2
YJ:2
M:3
YJ:6
T:YOU CAN TAKE ONLY 1,2, OR 3.
J:0
*T:THAT LEAVES 6, I TAKE 1 LEAVING 5.
T:HOW MANY ?
A:
M:1
YJ:5
M:2
YJ:4
M:3
YJ:3
T:YOU MUST TAKE 1,2 OR 3.
J:0
*T:THAT LEAVES 5, I TAKE 1 LEAVING 4.
T:HOW MANY ?
A:
M:1
YJ:3
M:2
YJ:2
M:3
YJ:1
T:YOU MUST TAKE 1,2 OR 3 ONLY .
J:0
*T:THAT LEAVES THE LAST ONE.
T:I TAKE IT ... YOU WIN.
J:5
*T:THAT LEAVES 2, I TAKE 1 LEAVING 1.
J:3
*T:THAT LEAVES 3, I TAKE 2 LEAVING 1.
J:2
*T:THAT LEAVES 4, I TAKE 3 LEAVING 1.
*T:HOW MANY ?
A:
M:1
NT:YOU HAVE NO CHOICE BUT TO TAKE 1.
NT:HOW MANY ?
NJ:0
T:YOU JUST TOOK THE LAST ONE ... I WIN.
*T:TO PLAY AGAIN PUSH THE DOLLAR SIGN.
S:
```

Normally statements are executed sequentially. The *jump* statement is used to alter the normal sequence. The format of the *jump* statement is J, followed by a colon, and a number from zero to nine. The statement J:0 causes a branch back to the last *accept* statement executed. Execution resumes from that statement. The J:0 statement can be used to allow the user to reanswer a previous question. For example:

```
T:HOW MANY FEET IN A YARD?

A:

M:3

YT:RIGHT.

NT:WRONG STUPID, TRY AGAIN.

NJ:0
```

The second form of the jump makes use of program markers. A program marker is an asterisk, *, preceding any statement. The statement J:n, where n is a number from 1 to 9, causes a branch to the nth program marker forward from the *jump*. This form of the *jump* is shown in the sample program in listing 2 which plays NIM.

The last type of statement is *stop*. This statement merely terminates execution of the program and returns control to the program editor. The format of the *stop* statement is S:

To increase the versatility of the language the S: statement can, at the user's option, be made to call a user written machine language subroutine from within the WADUZITDO program. To do this requires a one statement modification to the system which is detailed below. If you choose to make this modification you can consider S: to be the operation code for *subroutine* rather than *stop*. The format of the *subroutine* statement is S:x where x is any single character which serves as a parameter to the user written program. The value x will be stored in register A in both the 6800 and 8080 version. It can be used to select different functions to be performed by the program.

During execution any statement which does not fit the syntax of one of the five statement types is printed in its entirety, then execution resumes normally with the next statement. Table 1 summarizes the WADUZITDO instruction set.

When WADUZITDO is first entered control is passed to the program editor which is used to enter or alter source programs. Also an internal program pointer, called LOC, is automatically set to the beginning of the source area. As each statement is entered on the keyboard the characters are stored and the internal pointer advances. Typing errors may be corrected by entering a backspace and the correct character. To reset the pointer to the start of the program enter a backslash, \. To display the next line of the program enter the mirror image of the reset slash, /. To replace a line, display each line up to but not including the one to be replaced, then enter the new line. The new line should be no longer than the line it replaces. If it is longer, the next line of text is also overwritten. End the replacement line with a percent key rather than a carriage return. The % causes null characters to be stored as filler up to the start of the next line. To begin execution of the program enter a dollar sign, $. (The editing commands are summarized in table 2.)

If you already have a good text editor in your system it may be used instead of the one included. Each statement is variable length, terminated by a carriage return character. All other control characters between statements are ignored.

Complete 6800 and 8080 assembly listings containing source and object code are included to simplify implementation on your system. The 6800 version in listing 3 uses the MIKBUG monitor; the 8080 version in listing 4 uses the SOLOS/CUTER monitor. If you have one of these two system monitors you need not modify the program at all.

The entry point to the system is at location zero. Upon entry the stack pointer is assumed set to address some scratchpad memory area large enough to accommodate a few levels of call. In MIKBUG or SOLOS/CUTER, as with most system monitors, this is handled automatically by the GO or EXEC command. The 2 byte value stored in LOC (hexadecimal 100) must point to the place where the user program is to be stored. In the assembly listings note that this value is shown as hexadecimal 0106, the first location not occupied by the system.

If you don't have one of the above monitors you must supply character input and character output routines and change the references to IN and OUT to address these routines. In the listings you will find one reference to IN and one to OUT which needs to be changed. If your terminal requires a delay after each carriage return you can set the number of null padding characters by a one byte modification to the statement labeled PLF.

Any of the special characters used by the text editor ($, %, \, /, bs) can be easily changed to another more convenient character on your keyboard.

As shown in the assembly listings the S:

| STATEMENT | FORMAT | WHAT IT DOES |
|---|---|---|
| *type* | T:text | Display text on the terminal. |
| *accept* | A: | Input one character from the terminal keyboard. |
| *match* | M:x | Compare x to last input character and set match flag to Y if equal, N if not equal. |
| *jump* | J:n | If n=0 jump to last *accept*. If n=1 thru 9 jump to nth program marker forward from the J. |
| *stop* | S: | Terminate program and return to text editor. |
| *subroutine* | S:x | Call user machine language program (requires modification). |
| *conditionals* | Y<br>N | May precede any operation code.<br>Execute only if match flag is Y.<br>Execute only if match flag is N. |
| *program marker* | * | May precede any statement, serves as a *jump* destination. |

*Table 1: Program instructions for the WADUZITDO language.*

| EDIT CHARACTER | HEX | MEANING |
|---|---|---|
| $ | 24 | Start execution. |
| \ | 5C | Move edit pointer to program start. |
| / | 2F | Display next line of program |
| % | 25 | Pad inserted line with nulls. |
| bs or ← | 08 or 5F | Backspace to correct typing error. |
| cr | 0D | End of statement. |
| any other | | Character stored in program and edit pointer advances. |

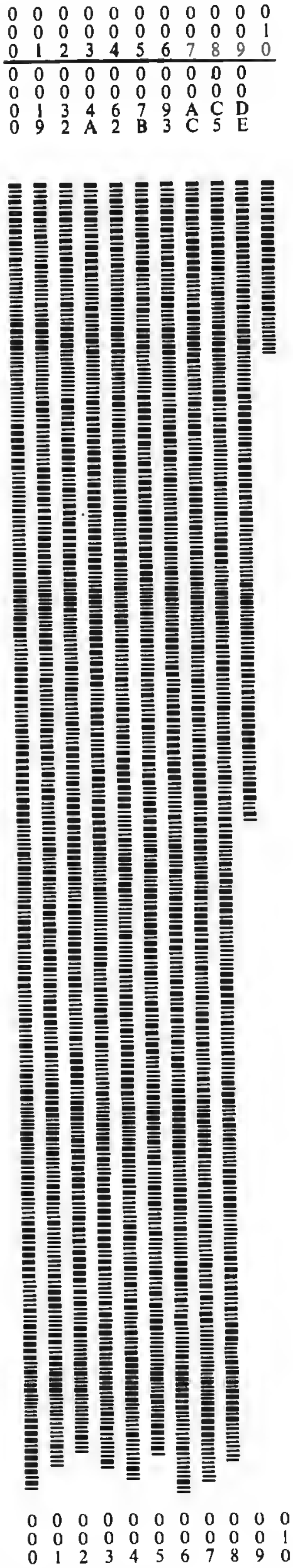
*Table 2: Editing characters used by the built-in text editor.*

statement halts execution by branching to the text editor. If you don't modify this you can treat it as a *stop* statement. To use it as a subroutine call you must modify the JMP SUB instruction to be a JSR or CALL (depending on the system) to the appropriate address. Upon entry to the subroutine the index register (6800) or HL register pair (8080) contains the location of the next program statement and should be saved and restored before returning from the subroutine. In the 8080 version the DE register pair should also be saved. Register A will contain the one character parameter, x, of the S:x. Its use is totally up to the subroutine.

The system has been organized so that the six bytes of changeable data are isolated from the read only portion. This means the rest of the 256 byte system could be

**Text continued after listings on page 103**

*Figure 1: Absolute loader format representation of the 6800 WADUZITDO program of listing 3.*




```
                 *          WADUZITDO
                 *       6800 VERSION BY LARRY KHERIATY
                 *
                 *    MIKBUG SUBROUTINES USED
                 IN       EQU    $E1AC     INPUT FROM KEYBOARD TO ACCA
                 OUT      EQU    $E1D1     OUTPUT FROM ACCA TO TERMINAL
                          ORG    $0000
                 SUB      EQU    $0000     USER SUBR START (CAN BE MODIFIED)
                 *   ENTER SYSTEM AT LOCATION 0 WITH STACK POINTER PRESET
                 *   TO SCRATCH PAD RAM ENOUGH FOR A FEW LEVELS OF CALL
0000 FE 0100     START    LDX    LOC       SOURCE PROGRAM AREA START
0003 8D 45       EGET     BSR    JIN       ACCEPT SOURCE CHAR
0005 81 5C                CMP A #$5C       \  ?
0007 27 F7                BEQ    START     YES, BACK UP TO PROGRAM START
                 *
0009 81 24                CMP A #$24       $  ?
000B 27 45                BEQ    EXEC      YES, GO EXECUTE THE PROGRAM
                 *
000D 81 08                CMP A #$08       BS  ?
000F 26 03                BNE    DIS       NO
0011 09                   DEX              YES, BACK UP ONE IN SOURCE
0012 20 EF                BRA    EGET      LOOP BACK
                 *   PROCESS DISPLAY OF NEXT LINE
0014 81 2F       DIS      CMP A #$2F       /  ?
0016 26 07                BNE    PAD       NO
0018 BD 00D5              JSR    PRT       GO PRINT TO CR
001B 8D 21       EPLF     BSR    PLF       PRINT LINE FEED AND NULLS
001D 20 E4                BRA    EGET      LOOP
                 *   DO LINE REPLACEMENT- PAD TO END OF STMT WITH NULLS
001F 81 25       PAD      CMP A #$25       %  ?
0021 26 12                BNE    CHAR      NO
0023 86 0D                LDA A #$0D       CR
0025 8D 27                BSR    JOUT      PRINT IT
0027 86 0D                LDA A #$0D       CR
0029 C6 40                LDA B #$40       COUNT OF 64
002B A1 00       PADL     CMP A 0,X        AT CR YET ?
002D 27 06                BEQ    CHAR      YES QUIT PADDING
002F 6F 00                CLR    0,X       PAD WITH NULL
0031 08                   INX              INCR LOC PTR
0032 5A                   DEC B            DECREMENT SAFETY COUNTER
0033 26 F6                BNE    PADL      LOOP TILL CR OR 64 NULLS
                 *   STORE ENTERED SOURCE CHAR IN PROGRAM
0035 A7 00       CHAR     STA A 0,X        CHAR TO SOURCE LOC
0037 08                   INX              MOVE LOC PTR UP ONE
0038 B1 0D                CMP A #$0D       IS IT A CR ?
003A 27 DF                BEQ    EPLF      YES, ECHO A LINE FEED
003C 20 C5                BRA    EGET      NO, GET ANOTHER CHAR
                 *   SUBROUTINE TO PRINT LINE FEED TO TERMINAL
003E C6 00       PLF      LDA B #$00       NUMBER OF NULLS TO PRINT
0040 4F          PLFL     CLR A            NULL
0041 8D 0B                BSR    JOUT      WRITE A NULL
0043 5A                   DEC B            DECREMENT COUNTER
0044 2A FA                BPL    PLFL      LOOP TILL ENOUGH NULLS
0046 86 0A                LDA A #$0A       LINEFFEED
0048 20 04                BRA    JOUT
                 *   NEXT FEW LINES MUST BE ALTERED IF YOU DONT USE MIKBUG
004A BD E1AC     JIN      JSR    IN        CALL CHAR INPUT ROUTINE
004D 39                   RTS              RETURN TO CALLER
004E BD E1D1     JOUT     JSR    OUT       CALL CHARACTER OUTPUT ROUTINE
0051 39                   RTS              RETURN TO CALLER
                 *
                 *   COME HERE TO BEGIN EXECUTION OF THE SOURCE PROGRAM
                 *
0052 FE 0100     EXEC     LDX    LOC       STARTING LOC OF PROGRAM
0055 09                   DEX              LESS ONE
0056 08          LOOPI    INX              ADR OF NEXT PGM BYTE
0057 A6 00       LOOP     LDA A 0,X        NEXT PGM BYTE
0059 B1 2A                CMP A #$2A       *  CHAR ?
005B 2F F9                BLE    LOOPI     YES(OR IGNOREABLE CONT CHAR)
                 *
                 *   PROCESS Y OR N FLAG TESTS
005D 81 59                CMP A #$59       Y  ?
005F 27 04                BEQ    TFLG      YES
0061 81 4E                CMP A #$4E       N  ?
0063 26 0F                BNE    XA        BRANCH IF NOT A FLAG TEST
                 *
0065 08          TFLG     INX              STEP LOC OVER Y OR N
0066 B1 0105              CMP A FLG        COMPARE TO CURRENT MATCH FLAG
0069 27 EC                BEQ    LOOP      ITS EQUAL SO EXECUTE THE STMT
                 *
                 *   ITS A FLAG FAILURE, SKIP OVER THE STMT
006B 08          SKIP     INX              STEP LOC PTR
006C A6 00                LDA A 0,X        NEXT CHAR IN PGM
```

*Listing 3: 6800 version of the WADUZITDO language. A dump of the MIKBUG format of WADUZITDO (shown in listing 3a, page 102) can be used for manual entry of the program. This version was run locally at BYTE using a SwTPC 6800.*

*Figure 2: Absolute loader format representation of the 8080 WADUZITDO program of listing 4.*

| 000 | 001 | 002 | 003 | 004 | 005 | 006 | 007 | 008 | 009 | 010 | 011 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0000 | 0019 | 0032 | 004B | 0063 | 007B | 0094 | 00AC | 00C4 | 00DD | 00F6 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | 001 | 002 | 003 | 004 | 005 | 006 | 007 | 008 | 009 | 010 | 011 |

```
ØØ6E 81 ØD              CMP A #$ØD      TO END OF STMT ?
ØØ7Ø 26 F9              BNE   SKIP      NOT YET, SO LOOP
ØØ72 2Ø E2              BRA   LOOPI     AT NEXT STMT, GO DO IT
                *
                *  PROCESS ACCEPT STATEMENT
ØØ74 81 41      XA      CMP A #$41      A  ?
ØØ76 26 11              BNE   XM        NO
ØØ7B FF Ø1Ø2            STX   LST       YES, SAVE LOC OF LAST ACCEPT
ØØ7B 8D CD              BSR   JIN       ACCEPT ONE CHAR FROM KYBD
ØØ7D B7 Ø1Ø4            STA A CHR       SAVE IT
ØØ8Ø Ø8                 INX             MOVE OVER A
ØØ81 86 ØD      PCR     LDA A #$ØD      CR
ØØ83 8D C9              BSR   JOUT      PRINT IT
ØØ85 8D B7              BSR   PLF       PRINT LINE FEED
ØØ87 2Ø CD              BRA   LOOPI     STEP OVER : AND GO ON
                *
                *  PROCESS MATCH STMT
ØØ89 81 4D      XM      CMP A #$4D      M  ?
ØØBB 26 12              BNE   XJ        NO
ØØ8D Ø8                 INX             STEP OVER M
ØØ8E Ø8                 INX             STEP OVER :
ØØ8F A6 ØØ              LDA A Ø,X       GET MATCH CHAR
ØØ91 C6 59              LDA B #$59      ASSUME Y
ØØ93 B1 Ø1Ø4            CMP A CHR       COMP MATCH CHAR TO INPUT CHAR
ØØ96 27 Ø2              BEQ   MX        BRANCH IF IT MATCHES,FLG=Y
ØØ98 C6 4E              LDA B #$4E      RESULT IS N
ØØ9A F7 Ø1Ø5    MX      STA B FLG       SET MATCH FLAG TO Y OR N
ØØ9D 2Ø B7              BRA   LOOPI     STEP OVER MATCH CHAR AND GO ON
                *
                *  PROCESS JUMP STATEMENT
ØØ9F 81 4A      XJ      CMP A #$4A      J  ?
ØØA1 26 17              BNE   XS        NO
ØØA3 E6 Ø2              LDA B 2,X       DESTINATION


ØØA5 C4 ØF              AND B #$ØF      CLEAR ZONE
ØØA7 26 Ø5              BNE   JF        ITS A JUMP FORWARD
ØØA9 FE Ø1Ø2            LDX   LST       ZERO.. JUMP BACK TO LAST ACCEPT
ØØAC 2Ø A9              BRA   LOOP      CONTINUE FROM THERE
                *
                *  SKIP FORWARD UNTIL PASS N *-MARKERS ( N IS IN ACCB )
ØØAE Ø8         JF      INX             STEP PGM LOC
ØØAF A6 ØØ              LDA A Ø,X       NEXT CHAR
ØØB1 B1 2A              CMP A #$2A      *-MARKER ?
ØØB3 26 F9              BNE   JF        NO, KEEP LOOPING
ØØB5 5A                 DEC B           FOUND ONE, COUNT IT
ØØB6 26 F6              BNE   JF        LOOP IF NEED TO FIND MORE
ØØB8 2Ø 9C              BRA   LOOPI     DESTINATION FOUND, GO EXECUTE
                *
                *  PROCESS STOP OR SUBROUTINE STATEMENT
ØØBA 81 53      XS      CMP A #$53      S  ?
ØØBC 26 ØA              BNE   XT        NO
ØØBE Ø8                 INX             STEP OVER S
ØØBF Ø8                 INX             STEP OVER :
ØØCØ A6 ØØ              LDA A Ø,X       PARAMETER TO REG A
ØØC2 Ø8                 INX             STEP OVER PARAMETER
                *  NEXT STMT MAY BE MADE TO BE A  JSR TO USER SUBR
ØØC3 7E ØØØØ            JMP   SUB       GO TO USER SUBR (OR TO EDITOR)
ØØC6 2Ø 8F              BRA   LOOP      GO ON UPON RETURN FROM USER SUBR
                *
                *  PROCESS TYPE STATMENT AND SYNTAX ERRORS
ØØC8 B1 54      XT      CMP A #$54      T  ?
ØØCA 26 Ø2              BNE   TE        NO, ITS AN ERROR
ØØCC Ø8                 INX             YES, STEP OVER T
ØØCD Ø8                 INX             STEP OVER :
ØØCE BD Ø5      TE      BSR   PRT       PRINT UP TO CR
ØØDØ BD ØØ3E            JSR   PLF       PRINT LNE FEED
ØØD3 2Ø 82              BRA   LOOP      DONE WITH T
                *
                *  SUBR TO PRINT UP TO NEXT CR
ØØD5 C6 4Ø      PRT     LDA B #$4Ø      COUNT OF 64
ØØD7 A6 ØØ      PRTA    LDA A Ø,X       NEXT CHAR
ØØD9 5A                 DEC B           DECREMENT SAFETY COUNTER
ØØDA 27 ØA              BEQ   PRTB      EXIT IF OVER 64 TILL CR
ØØDC BD ØØ4E            JSR   JOUT      PRINT IT
ØØDF A6 ØØ              LDA A Ø,X       RELOAD CHAR TO ACCA
ØØE1 Ø8                 INX             STEP LOC PTR
ØØE2 81 ØD              CMP A #$ØD      CR ?
ØØE4 26 F1              BNE   PRTA      NOT CR, LOOP
ØØE6 39         PRTB    RTS             DONE, RETURN
                *
                *  ABOVE IS END OF READ ONLY PORTION OF THE PROGRAM
                *
                *  THE FOLLOWING IS CHANGEABLE DATA
                *
Ø1ØØ                    ORG   $1ØØ      MOVE TO START OF DATA AREA
Ø1Ø2    Ø1Ø6    LOC     FDB   $Ø1Ø6     ADDR OF SOURCE PROGRAM AREA
Ø1Ø4    ØØØØ    LST     FDB   Ø         PLACE TO SAVE LOC OF LAST A:
Ø1Ø5    ØØ      CHR     FCB   Ø         PLACE TO SAVE LAST INPUT CHAR
        ØØ      FLG     FCB   Ø         PLACE TO SAVE MATCH FLAG
                *
                        END
```

*Listing 4: 8080 version of the WADUZITDO language. A hexadecimal dump (shown in listing 4a) is provided for manual entry. This version was run locally at BYTE using a SOL-20.*

```
                 *              WADUZITDO
                 *         8080 VERSION BY LARRY KHERIATY
                 *
                 *    SOLOS/CUTER SUBROUTINES USED
                 IN      EQU   0C01FH    INPUT FROM KEYBOARD TO A-REG
                 OUT     EQU   0C019H    OUTPUT FROM B-REG TO TERMINAL
                 *
                         ORG   0000H
                 SUB     EQU   0000H     USER SUBR START (CAN BE MODIFIED)
                 *   ENTER SYSTEM AT LOCATION 0 WITH STACK POINTER PRESET
                 *   TO SCRATCH PAD RAM ENOUGH FOR A FEW LEVELS OF CALL
                 *
0000 2A 0001 START   LHLD  LOC       SOURCE PROGRAM AREA START
0003 CD 4600 EGET    CALL  JIN       ACCEPT SOURCE CHAR
0006 FE 5C           CPI   5CH       \  ?
0000 CA 0000         JZ    START     YES, BACK UP TO PROGRAM START
                 *
000B FE 24           CPI   24H       $  ?
000D CA 5200         JZ    EXEC      YES, GO EXECUTE THE PROGRAM
                 *
0010 FE 5F           CPI   5FH       BS  ?
0012 C2 1900         JNZ   DIS       NO
0015 2B              DCX   H         YES, BACK UP ONE IN SOURCE
0016 C3 0300         JMP   EGET      LOOP BACK
                 *
                 *   PROCESS DISPLAY OF NEXT LINE
0019 FE 2F   DIS     CPI   2FH       /  ?
001B C2 2400         JNZ   PAD       NO
001E CD DF00         CALL  PRT       GO PRINT TO CR
0021 C3 0300         JMP   EGET      LOOP
                 *
                 *   DO LINE REPLACEMENT- PAD TO END OF STMT WITH NULLS
0024 FE 25   PAD     CPI   25H       %  ?
0026 C2 3C00         JNZ   CHAR      NO
0029 06 0D           MVI   B,0DH     CR
002B 78              MOV   A,B       CR TO A ALSO
002C CD 4D00         CALL  JOUT      PRINT IT
002F 0E 40           MVI   C,40H     COUNT OF 64
0031 BE      PADL    CMP   M         AT CR YET ?
0032 CA 3C00         JZ    CHAR      YES QUIT PADDING
0035 36 00           MVI   M,00H     PAD WITH NULL
0037 23              INX   H         INCR LOC PTR
0038 0D              DCR   C         DECREMENT SAFETY COUNTER
0039 C2 3100         JNZ   PADL      LOOP TILL CR OR 64 NULLS
                 *
                 *   STORE ENTERED SOURCE CHAR IN PROGRAM
003C 77      CHAR    MOV   M,A       CHAR TO SOURCE LOC
003D 23              INX   H         MOVE LOC PTR UP ONE
003E FE 0D           CPI   0DH       IS IT A CR ?
0040 CC F000         CZ    PLF       YES, ECHO A LINE FEED
0043 C3 0300         JMP   EGET      NO, GET ANOTHER CHAR
                 *
                 *   CHANGE NEXT FEW LINES IF YOU DONT USE SOLOS/CUTER
0046 CD 1FC0 JIN     CALL  IN        CALL CHAR INPUT ROUTINE
0049 CA 4600         JZ    JIN       TRY AGAIN IF NO CHAR YET THERE
004C 47              MOV   B,A       PREPARE TO ECHO THE CHAR
004D CD 19C0 JOUT    CALL  OUT       CALL CHARACTER OUTPUT ROUTINE
0050 78              MOV   A,B       RESTORE JIN CHAR TO A
0051 C9              RET             RETURN TO CALLER
                 *
                 *   COME HERE TO BEGIN EXECUTION OF THE SOURCE PROGRAM
                 *
0052 2A 0001 EXEC    LHLD  LOC       STARTING LOC OF PROGRAM
0055 2B              DCX   H         LESS ONE
0056 23      LOOPI   INX   H         ADR OF NEXT PGM BYTE
0057 7E      LOOP    MOV   A,M       NEXT PGM BYTE
0058 FE 2B           CPI   2BH       *  CHAR ? (NOTE 2BH IS '*'+1)
005A FA 5600         JM    LOOPI     YES(OR IGNOREABLE CONT CHAR)
                 *
                 *   PROCESS Y OR N FLAG TESTS
005D FE 59           CPI   59H       Y  ?
005F CA 6700         JZ    TFLG      YES
0062 FE 4E           CPI   4EH       N  ?
0064 C2 7600         JNZ   XA        BRANCH IF NOT A FLAG TEST
                 *
0067 23      TFLG    INX   H         STEP LOC OVER Y OR N
0068 BA              CMP   D         COMPARE TO CURRENT MATCH FLAG
0069 CA 5700         JZ    LOOP      ITS EQUAL SO EXECUTE THE STMT
                 *
                 *   ITS A FLAG FAILURE, SKIP OVER THE STMT
006C 23      SKIP    INX   H         STEP LOC PTR
006D 7E              MOV   A,M       NEXT CHAR IN PGM
006E FE 0D           CPI   0DH       TO END OF STMT ?
0070 C2 6C00         JNZ   SKIP      NOT YET, SO LOOP
0073 C3 5600         JMP   LOOPI     AT NEXT STMT, GO DO IT
                 *
                 *   PROCESS ACCEPT STATEMENT
0076 FE 41   XA      CPI   41H       A  ?
0078 C2 8E00         JNZ   XM        NO
```

```
S1130000FE01000D45015C27F78124274581092660
S11300100030720EF012F2607BD00D58D2120E4811F
S1130020252612060D8D27860DC640A10027066F52
S1130030000085A26F6A7000010D27DF20C5C60050
S1130040 4F0D0B542AFA860A2004BDE1AC39BDE172
S1130050D139FE01000908A60081 2A2FF98159270B
S11300600401 4E260F00B1010527EC08A600810D76
S113007026F920E2814126 11FF01028DCDB701044A
S113008000060D8DC70DB720CD814D261200 0BA68E
S1130090 00C659B10104 2702C64EF7010520B781F5
S11300A04A2617E602C40F2605FE010220A70BA667
S11300B00012A26F95A26F6209C8153260A08082C
S11300C0A600087E000020BFB1542602000 8D05B2
S11300D0BD003E2082C640A6005A270ABD004EA697
S10A00E00008B10D26F1392F
```

*Listing 3a: MIKBUG format for the 6800 version of WADUZITDO.*

```
00002A0001CD4600FE5CCA0000FE24CA5200
0010FE5FC219002BC30300FE2FC22400CDDF
002000C30300FE25C23C00060D78CD4D000E
003040BECA3C003600230DC231007723FE0D
0040CCF000C30300CD1FC0CA460047CD19C0
00507BC92A00012B237EFE2BFA5600FE59CA
00606700FE4EC27600238ACA5700237EFE0D
0070C26C00C35600FE41C20E00220201CD46
00800005F23060DCD4D00CDF000C35600FE4D
0090C2A10023237E1659BBCA9E00164EC356
00A000FE4AC2C30023237EE60F47C2B5002A
00B00201C35700237EFE2AC2B500005C2B500
00C0C35600FE53C2D20023237E23C30000C3
00D05700FE54C2D9002323CDDF00C357000E
00E040460DCAF000CD4D007E23FE0DC2E100
00F00E000600CD4D000DF2F200060AC34D00
0100006010000000
```

*Listing 4a: Dump of the 8080 version of WADUZITDO. The format consists of 4 character hexadecimal address and 16 hexadecimally coded bytes of information. There is no checksum computed for any of the information.*

## PAPERBYTE® Bar Codes for WADUZITDO

*In figure 1 and figure 2, we provide a PAPERBYTE® bar code representation for the WADUZITDO programs of listing 3 and listing 4. These bar code representations were created in the absolute loader format documented in detail in the PAPERBYTE book,* Bar Code Loader, *written by Ken Budnick of Micro-Scan Associates, and available for $2 at local computer stores or by mail (add $.60 postage and handling) from BYTE Books, 70 Main St, Peterborough, NH 03458.*

**Text continued from page 99**

placed in read only memory. It would fit in a single 1702A EROM chip.

It is easy to see how this language could be used to write a question and answer conversation using multiple choice or true, false answers. It may not be so obvious that more complex logic is possible. The example in listing 2 is a computer versus user NIM game which demonstrates a way this can be done.

Although WADUZITDO is not the ultimate answer to personal computing, it is something that almost anyone can have some fun with, and it definitely squeezes the most out of 256 bytes of memory.

## A Pascal WADUZITDO

**Notes by Ray Cote**
**Program by Larry Kheriaty**

*Along with the assembly language versions of WADUZITDO, Larry Kheriaty sent us the Pascal version shown in listing 5. The program is basically self-documenting and very easy to translate into assembly level programs for any particular processor. The program is indented to show logical relationships between related areas of text. This is sometimes known as* prettyprinting.

*The first four lines of the program are definition lines for the main program. In Pascal, all variables must be defined completely at the start of the section in which they are used. "Completely" means name and data type. This is a great help since all variables must be explicitly defined. You can easily check to see what type of variable is being used.*

*WADUZITDO uses two types of variables: integer and character. There is also a definition for constants (CONST). CONST informs the compiler that the value being assigned to this variable will not change. Integer variables will only take on whole number values.*

*The type character (CHAR) means that the variables will take on the values of ASCII characters, including all letters, numbers and special symbols.*

*The last line of the definition section defines a variable PROG as an array of characters. This definition also states that the relative base address of the array will be unity and the variable PZ will be used to specify locations within the array.*

*After defining our variables we are ready to start the first executable part of the program. In Pascal, the logical parts of the pro-*

*Listing 4, continued:*

```
007B 22 0201          SHLD  LST     YES, SAVE LOC OF LAST ACCEPT
007E CD 4600          CALL  JIN     ACCEPT ONE CHAR FROM KYBD
0081 5F               MOV   E,A     SAVE IT
0082 23               INX   H       MOVE OVER A
0083 06 0D            MVI   B,0DH   CR
00B5 CD 4D00          CALL  JOUT    PRINT IT
0088 CD F000          CALL  PLF     PRINT LINE FEED
008B C3 5600          JMP   LOOPI   STEP DVER : AND GO ON
               *
               *   PROCESS MATCH STMT
00BE FE 4D     XM     CPI   4DH     M  ?
0090 C2 A100          JNZ   XJ      NO
0093 23               INX   H       STEP OVER M
0094 23               INX   H       STEP OVER :
0095 7E               MOV   A,M     GET MATCH CHAR
0096 16 59            MVI   D,59H   ASSUME Y
0098 BB               CMP   E       COMP MATCH CHAR TO INPUT CHAR
0099 CA 9E00          JZ    MX      BRANCH IF IT MATCHES,FLG=Y
009C 16 4E            MVI   D,4EH   RESULT IS N
009E C3 5600 MX       JMP   LOOPI   SET MATCH FLAG TO Y OR N
               *
               *   PROCESS JUMP STATEMENT
00A1 FE 4A     XJ     CPI   4AH     J  ?
00A3 C2 C300          JNZ   XS      NO
00A6 23               INX   H       STEP OVER J
00A7 23               INX   H       STEP OVER :
00A8 7E               MOV   A,M     DESTINATION
00A9 E6 0F            ANI   0FH     CLEAR ZONE
00AB 47               MOV   B,A     NUMBER OF *S TO SKIP
00AC C2 B500          JNZ   JF      ITS A JUMP FORWARD
00AF 2A 0201          LHLD  LST     ZERO.. JUMP BACK TO LAST ACCEPT
00B2 C3 5700          JMP   LOOP    CONTINUE FROM THERE
               *
               *   SKIP FORWARD UNTIL PASS N *-MARKERS ( N IS IN BREG )
00B5 23        JF     INX   H       STEP PGM LOC
00B6 7E               MOV   A,M     NEXT CHAR
00B7 FE 2A            CPI   2AH     *-MARKER ?
00B9 C2 B500          JNZ   JF      NO, KEEP LOOPING
00BC 05               DCR   B       FOUND ONE, COUNT IT
00BD C2 B500          JNZ   JF      LOOP IF NEED TO FIND MORE
00C0 C3 5600          JMP   LOOPI   DESTINATION FOUND, GO EXECUTE
               *
               *   PROCESS STOP OR SUBROUTINE STATEMENT
00C3 FE 53     XS     CPI   53H     S  ?
00C5 C2 D200          JNZ   XT      NO
00C8 23               INX   H       STEP OVER S
00C9 23               INX   H       STEP OVER :
00CA 7E               MOV   A,M     PARAMETER TO REG A
00CB 23               INX   H       STEP OVER PARAMETER
               *   NEXT STMT MAY BE MADE TO BE A CALL TO USER SUBR
00CC C3 0000          JMP   *SUB    GO TO USER SUBR (OR TO EDITOR)
00CF C3 5700          JMP   LOOP    GO ON UPON RETURN FROM USER SUBR
               *
               *   PROCESS TYPE STATMENT AND SYNTAX ERRORS
00D2 FE 54     XT     CPI   54H     T  ?
00D4 C2 D900          JNZ   TE      NO, ITS AN ERROR
00D7 23               INX   H       YES, STEP OVER T
00DB 23               INX   H       STEP OVER :
00D9 CD DF00 TE       CALL  PRT     PRINT UP TO CR
00DC C3 5700          JMP   LOOP    DONE WITH T
               *
               *   SUBR TO PRINT UP TO NEXT CR
00DF 0E 40     PRT    MVI   C,40H   COUNT OF 64
00E1 46        PRTA   MOV   B,M     NEXT CHAR
00E2 0D               DCR   C       DECREMENT SAFETY COUNTER
00E3 CA F000          JZ    PLF     EXIT IF OVER 64 BEFORE CR
00E6 CD 4D00          CALL  JOUT    PRINT IT
00E9 7E               MOV   A,M     RELOAD CHAR TO ACCA
00EA 23               INX   H       STEP LOC PTR
00EB FE 0D            CPI   0DH     CR ?
00ED C2 E100          JNZ   PRTA    NOT CR, LOOP
               *
               *   SUBROUTINE TO PRINT LINE FEED AND PAD
00F0 0E 00     PLF    MVI   C,00H   NUMBER OF NULLS TO PRINT
00F2 06 00     PLFL   MVI   B,00H   NULL
00F4 CD 4D00          CALL  JOUT    WRITE A NULL
00F7 0D               DCR   C       DECREMENT COUNTER
00F8 F2 F200          JP    PLFL    LOOP TILL ENOUGH NULLS
00FB 06 0A            MVI   B,0AH   LINE FEED
00FD C3 4D00          JMP   JOUT    PRINT THEN RETURN
               *
               *   ABOVE IS END OF READ ONLY PORTION OF THE PROGRAM
               *
               *   THE FOLLOWING IS CHANGEABLE DATA
               *
                      ORG   0100H   MOVE TO START OF DATA AREA
0100 0601      LOC    DW    0106H   ADDR OF SOURCE PROGRAM AREA
0102 0000      LST    DW    0000H   PLACE TO SAVE LOC OF LAST A:
               *   THE NEXT TWO BYTES ARE ONLY FOR 6800 COMPATIBILITY
0104 00        CHR    DB    00H     UNUSED, LAST INPUT CHAR IN EREG
0105 00        FLG    DB    00H     UNUSED,MATCH-FLAG IN DREG
               *
                      END
```

*gram are broken into procedures, equivalent to subroutines in languages such as FORTRAN. Every procedure is blocked off by BEGIN and END statements. The name of the first procedure is CHIN. After we have determined the name, we are told to begin executing procedure ACCEPT (which will return to us input values in variable CBUF). This is a subroutine which is not shown since it is specific to the processor being used. The next two procedures are also calls to subroutines used to DISPLAY the contents of the buffer and move the output to a new line. These two procedures are also machine dependent. Notice that Pascal allows you to use descriptive names. This is very important when writing a program that you want other people to read or that you want to understand at a later date.*

*The next procedure, LIST, first defines its own local variables, which it will use only within the LIST routine. As before, the procedure is delimited by BEGIN and END statements. This procedure introduces us to the concept of loops. Here we have a related pair of commands: REPEAT and UNTIL. These two commands cause the one line of three instructions and the call to procedure CHOUT to execute until either the value I is greater than 64 or the variable CBUF is equal to CEOL. Once either of these two conditions occurs, the program logic proceeds to call procedure NEWLINE. At this point the LIST procedure ends and returns to whatever procedure called it.*

*Procedure EXECUTE looks structurally the same as procedure LIST. There is a definition of variables, the BEGIN and END delimiters, and a REPEAT-UNTIL structure. This time the REPEAT-UNTIL statement is not waiting for a relation to be true, but is rather checking against one variable. Looking at how DONE was defined at the beginning of the procedure, we see that its designation is BOOLEAN. This means that the variable is being used as a logical variable and can take on the value true or false. The REPEAT-UNTIL instruction waits to see if the variable DONE is true. If so, we have finished this procedure and can stop it.*

*Procedure EXECUTE also contains an IF-THEN-ELSE statement. If the value of CBUF is not contained within the brackets, perform procedure LIST. If the value of CBUF is somewhere within the square brackets, we want to perform an operation related to that value. We now come to another Pascal instruction, the CASE statement.*

*We are given a set of cases to choose from. The CASE statement tells us that we will be using the value in variable CBUF to determine what is to be done. We scan down each of the cases and find the one labeled with the value in CBUF. Since CBUF is type character we are looking at ASCII characters. Once we find the value of CBUF we execute the statements associated with it that are blocked off by another set of BEGIN and END statements. After we have finished, we move to the end of the CASE statement and then the last line of REPEAT-UNTIL statement.*

*The next section of the program does not look like the preceding sections. It does not start with a PROCEDURE statement, but has a BEGIN statement. So far we have discussed procedures. Any of the procedures that needed to use variables have defined their own. So why did we define those variables at the very beginning of the program? The reason is not to use them in a pro-*

*Listing 5: Pascal listing of WADUZITDO. See notes by Ray Cote.*

```
PASCAL VERSION OF WADUZITDO, LARRY KHERIATY
PROGRAM WADUZITDO;
  CONST PZ=5000; BS=127; EOL=10;
  VAR LOC,LST,I : INTEGER; LCHR,FLG,CBUF,CBS,CEOL : CHAR;
    PROG : ARRAY[1..PZ] OF CHAR;

  PROCEDURE CHIN; BEGIN ACCEPT (CBUF); END;
  PROCEDURE CHOUT; BEGIN DISPLAY (CBUF); END;
  PROCDURE NEWLINE; BEGIN DISPLAY (NL) ; END;

  PROCEOURE LIST; VAR I:INTEGER;
    BEGIN I:= 0;
      REPEAT
        CBUF := PROG [LOC]; LOC := LOC+1; I:=I+1;
        CHOUT
      UNTIL (I>64) OR (CBUF=CEOL); NEWLINE
    END;

  PROCEDURE EXECUTE; VAR DONE : BOOLEAN;
    BEGIN LOC := 1; DONE := FALSE;
      REPEAT
        CBUF := PROG[LOC] ; IF CBUF < '*' THEN CBUF := '*';
        IF NOT(CBUF IN ['*','Y','N','A','M','J','T','S'])THEN LIST ELSE
          CASE CBUF OF
            '*': LOC := LOC+1;
            'Y','N' : IF CBUF=FLG THEN LOC := LOC+1
                      ELSE REPEAT CBUF := PROG[LOC]; LOC:=LOC+I
                           UNTIL CBUF=CEOL;
            'A' : BEGIN LST := LOC; CHIN; LCHR :=CBUF;
                    NEWLINE; LOC :=LOC+2 ENO;
            'M' : BEGIN IF LCHR=PROG[LOC+2] THEN FLG :='Y'
                        ELSE FLG := 'N';
                    LOC := LOC+3 END;
            'J' : IF PROG[LOC+2] = '0' THEN LOC :=LST
                  ELSE BEGIN I:= ORD(PROG[LOC+2])-48;
                         REPEAT LOC:=LOC+1;
                           IF PROG[LOC] = '*' THEN I := 1-1;
                         UNTIL I=0 ENO;
            'T' : BEGIN LOC := LOC+2; LIST ENO;
            'S' : BEGIN DONE := TRUE; LOC := 1 ENO
          ENO
      UNTIL OONE
  END;

  BEGIN CBS := CHR(BS); CEOL := CHR(EOL); CBUF :='\';
    WHILE TRUE DO BEGIN
      IF CBUF ='\' THEN LOC :=1
      ELSE IF CBUF=CBS THEN LOC := LOC-1
      ELSE IF CBUF='/' THEN LIST
      ELSE IF CBUF='$' THEN EXECUTE
      ELSE IF CBUF='%' THEN
        BEGIN I:=0;
          WHILE (I<64) AND (PROG[LOC] <> CEOL) DO
            BEGIN PROG[LOC] := CHR(0); LOC := LOC+1 END;
          PROG[LOC] := CEOL; LOC := LOC +1; NEWLINE
        END
      ELSE BEGIN PROG[LOC] := CBUF; LOC := LOC+1;
        IF CBUF=CEOL THEN NEWLINE END;
      CHIN
    END
  END.
```

*cedure, but to use them in the main program. This BEGIN statement is nothing more than the start of the mainline logic for program WADUZITDO. The mainline logic inputs characters and either stores them in an array as program or executes them as commands. This routine will not jump out of the loop and will have to be interrupted to stop. Of course it is possible to create another command that will allow you to exit from this cycle.*

*Now that we have looked at the Pascal version of WADUZITDO, the reader should refer back to either of the assembly versions. The Pascal version performs the same function as the assembly versions.*

*The assembly language versions need to be heavily commented for the reader to understand what is happening. Even liberal comments will not help when converting from one assembly language to another. The Pascal version can be easily converted into any machine language. It is also self-documenting. Notice that even without a single comment, the Pascal listing is extremely easy to decipher. . . .*RGAC■

# Creating a Chess Player

## Part 1: An Essay on Human and Computer Chess Skill

**Peter W Frey**
**Larry R Atkin**

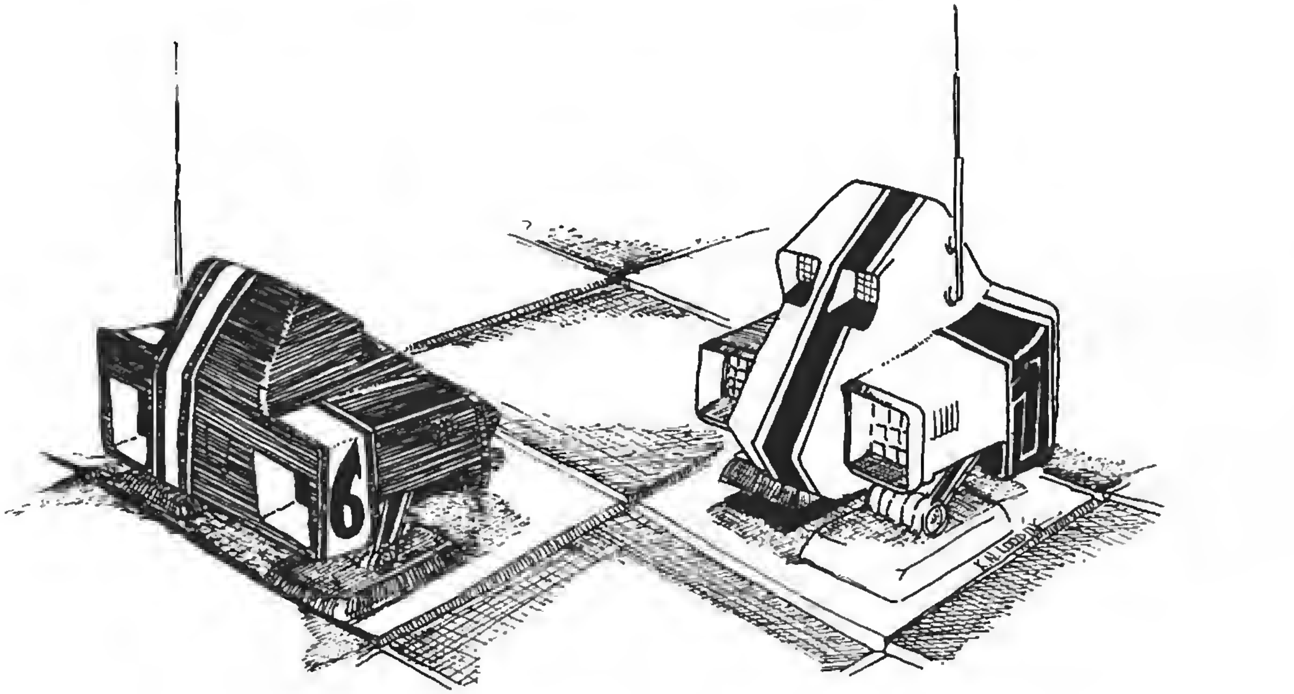
In a recent *Time* essay (see references) Robert Jastrow, director of NASA's Goddard Institute for Space Studies, predicted that history is about to witness the birth of a new intelligence, a form superior to humanity's. The pitiful human brain has "a wiring defect" that causes it to "freeze up" when faced with "several streams of information simultaneously." Jastrow suggests that "the human form is not likely to be the standard form for intelligent life" in the cosmos. Even on our own small planet, a new day is near at hand: "In the 1990s, . . . the compactness and reasoning power of an intelligence built out of silicon will begin to match that of the human brain."

We have always been fascinated by the idea of a machine that is capable of rational thought. Jastrow is neither the first nor the last person who is betting on rapid improvements in machine intelligence. His expectation that computers will rival humanity within 15 years seems optimistic to anyone who has watched half-a-dozen excited technicians flutter about for several hours trying to bring a crashed system back to life. This prophecy seems even more fanciful to those who have attempted to program machines to cope with pattern recognition, language translation or a complex game such as chess.

The chess environment, in fact, provides a particularly good example of the difficult problems which still need to be solved before silicon intelligence can become a reality. More than 20 years ago, Herbert Simon, a recognized expert in the field of artificial intelligence, predicted that within a decade, the world's chess champion would be a computer. This prognostication has not come to pass. Why was an informed scientist like Simon so wrong in his assessment of computer capabilities? A major factor is that computer scientists have often failed to appreciate the level of knowledge which is required to play master-level chess. They have also commonly underestimated the tremendous information-processing capacity of the human brain. Even though chess is a game of logic in which all legal moves can be precisely specified and in which nothing is left to chance, several centuries of intensive analysis have not exhausted the perennial challenge and novelty of the game. Psychologists have been actively studying the human brain for several decades and have discovered a fascinating mystery wrapped within an enigma. The more we learn about the brain, the more we are aware of our lamentable state of ignorance.

### The Mind of the Chess Player

At a general level of knowledge, we have several provocative insights on the nature and structure of human chess skill. We know, for example, that the skilled chess player does not examine hundreds of possible continuations before selecting a move. We also know that superior chess players are not formidable "thinking machines" but in fact display a normal range of intelligence scores. Strong chess players, as a group, do not even appear to have special retention abilities such as having "photographic" memories. In most



Artwork by K N Lodding.

De Groot's "law" of chess is that Grandmasters play better chess simply because they pick better moves.

respects, top-flight chess players have the same intellectual capacities as the rest of the population and, in the technical details of move selection, seem to engage in the same type of information processing that is observed in much weaker players.

Our knowledge in these matters is based on the early work of Binet in France and that of de Groot in Holland and on more recent investigations by other scientists in the USSR and the United States. In the late nineteenth century, Binet was surprised to discover that masters did not have a vivid image of the board when playing blindfolded chess. Instead, they seemed to remember positions in abstract terms such as by specific relations among pieces. Interviews with masters clearly indicated that a photographic memory was not a prerequisite for being able to play many simultaneous games of blindfolded chess. In the 1930s and 1940s, de Groot worked with a number of strong chess players (from Grandmasters to strong club players) and had them verbalize their thought processes while selecting a move in a complicated position. His research indicated that the Grandmasters' general approach was highly similar to that of weaker players. They analyzed a similar number of moves (about four) from the initial position, a similar number of total moves (about 35), made a similar number of fresh starts (about six), and calculated combinations to the same maximal depth (about seven plies or half-moves, where a move is defined as a play by one side and a response by the other). The only clear measurable difference was that the Grandmasters invariably chose the strongest move while the weaker players did not. Thus de Groot concluded that Grandmasters play better chess because they pick better moves. Unfortunately, this conclusion is not very informative since it is obviously circular. The fact that de Groot's extensive study did not uncover any prominent differences in the move-selection strategies used by strong and average players implies that the analysis procedure itself is not the critical factor which determines chess skill.

An important clue to the difference between skilled and unskilled players was discovered by de Groot when he displayed an unfamiliar chess position to his subjects for a few seconds and then asked them to recall the position from memory. He found that masters recalled almost all the pieces while club players remembered only about half of them. Recent work in this country by Chase and Simon at Carnegie-Mellon University has indicated that novice players recall only about a third of the pieces. Chase and Simon also added an important control procedure. They demonstrated that the differences in recall ability completely disappear if the pieces are positioned randomly. This outcome indicates that the superior memory of the chess master is chess-specific and not a general trait.

Simon and Gilmartin have proposed that skilled chess players learn to recognize a large number of piece combinations as perceptual chunks and perform well in the recall task because they remember four or five chunks rather than four or five pieces like the novice. If the average chunk size is three to four, the skilled player will recall 16 to 18 pieces.

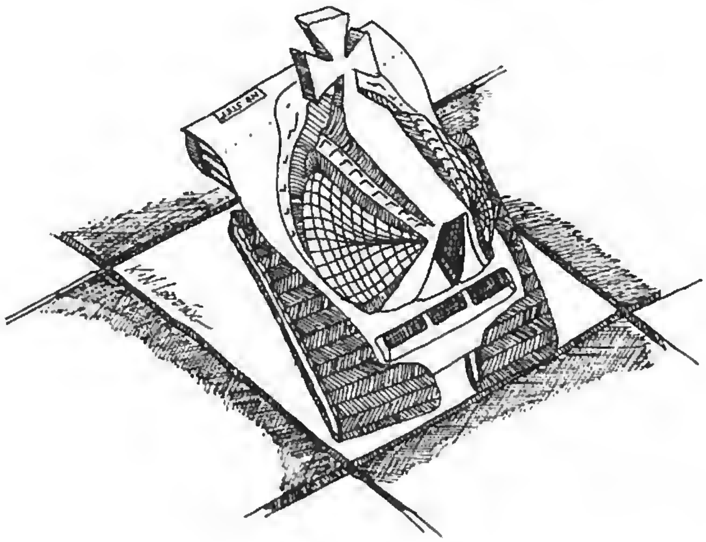
On the basis of this analysis, skill in chess depends on a learned perceptual ability which is highly similar to that acquired by every schoolchild as he or she slowly builds up a large repertoire of words. Initially the child learns to read each word character by character and often does not understand the meaning of the word. The novice chess player perceives the chessboard in a similar way, assessing a position piece by piece and failing to recognize the *meaning* of common piece configurations. The adult reader recognizes words and phrases as basic units (chunks) rather than individual characters and has a recognition vocabulary of approximately 50,000 words. The skilled chess player, in a similar vein, recognizes a very large number of piece configurations (chunks) and understands what they imply both individually and in combination.

The critical aspect of move selection occurs in the first few seconds of the task. Based on his assessment of the position, the skilled player immediately recognizes appropriate long-term and short-term goals and has a good feel for the specific moves which are compatible with these goals. For this reason, only two to four moves on the average are given serious consideration. The difference between the Grandmaster and the expert lies in the fine distinctions which are made in the first few seconds of their analysis. Skilled chess players can play a remarkably strong game when they are given only five seconds for each move. In this short time, it is not possible to make a careful analysis of many different continuations. The player must have an "instinctive" feel for the correct move and be able to recognize key features and to understand both their immediate and long-term implications.

Human chess skill, therefore, is based on two highly refined capacities, pattern recognition and rapid information retrieval. The latter ability depends on the fact that human memory is content-addressable rather than location-addressable like that of a computer. Computer systems often have to search for a specific item of information in memory by conducting an exhaustive, linear search of an entire file. Human memory however is organized in an amazingly complex fashion such that most of us can easily recall a specific fact on the basis of a completely novel retrieval cue. For example, name a flower that rhymes with *nose*. In this case, your quick response demonstrates that words are grouped together on the basis of their phonetic similarity (ie: sound). Your ability to quickly recall words which are similar in meaning to the word *fat* (such as obese, chubby, rotund, flabby, plump and stout) demonstrates that human memory is also organized by semantic similarity (ie: meaning). When a person is given a retrieval cue which does not elicit an immediate response, he or she can usually find the correct information after a brief search of related ideas or concepts. This facility contrasts sharply with the extremely limited linear searches which are generally conducted with large computer based storage systems. Even sophisticated computer retrieval strategies which arrange the data base in multilinked lists with elaborate tree structures presently lack the large system efficiency displayed by their biological counterparts.

Pattern recognition and rapid information retrieval are not only key capacities for chess, but are also essential for a wide range of important human problem solving skills. Whether your field is medicine, engineering, plumbing or computer programming, you would be a complete failure at your job without these essential abilities. Jastrow's claim that machine intelligence will soon equal man's intelligence seems to overlook the important points made in BYTE by Ernest Kent (see references). Kent emphasizes the fact that biological information processors have a vastly different architecture than their silicon imitations. In fact, he suggests that our lack of success in building a thinking machine stems from our attempts "to make a wrench do a screwdriver's job." Our modern high-speed computers were designed to do important tasks which men are not very good at, such as complex mathematical calculations.

The human brain evolved, in contrast, on its ability to identify important environmental events and to quickly recognize their significance. Natural selection has never placed much emphasis on our ability to multiply or our ability to compute the inverse of a matrix. Kent also reminds us that organic evolution worked with a very different kind of hardware than that which is available to the modern computer engineer. Biological information processors have an incredibly slow cycle time, less than 100 operations per second. The basic unit, the neuron, operates in milliseconds rather than in nanoseconds. The brain, however, makes up in quantity and in structural complexity what it lacks in speed. Computers, on the other hand, have many fewer components and a much simpler



The superior memory of the chess master is chess-specific and not a general trait.

gating architecture, but are orders of magnitude faster.

It may be that present machine hardware configurations are simply inappropriate for efficient pattern recognition or semantic recall. An analysis of the history of computer chess is instructive. Although there have been numerous advocates for chess programs which imitate human playing methods, only a few have been attempted, and none of these have played reasonable chess. The earliest paper on machine chess, written by Claude Shannon in 1950 (see references), proposed a mechanical algorithm which was not modeled on human chess play. Shannon suggested a workable procedure for representing the board and piece locations, specified simple mathematical algorithms for generating the legal moves of each piece and gave an example of a straightforward technique for evaluating a position (see *Chess Skill in Man and Machine*, chapter 3). The key feature of Shannon's proposal was the adoption of the *minimax* technique as described by von Neuman and Morgenstern in 1944. The basic idea of the minimax technique is to assume that the player whose turn it is to play will always choose the move which minimizes his opponent's maximum potential gain. Hence, the name minimax.

### The Type B Strategy

One of the difficulties of this approach is that a complete analysis of all possible continuations (type A strategy) very rapidly leads to an overwhelming number of potential positions. The look-ahead tree grows at an exponential rate and with an average, according to de Groot, of 38 legal moves at each position, a search involving three moves (three half-moves for each player) produces over 3 billion ($38^6$) terminal positions. You may recall that de Groot's research indicated that human players regularly searched a tree to seven plies and sometimes much deeper. Because of this, Shannon concluded that it would not be possible for the machine to consider all possible legal continuations at each *node* of the game tree. Instead, he proposed a type B strategy in which only reasonable (ie: plausible) moves are pursued at each branching point. If the program considered only five continuations at each node instead of all 38, a 6 ply look-ahead would involve only 15,625 ($5^6$) terminal positions.

The attractiveness of the type B approach seems overwhelming when the number of terminal positions increases exponentially with depth. The fact that skilled human players explore only a limited number of continuations at each choice point is additional evidence which favors the adoption of this strategy. It is not surprising, therefore, that most programmers have used Shannon's type B strategy in designing a chess program.

Sometimes our understanding of the real world, however, is not always as accurate as we presume. In selecting a type B strategy in preference to a type A strategy, the programmer does not necessarily simplify the problem. This approach was competently implemented in 1967 by Greenblatt at MIT. His program played reasonable, and at that time, fairly impressive chess. The major design problem in a selective search is the possibility that the look-ahead process will exclude a key move at a low level in the game tree. The failure to consider an important move can lead to a very serious miscalculation. A chess game can be lost by a single weak move. For this reason, it is of critical importance that a necessary move not be missed. The type B programs place a critical dependence on the accuracy of their plausible move generator. Chess is an extremely complex game and in many situations a move which at a superficial level seems unlikely, is, in fact, the best one. Grandmasters find these moves while lesser players, including machines, fail to see them. For a decade, several dozen individuals have tried to create a plausible move generator that is superior to Greenblatt's. The evidence is fairly clear, however, that type B programs have improved very little since 1967.

As strange as it may seem, recent progress in computer chess has come by abandoning the type B strategy. Shannon's logical analysis was made in a "stone-age" hardware environment and without knowledge of several important algorithms. Today, the type A strategy is not as ridiculous as it seemed in 1950. In addition, very few individuals anticipated the immense difficulty involved in constructing a competent plausible move generator. To become a chess master, a man has to study chess intensively (20 hrs or more a week) for at least 5 years. During this time he acquires an immense amount of detailed knowledge about the game of chess. Subtle features of a particular position are recognized immediately and suggest both short-term and long-term goals as well as specific moves. This kind of knowledge is sufficiently abstract that most players find it impossible to verbalize the relevant thought processes. The one factor which stands out clearly, however, is that the chess master has acquired a tremendous library of factual information which can be retrieved quickly and applied in apparently novel situations. No chess program has been able to duplicate this facility and, without it, the creation of a workable plausible move generator is next to impossible.

When a type A strategy is employed, however, this problem can be bypassed. By making all the moves *plausible*, the program never overlooks a subtle but important one. In fact, by reverting to a brute force search of all possible continuations, the program often finds interesting combinations that are commonly missed even by strong human players. It seems ironic that the brute force approach (full width searching) produces many more brilliant moves than the smart approach (selective searching). This important discovery was made independently by Slate and Atkin at Northwestern (the authors of the current world champion chess program, Chess 4.6) and by the Russian KAISSA team.

## Minimax and the Alpha-Beta Algorithm

Slate and Atkin's work has demonstrated that a full width search can be conducted considerably more efficiently than anyone had previously suspected (including Slate and Atkin; see references). There are a number of important developments which are responsible for this reassessment. The most important discovery was made in the late 1950s by Newell, Shaw and Simon as well as by Samuels. Because of the basic logic underlying a minimax search, it is not necessary to search the entire look-ahead tree before selecting the best move. Consider a simple 2 ply search (one move for you and one for your opponent). First you examine one of your possible moves and the 38 or so terminal positions which result from each of your opponent's legal replies. You select the one reply which is best, according to your evaluation function, for your opponent (ie: the one which minimizes your own maximum potential gain). Next, you consider a second move for yourself and the 38 or so replies that your opponent can make to this move. In considering these moves, you discover that the third reply you examine would give your opponent a better outcome than his best reply to your first candidate. Immediately you realize that it is a complete waste of time for you to analyze any more of his replies to your second candidate. Since you are already guaranteed a worse position after the second move than after the first, it is reasonable to reject the second one and turn to your third candidate. This decision eliminates the need for evaluating 35 of the potential replies to your second candidate. A very tidy savings.

Historically, the score for the best move so far for White has been designated as $\alpha$ and the score for the best move so far for Black has been called $\beta$. Thus the name alpha-beta ($\alpha$–$\beta$) algorithm. When the tree is both wide and deep, this algorithm can reduce the number of terminal nodes to a small fraction of the number which would be examined by a complete minimax search. The beauty of this procedure is that it always produces the same result as the full minimax search.

An important factor in determining the efficiency of the alpha-beta algorithm is the order in which the moves are examined. If White's best moves and Black's best replies

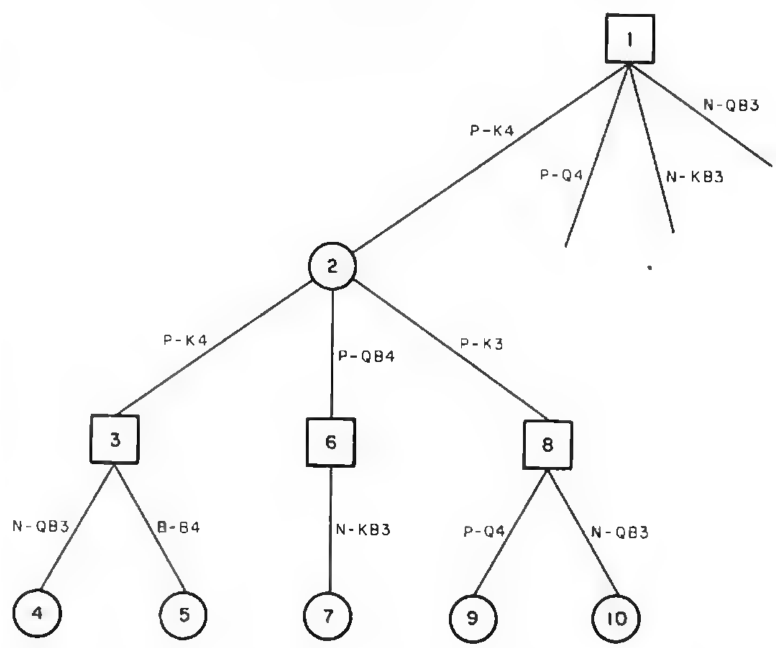



*Figure 1: Portion of a game tree for the opening game in chess. Square nodes indicate that White is to play; round nodes that Black is to play. Techniques such as alpha-beta pruning and minimax strategy are used to optimize the use of trees like this.*

are considered first at each choice point, the search of the uniform game tree of height h (number of plies deep) and width d (number of successors at each node) will involve approximately $2 \cdot d^{h/2}$ terminal positions instead of $d^h$ (see references, Knuth and Moore). The potential magnitude of this saving can be appreciated by considering our previous example with a 6 ply search: $38^6$ is more than 3 billion while $2 \times 38^3$ is about 110,000. Shannon might have given more consideration to the type A strategy if he had been aware of the alpha-beta algorithm and some of the other technical improvements which were to follow.

## General Strategy

To maximize the benefit of the alpha-beta procedure, it is necessary to devise an efficient strategy for generating the moves at each node in an order which is likely to produce a cut-off, such that searching can be terminated at that node. There are several general heuristics which have proven their value time and time again. One is extremely simple and powerful: try capturing moves first. Because a full width search includes many ridiculous moves, a reply which involves a capture will often remove a piece which was "stupidly" placed *en prise* (ie: attacked and insufficiently defended). Captures also have the beneficial effect of reducing the number of potential offspring. An additional important characteristic of a capturing move is that it will generally have to be examined sooner or later in order to insure the quiescence of the terminal position. Because of this, every capture that is examined early generally reduces the amount of work which will have to be done later. In practice, investigators have reported a speed-up in search time of as much as 2 to 1 by simply putting all the captures at the beginning of the move list.

In addition to captures, there is another class of moves which is also effective for producing cut-offs. These are called *killers* because they are moves which have produced cut-offs in the immediate past and have been specifically remembered for that reason. A short list of killers is maintained by the program and whenever the legal capturing moves fail to produce a cut-off, each of the killers (if legal in the given position) is then examined. This *killer heuristic* is quite effective in producing a move order which enhances the probability of a quick cut-off.

The general features of the alpha-beta algorithm and its important servants, the capture and killer heuristics, were reasonably well-known late in the 1960s. In recent years, several important refinements have been added to this list. One of the most important is the staged or iterative alpha-beta search. For example, instead of conducting a 5 ply search all at once the search is done in stages, first a 2 ply search, then a 3 ply search, then a 4 ply search, and finally a 5 ply search. Superficially this might appear to be wasteful since the staged search requires the full 5 ply search eventually anyway. This is not at all the case. As each search is completed, the principal variation (best moves for each side at each depth) is used as the base for the next (1 ply deeper) search. The 3 ply search therefore starts with a move at ply 1 and a reply at ply 2 which has already been proven to be reasonable (from the machine's limited perspective). The 4 ply search starts with reasonable moves at its first three plies. The 5 ply search has the benefit of reasonable moves at its first four plies. Because the efficiency of the alpha-beta algorithm is tremendously sensitive to move ordering, the spill-over in information from one iteration to the next has a surprisingly powerful effect. A single 1 stage 5 ply search might require 120 seconds of processor time. The last segment of the staged 5 ply search might require only half as much time (ie: 60). Since each iteration requires about five times as much processor time as its predecessor (the exponential character of the look-ahead tree is diminished somewhat by the alpha-beta algorithm), the staged 4 ply search would take about 12 seconds, the staged 3 ply search about 3 seconds, and the 2 ply search about 1 second. The total time for the iterative search would be approximately 76 seconds (1 + 3 + 12 + 60) rather than 120 seconds.

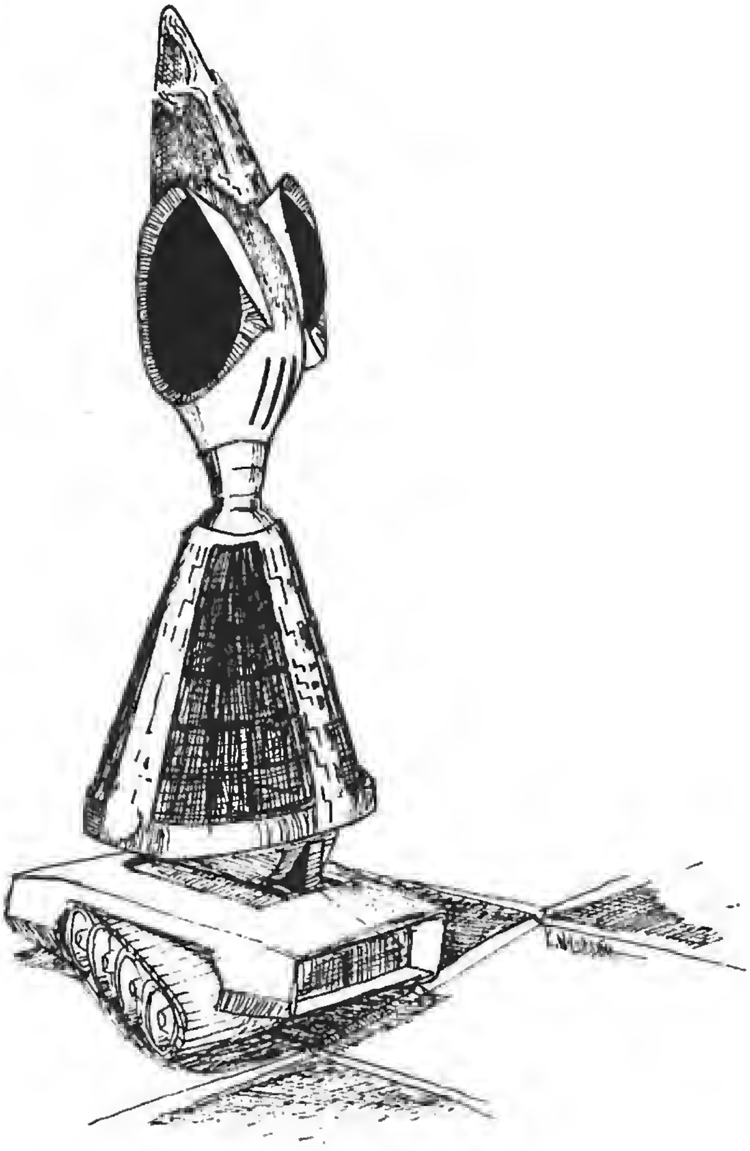
An added benefit of the iterative search, and, incidentally, the reason for its discovery in the first place, is that it provides a useful mechanism for time control. In tournaments, a move must be calculated within a fixed time limit such as 90 to 120 seconds. If one decides to do a 5 ply search in a single stage, it is possible to find oneself tied up in calculation after 120 seconds with no idea of how much more time will be needed to complete the search, and without a move to make until the search is completed. In some complex situations the search might take as long as 10 minutes – a disaster for time control. An iterative search allows one to predict the probable duration of the next iteration and to make a decision whether it is cost effective to initiate the next one. If this decision is a go and the search, for some reason, fails to terminate in the anticipated time, the machine can abort and play the move selected by the last iteration. This provides relatively neat and tidy time control. The iterative search was first mentioned by Scott in 1969 and was apparently discovered independently several years later by Jim Gillogly at Carnegie-Mellon, by Slate and Atkin at Northwestern and by the Russian KAISSA team.

### Refinements to the Type A Strategy

Several other refinements have also made the type A strategy more manageable. One of the time intensive activities involved in tree searching is move generation. This can be minimized by generating only one move at a time and seeing if it produces a cut-off before generating the next move. If a cut-off occurs and the node is abandoned, one can avoid generating a large number of potential moves. With the n-best approach, it is customary to generate all moves at each node and then invest time attempting to decide which ones are worthy of further consideration. Thus the smaller tree, obtained by selective searching, has to be partially paid for by an additional time investment in plausibility analysis.

Another time-intensive activity in the tree search is the repeated use of the evaluation function. Since many thousands of terminal nodes have to be evaluated in each move selection, any refinement that reduces the work of the evaluation function will pay rich dividends. There are three important techniques which fall in this category. One of these is called *incremental updating*. In order to make an evaluation of a node, it is necessary to have certain key facts available, such as which squares are attacked by each piece, which pieces are present, etc. This information can be newly calculated at each terminal node or can be incrementally maintained by updating the appropriate tables as the tree is generated during the search. This latter procedure is more complex to program but tremendously more efficient in terms of computing time because neighboring terminal positions are highly similar. They usually differ in respect to only a single piece, and therefore the updating procedure requires about 10 percent of the computations that would be expended if the evaluation data base were recalculated from scratch for each evaluation.

A second refinement in this category is the use of serial organization in the evaluation function. In order to assess the relative merit of a chess position, most programs place heavy emphasis on the material balance (ie: the relative number of pieces for each side). This tradition is founded on the idea that winning or losing is strongly correlated with being ahead or behind in material. An additional rationale is that this information is readily available and easily updated.



In most programs material factors are so dominant that the other evaluation terms, such as mobility, pawn structure, King safety, area control, etc, taken together almost never account for more than two pawns. Because of this, it makes sense to compute the material balance factor first and then determine if the result is within two pawns of the target value. If not, there is no need to assess the other factors, because the final decision will be independent of their value.

This simple idea encourages one to organize the evaluation function in strict serial order such that influential (heavily weighted) terms are analyzed first and the result examined to see if a decision is possible based on this initial information. If not, the next most influential term(s) are examined and another determination is made. This process is repeated until an escape condition occurs or until all terms have been examined. In most cases, the evaluation will be terminated long before the list of potential terms has been exhausted. This technical refinement can save a significant amount of time.

A third procedure for speeding the evaluation process is to remember past evaluations. For instance, one should avoid reassessing the same position two or more times. In chess, there are many pathways by which one can reach identical positions. In a 3 ply sequence in which the middle move remains constant, for example, the first and third moves can be interchanged and the resulting position will be the same. Transpositions such as this occur frequently in the end game where the King may have literally hundreds of 4 move pathways that end on the same square. Rooks, Bishops and Queens also have a special facility for reaching a particular destination square in multiple moves rather than in one or two.

A full width search (ie: type A strategy) greatly accentuates this foolishness. By creating a large table of past positions which have been already evaluated, and using a hashing procedure to check if the present position is in the table, the programmer can completely eliminate a portion of the evaluation effort. In most middle game positions, this technique will produce a 10 to 50 percent saving. In certain end game positions, however, the transposition table can eliminate more than 80 percent of the evaluation effort. This idea seems to have been implemented first by Greenblatt in 1967.

An extension of this idea is to use the table to store likely moves as well as evaluations. By remembering a move which previously produced a cut-off, the table can facilitate move ordering decisions. In addition, the use of the same reply at a familiar position may have the added benefit of increasing the number of transpositions which will be encountered at later nodes. Additional details on the use of a transposition table are discussed in chapter 4 of *Chess Skill in Man and Machine*.

One of the most difficult challenges for a chess program is the end game. A machine which calculates a move for each position has difficulty competing with humans who "know" the correct move on the basis of their own or someone else's past experience. There are a huge number of end game situations in which a specific and highly technical strategy is required. Strong chess players study these intricacies at great length and use this knowledge at the chessboard to avoid unnecessary calculations. For example, a King and a pawn against a lone King is a win in some positions, and a draw otherwise. The same is true for a King and two pawns against a King and a pawn. If a Rook or minor piece is added to each side, the situation changes dramatically. Unfortunately our present day programs are oblivious to these subtleties. For this reason they can find the correct move only by engaging in prodigious calculations. Their human counterpart, on the other hand, "knows" the correct move after a cursory glance at the position.

Newborn (see references) has introduced a useful technique for reducing this knowledge gap. The main idea is to categorize familiar end game positions as wins or draws. Many games end with a King and a pawn fighting a lone King. Skilled players usually terminate the contest before it runs its inevitable course because the outcome is not in doubt. Newborn has shown that it is feasible, taking advantage of the symmetries of the chessboard, to make a bit map that indicates either a win (1) or a draw (0) for each potential square on which the lone King might reside for each of the potential locations of the opposing King and pawn. This knowledge can be encoded in approxmately 300 bit boards of 64 bits each (see chapter 5 of *Chess Skill in Man and Machine*).

Although a tremendous amount of work and chess knowledge is required to complete this task, the end result is well worth the effort. When a position involving two Kings and a pawn is encountered anywhere in the look-ahead tree, it can be immediately scored with 100 percent accuracy as a win or a draw. This extends the look-ahead horizon of the program by as much as 12 to 15 plies for these specific situations, and eliminates all the tree searching effort which would normally be required. Furthermore, it permits accurate evaluations at the end points of a deep search, which allows the program to select a continuation which leads to a favorable end game. If this approach were extended to a wider range of situations, the machine's present knowledge deficit with respect to the end game would be greatly reduced.

These programming refinements, together with rapid hardware advances, have made the Shannon type A strategy feasible if not particularly elegant. For this reason it is possible to program a machine to play a game of chess which is free of gross blunders and which sometimes even contains an innovative move or two. Although this approach is clearly not a final solution, it does provide a solid base which can be used as a reliable starting point for future developments.■

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# Creating Chess Player

## Part 2: Chess 0.5

**Peter Frey**
**Larry Atkin**

*Part 1 of this series ("Creating a Chess Player," October 1978 BYTE, page 182[1]) was an essay on human and computer skill. In Parts 2 and 3 we present Chess 0.5, a program written in Pascal by Larry Atkin, who is coauthor with David Slate of the world championship computer chess program Chess 4.6. The program is readily adaptable to personal computers having Pascal systems such as the UCSD Pascal project software. Part 4 of the series will conclude with some thoughts about computer chess strategy.*

We have attempted to incorporate several features which make the search process more efficient and others which increase the user's options. Both of these enhancements are important. The first set of features (incremental updating, iterative searching, staged move generation, etc) were described in general terms in part 1. These features reduce computation to the point where a move can be selected in a reasonable amount of time even with a full-width search. The second set of features (special control and print commands, accepting chess moves in standard notation) not only add to the pleasure of using the program, but also make the debugging process much easier. The price for these enhancements is a longer, more complicated program. We hope the length of our listing will not discourage the reader from becoming actively involved.

Pascal was developed to provide a logical and systematic higher level language which could produce reasonably efficient machine code for existing hardware. Computer programs can be conceptualized in terms of two essential parts, descriptions of data and descriptions of actions which are to be performed on the data. Pascal requires that every variable occurring in the program be introduced by a declaration statement which associates an identifier and a data type with that variable. The data type defines the set of values which may be assumed by the variable. Since a chess program involves a large number of variables, our program begins with a long list of declaration statements.

A constant definition introduces an identifier as a synonym for a constant. This is very useful since the value of the constant as stated in the declaration list can be changed at some later date, and this change will then be reflected throughout the program in every place where the constant is used. In the chess program, the values of some of the constants depend on the characteristics of the user's hardware. For example, the values of ZK (maximum search depth) and ZW (move stack limit) will reflect the amount of memory which is available on your system. On personal computers, ZX will generally be set at 7 if you have an 8 bit processor and at 15 if you have a 16 bit processor. Note also that the value of PZX8 depends on the value of ZX. To implement this program on a given computer, it is necessary to insert at the beginning of the program the appropriate values for these constants.

For the sake of clarity, specific data types

**Note:** *The Pascal subset described in "A 'Tiny' Pascal Compiler" (page 182[2]) is not compatible with the more sophisticated Pascal used here . . .* **CM**

1. Page 107 of this edition.
2. Page 81 of this edition.

are declared for a number of different chess concepts and for certain useful indices. The program also takes advantage of the different properties represented in Pascal's data structures: the set, array and record. It is unlikely that anyone will immediately memorize the names of all the variables. Therefore it is useful to have them listed at the beginning where they can easily be found for later reference.

There is a comment statement accompanying almost every instruction in the program. Although these brief statements may not initially be very meaningful, we expect them to be helpful when the user becomes familiar with the program. Because Pascal requires that all procedures and functions be defined in the serial listing before they are called by another portion of the program, the procedures and functions which are first defined tend to be primitives. The main part of the program is concentrated at the end of the listing.

The most important part of the variable declaration list in terms of understanding the program is the portion which specifies the global data base. This includes the current board (BOARD, a record) and a number of important arrays. The look-ahead board (NBORD) is an array listing the piece occupying each square. The attacks emanating from each square are represented by ATKFR, an array which lists an 8 by 8 bit board for each of the 64 squares. The attacks to each square are represented by a similar array, ATKTO. The combined attacks for each side are represented by a 2 item array of 8 by 8 bit boards called ALATK.

The location of all pieces by type is represented by an array of 12 8 by 8 bit boards, TPLOC. The location of all pieces by color is represented by an array of two 8 by 8 bit boards, TMLOC. The moves are stored in an array (MOVES) of records. Each record (RM) contains information about the from square, to square; whether a capture is involved and the type of piece captured, whether the move affects castle status, involves check or mate, involves a piece promotion, and whether the move has been searched yet. Additional arrays provide information on castling squares, en passant squares, the location of all pieces, the location of pawns, etc. To be successful, a chess program must organize the data base in a logical manner and be able to manipulate it efficiently.

For reasons of efficiency, the program often stores the same information in two or more different ways. Because of this, it is necessary to be able to translate from one form to the other. These activities are handled by special arrays. For example, the XTPC array allows one to use a piece designator (LP, LQ, LK, DQ, etc) as an index and returns the corresponding character (1 thru 6 for Black pieces and A thru F for White pieces) which is used when a board representation is printed on the terminal.

There are several general purpose routines which are needed by the program. Two functions, MIN and MAX, provide the smaller or larger of two numbers upon request. A third function, SIGN, applies the sign of one number to the absolute value of another number. A general purpose sort routine, SORTIT, is also provided.

### Manipulating the Bit Boards

There are a number of primitive operations which involve the manipulation of information represented in bit board form. A bit board is one or more computer words which have a bit set in specific locations to represent the occurrence or nonoccurrence of a particular event. For example eight 8 bit words can be used to represent the eight rows of a chessboard. Each bit corresponds to one square. To represent the location of all White pawns, a bit is set (ie: 1) in the proper locations and all other locations remain clear (ie: 0). This method for representing and manipulating information is very useful in chess programming. For this reason, the first actions defined by our chess program are a set of procedures and functions for manipulating bit boards.

The actions represented are:

(1) the intersection of two bit boards (ANDRS);

(2) the union of two bit boards (IORRS);

(3) the complement of a bit board (NOTRS);

(4) setting a bit in a bit board (SETRS);

(5) removing a bit from a bit board (CLRRS);

(6) counting the number of bits that are set on a bit board (CNTRS);

(7) making a copy of a bit board (CPYRS);

(8) setting all bits to 0 (NEWRS);

(9) shifting all bits in a particular direction (SFTRS);

(10) determining whether a particular bit is set (INRSTB);

(11) determining whether a bit board is empty, ie: has no bits set (NULRS); and

(12) finding and reporting integer value for a location where a bit is set (NXTTS).

Since these routines are used repeatedly by the program, you can decrease the move calculation time quite a bit by implementing these primitives in assembly language. You will note that the function NXTTS is written in two ways: machine independent code, and code which is compatible only with the Control Data 6000 series machines. There are a number of places in the program where execution time can be enhanced by substituting machine dependent code which takes advantage of one or more special features of the hardware you are using. It would be helpful, also, if functions in Pascal could return an array or record instead of just a single value. There are many places in the program where this type of function would be more logical and more efficient than using a procedure (ie: subroutine). If one were to consider the best of all possible worlds, it would be especially nice if the bit map manipulations could be compiled in line. With the Pascal arrangement, many of the procedure calls take as much time as the execution of the procedure.

### Initial Steps

It is also necessary at the beginning of the program to provide values for the variables which define the chess environment, such as piece characteristics. For example, a White pawn is represented as LP for some purposes and as the letter A for other purposes. It has the color LITE, is not a sweep piece, and moves only in certain directions. It is necessary to initialize the translation tables, the constant and variable 8 by 8 bit boards, and a number of other tables. The three routines which are called to do this when the program is first activated are INISYN, INIXTP and INICON. A fourth procedure (INITAL) is called by the main program to get ready for a new game. It will be called more than once if the user wishes to play more than one game.

During the development of the program, it is necessary to determine whether the individual procedures are functioning properly. To do this, it is helpful to have a few primitive print routines which can provide information about the internal workings in a form which is understandable to the programmer. These same routines are also called by the main input/output (IO) routine (READER) which appears later in the program.

One of these routines (PRIMOV) prints an internal representation of the machine's move. Another prints an 8 by 8 array representing the board (PRINTB). This consists of numbers for Black's pieces (Black pawn = 1; Black King = 6) and letters for White's pieces (White pawn = A; White King = F) with empty squares represented by a —. The PRINBB routine prints an 8 by 8 array representing a bit board. In this case an asterisk (*) stands for a square where a bit is set and a minus sign (—) stands for a square where a bit has not been set. An attack map is printed by PRINAM and this consists of 64 (one for each square) 8 by 8 bit maps in which an * stands for a bit which is set and a — stands for a clear bit.

Other useful print routines include one which permits a user controlled pause during printing (PAUSER) and one which informs the programmer of the status of particular control switches (PRISWI). Because of Pascal's serial requirement (ie: every procedure must be defined before it can be called by another procedure), these routines appear early in the program so that they can be used to test the procedures and functions which follow.

In part 1 we mentioned incremental updating as an important feature of an efficient chess program. It is necessary to apply an evaluation function to the terminal nodes of the look-ahead tree. These evaluations; if they are at all sophisticated, require a substantial amount of detailed information about the position. Although it is possible to calculate this information separately for each evaluation, this is not a very efficient procedure, because adjacent nodes are almost identical. Most of the information which would be calculated each time would be redundant. A more efficient alternative is to "update" and "downdate" the relevant data base incrementally as the program moves about in the look-ahead tree. This capability requires quite a bit of special programming.

Several primitive routines are very useful for this. If the move involves a capture, it is necessary to change the material balance function. The actual scoring itself is handled by MBEVAL. This routine is called either by MBCAPT or MBTPAC when a piece is lost (update) or gained (downdate); or by MBPROM or MBMORP when a pawn is promoted (update); or when a newly promoted pawn is demoted (downdate). There are other changes which are required in the data base for both capture and noncapture moves. The new squares which are attacked by the piece need to be added to the attack maps (ATKFR, ATKTO, ALATK). This is done by ADDATK. The new square for the piece is added to the data base by ADDLOC. The attacks of sliding pieces which are blocked by the newly moved piece are recomputed by CUTATK. The attacks of sliding pieces which are unblocked by vacating the former square are recomputed by PRPATK. The attacks which emanated from the piece on its former square are deleted by DELATK. These primitive routines are called by LOSEIT when a capture is involved or by MOVEIT otherwise. If the move affects castling status, the necessary data base changes are made by PROACA and PROACS. If a pawn promotion is involved, PROMOT makes the necessary adjustments.

### Move Generation

A major part of any chess program is the move generation module. Because of the complexity of the game, many programs simply ignore some of the more unusual moves, such as Queenside castling, en passant pawn captures, or promotion of a pawn to a piece other than a Queen (ie: underpromotion). This arrangement will suffice to play legal chess, but it may be costly if one of the omitted move types is highly desirable in a specific game situation. In addition, an incomplete move generation facility prevents the machine from checking the legality of its opponent's moves.

Rather than being satisfied with an approximate solution, we have heeded the old maxim, "If a job is worth doing, it is worth doing well," and have implemented a move generator which permits the program to play a complete game of legal chess. As you can see from the listing, this requires extensive programming.

The first step in move generation is to create the data base for the important features of the existing board configuration. This is done by CREATE. Once a move has been selected, it is necessary to change the data base. This is done by UPDATE which makes use of the routines which were just described (eg: ADDATK, CUTATK, ADDLOC, CLSTAT, PRPATK, DELATK, MOVEIT, LOSEIT). The move is placed on the move stack by GENONE. Special routines exist for generating moves which involve the promotion of a pawn (PWNPRO) and for generating the standard pawn moves (GENPWN). When a move is tried and produces an $\alpha$-$\beta$ cutoff, the program backs down the look-ahead tree and begins to explore moves at a different node. Several procedures are employed to downdate the data base. These include the main routines RTRKIT and DNDATE, which are essentially the complement of MOVEIT and UPDATE. Two other procedures are also needed, one to unpromote a pawn (PAWNIT) and one to resurrect a captured piece (GAINIT). This set of routines permits the program to move about the look-ahead tree and incrementally update or downdate the data base.

The executive routines which are responsible for move generation are GENFSL, which generates all legal moves from a set of squares, and GENTSL, which generates all legal moves to a set of squares. The rationale for having two routines is that we wish to generate the moves in stages. For example, captures should be searched first at each node (ie: the capture heuristic). To do this, we identify the square locations of the opponent's pieces, and then call GENTSL to generate all capturing moves. These moves are searched before any other moves are generated. If one of these produces a cut-off the rest of the moves need not be generated at all. A third executive routine (GENCAS) generates all castling moves. These moves are generated after the captures if castling is still legal.

A fourth executive routine for move generation is GENALL. This procedure generates all legal moves and is used by the program to check the legality of the opponent's move. It is called by LSTMOV which makes a list of all the legal moves and each of these are compared with the opponent's move by YRMOVE (presented later). If the opponent's move is not on the list, the machine prints "illegal move." If the opponent's move is compatible with more than one of the moves on the list (eg: P-R3 could be either P-QR3 or P-KR3), the machine prints the message, "ambiguous move." When the machine has completed its own move selection or has determined that the opponent's move is legal and not ambiguous, the move is actually made by THEMOV.■

*Listing 1 (opposite): The first half of Chess 0.5, written in Pascal. The second half of the program will be presented in part 3 (December 1978 BYTE)*[3] *of this series. The portion of the program presented here covers initialization of the program, variable declaration, manipulation of the "bit boards" (used to represent positions on the chessboard), user print routines and move generation. The second half of the listing will include procedures for evaluation of terminal positions, the look-ahead procedure, and user commands.*

3. Page 131 of this edition.

```
PROGRAM CHESS(INPUT,OUTPUT);
LABEL

  1,                              (* INITIALIZE FOR A NEW GAME *)
  2,                              (* EXECUTE MACHINES MOVE *)
  9;                              (* END OF PROGRAM *)


CONST

  AA = 1; ZA = 10;                (* CHARACTERS IN A WORD *)
  AC = "A"; ZC = ",";             (* CHARACTER LIMITS *)
  AD = -21; ZD = +21;             (* DIRECTION LIMITS *)
  AJ = 0; ZJ = 73;                (* CHARACTERS IN A STRING *)
  AK = 0; ZK = 16;                (* SEARCH DEPTH LIMITS *)
  AKM2 = -2;                      (* AK-2 *)
  ZKP1 = 17;                      (* ZK+1 *)
  AL = 0; ZL = 119;               (* LARGE BOARD VECTOR LIMITS *)
  AZL = -119; ZAL = 119;          (* LARGE BOARD DIFFERENCES
                                     LIMITS *)
  AN = 1; ZN = 30;                (* MESSAGE LIMITS *)
  AS = 0; ZS = 63;                (* BOARD VECTOR LIMITS *)
  AT = -1; ZT = 63;               (* BOARD VECTOR LIMITS AND
                                     ANOTHER VALUE *)
  AV = -32767; ZV = +32767;       (* EVALUATION LIMITS *)
  AW = 1; ZW = 500;               (* MOVE STACK LIMITS *)
  AX = 0; ZX = 31;                (* SUBSETS OF SQUARES *)
  AY = 0; ZY = 1;                 (* ARRAY OF SUBSETS TO FORM A SET
                                     OF ALL SQUARES ON BOARD *)

  LPP = 20;                       (* LINES PER PAGE *)
  PZX8 = 16777216;                (* 2^(ZX-7) *)

  SYNCF = 1;                      (* FIRST CAPTURE SYNTAX *)
  SYNCL = 36;                     (* LAST CAPTURE SYNTAX *)
  SYNMF = 37;                     (* FIRST MOVE SYNTAX *)
  SYNML = 47;                     (* LAST MOVE SYNTAX *)


TYPE

  (* SIMPLE TYPES *)

  TA = AA..ZA;                    (* INDEX TO WORDS OF CHAR *)
  TB = BOOLEAN;                   (* TRUE OR FALSE *)
  TC = CHAR;                      (* SINGLE CHARACTERS *)
  TD = AD..ZD;                    (* DIRECTIONS *)
  TE = (B1,B2,B3,B4,S1,S2,S3,S4,N1,N2,N3,N4,N5,N6,N7,N8);
                                  (* NUMBER OF DIRECTIONS *)
  TF = (F1,F2,F3,F4,F5,F6,F7,F8); (* FILES *)
  TG = (PQ,PR,PN,PB);             (* PROMOTION PIECES *)
  TH = (H0,H1,H2,H3,H4,H5,H6,H7);
                                  (* TREE SEARCH MODES *)
  TI = INTEGER;                   (* NUMBERS *)
  TJ = AJ..ZJ;                    (* INDEX TO STRINGS *)
  TK = AK..ZK;                    (* PLY INDEX *)
  TL = AL..ZL;                    (* LARGE (10X12) BOARD *)
  TM = (LITE,DARK,NONE);          (* SIDES *)
  TN = AN..ZN;                    (* INDEX TO MESSAGES *)
  TP = (LP,LR,LN,LB,LQ,LK,DP,DR,DN,DB,DQ,DK,MT);
                                  (* PIECES: LIGHT PAWN, LIGHT
                                     ROOK, ... , DARK KING, EMPTY
                                     SQUARE *)
  TQ = (LS,LL,DS,DL);             (* QUADRANTS *)
  TR = (R1,R2,R3,R4,R5,R6,R7,R8); (* RANKS *)
  TS = AS..ZS;                    (* SQUARES *)
  TT = AT..ZT;                    (* SQUARES, AND ANOTHER VALUE *)
  TU = (EP,ER,EN,EB,EQ,EK);       (* TYPES: PAWN, ROOK, ... ,
                                     KING *)
  TV = AV..ZV;                    (* EVALUATIONS *)
  TW = AW..ZW;                    (* MOVES INDEX *)
  TX = AX..ZX;                    (* SOME SQUARES *)
  TY = AY..ZY;                    (* NUMBER OF TX'S IN A BOARD *)
  TZ = REAL;                      (* FLOATING POINT NUMBERS *)

  (* SETS *)

  SC = SET OF AC..ZC;             (* SET OF CHARACTERS *)
  SF = SET OF TF;                 (* SET OF FILES *)
  SQ = SET OF TQ;                 (* SET OF CASTLING TYPES *)
  SR = SET OF TR;                 (* SET OF RANKS *)
  SX = SET OF TX;                 (* SET OF SOME SQUARES *)

  (* RECORDS *)

  RB = RECORD                     (* BOARDS *)
    RBTM : TM;                    (* SIDE TO MOVE *)
    RBTS : TT;                    (* ENPASSANT SQUARE *)
    RBTI : TI;                    (* MOVE NUMBER *)
    RBSQ : SQ;                    (* CASTLE FLAGS *)
    CASE INTEGER OF
      0: ( RBIS: ARRAY [TS] OF TP);       (* INDEXED BY SQUARE *)
      1: ( RBIRF: ARRAY [TR,TF] OF TP)    (* INDEXED BY RANK AND FILE *)
    END;

  RA = PACKED ARRAY [TA] OF TC;   (* WORDS OF CHARACTERS *)
  RC = ARRAY [TS] OF TP;          (* BOARD VECTORS *)
  RN = PACKED ARRAY [TN] OF TC;   (* MESSAGES *)
  RJ = PACKED ARRAY [TJ] OF TC;   (* STRINGS *)

  RD = PACKED RECORD              (* SYNTAX DESCRIPTOR FOR
                                     SINGLE SQUARE *)
    RDPC : TB;                    (* PIECE *)
    RDSL : TB;                    (* / *)
    RDKQ : TB;                    (* K OR Q *)
    RDNB : TB;                    (* R, N, OR B *)
    RDRK : TB;                    (* RANK *)
    END;

  RX = RECORD
    CASE INTEGER OF               (* KLUDGE TO FIND NEXT BIT *)
      0: (RXTB: SET OF 0..47);    (* BITS *)
      1: (RXTZ: TZ);              (* FLOATING POINT NUMBER *)
    END;

  RM = PACKED RECORD              (* MOVES *)
    RMFR : TS;                    (* FROM SQUARE *)
    RMTO : TS;                    (* TO SQUARE *)
    RMCP : TP;                    (* CAPTURED PIECE *)
    RMCA : TB;                    (* CAPTURE *)
    RMAC : TB;                    (* AFFECTS CASTLE STATUS *)
    RMCH : TB;                    (* CHECK *)
    RMMT : TB;                    (* MATE *)
    RMIL : TB;                    (* ILLEGAL *)
    RMSU : TB;                    (* SEARCHED *)
    CASE RMPR : TB OF             (* PROMOTION *)
      FALSE: (
        CASE RMOO : TB OF         (* CASTLE *)
          FALSE: (RMEP : TB);     (* ENPASSANT *)
          TRUE : (RMQS : TB);     (* QUEEN SIDE *)
            );
      TRUE : (RMPP : TG);         (* PROMOTION TYPE *)
    END;

  RS = RECORD                     (* BIT BOARDS *)
    CASE INTEGER OF
      0: (RSSS: ARRAY [TY] OF SX);   (* ARRAY OF SETS *)
      1: (RSTI: ARRAY [TY] OF TI);   (* ARRAY OF INTEGERS *)
    END;

  RK = ARRAY [TS] OF RS;          (* ATTACK MAPS *)

  RY = PACKED RECORD              (* MOVE SYNTAX DESCRIPTOR *)
    RYLS : RD;                    (* LEFT SIDE DESCRIPTOR *)
    RYCH : TC;                    (* MOVE OR CAPTURE *)
    RYRS : RD;                    (* RIGHT SIDE DESCRIPTOR *)
    END;

  RE = ARRAY [TW] OF TV;          (* ARRAY OF VALUES *)
  RF = ARRAY [TW] OF RM;          (* ARRAY OF MOVES *)


VAR

  (* DATA BASE *)

  BOARD : RB;                     (* THE BOARD *)
  NBORD : ARRAY [TS] OF TP;       (* LOOK-AHEAD BOARD *)
  ATKFR : ARRAY [TS] OF RS;       (* ATTACKS FROM A SQUARE *)
  ATKTO : ARRAY [TS] OF RS;       (* ATTACKS TO A SQUARE *)
  ALATK : ARRAY [TM] OF RS;       (* ATTACKS BY EACH COLOR *)
  TPLOC : ARRAY [TP] OF RS;       (* LOCATIONS OF PIECE BY TYPE *)
  TMLOC : ARRAY [TM] OF RS;       (* LOCATIONS OF PIECE BY COLOR *)
  MOVES : ARRAY [TW] OF RM;       (* MOVES *)
  VALUE : ARRAY [TW] OF TV;       (* VALUES *)
  ALLOC : ARRAY [TK] OF RS;       (* ALL PIECES *)
  BSTMV : ARRAY [TK] OF TW;       (* BEST MOVE SO FAR *)
  BSTVL : ARRAY [AKM2..ZKP1] OF TV;   (* VALUE OF BEST MOVE *)
  CSTAT : ARRAY [TK] OF RS;       (* CASTLING SQUARES *)
  ENPAS : ARRAY [TK] OF RS;       (* ENPASSANT SQUARES *)
  GENPN : ARRAY [TK] OF RS;       (* PAWN ORIGINATION SQUARES *)
  GENTO : ARRAY [TK] OF RS;       (* MOVE DESTINATION SQUARES *)
  GENFR : ARRAY [TK] OF RS;       (* MOVE ORIGINATION SQUARES *)
  MBVAL : ARRAY [TK] OF TV;       (* MATERIAL BALANCE VALUES *)
  MVSEL : ARRAY [TK] OF TI;       (* COUNT MOVES SELECTED BY PLY *)
  INDEX : ARRAY [AK..ZKP1] OF TW; (* CURRENT MOVE FOR PLY *)
  KILLR : ARRAY [TK] OF RM;       (* KILLER MOVES BY PLY *)
  LINDX : ARRAY [TK] OF TW;       (* LAST MOVE FOR PLY *)
  SRCHM : ARRAY [TK] OF TH;       (* SEARCH MODES *)
  GOING : TI;                     (* NUMBER OF MOVES TO EXECUTE *)
  LSTMV : RM;                     (* PREVIOUS MOVE *)
  MAXPS : TV;                     (* MAXIMUM POSITIONAL SCORE *)
  MBLTE : TV;                     (* MATERIAL BALANCE LITE EDGE *)
  MBPWN : ARRAY [TM] OF TI;       (* NUMBER OF PAWNS BY SIDE *)
  MBTOT : TV;                     (* TOTAL MATERIAL ON NBORD *)
  NODES : TI;                     (* NUMBER OF NODES SEARCHED *)

  JNTK  : TK;                     (* PLY INDEX *)
  JMTK  : TK;                     (* ITERATION *)
  JNTM  : TM;                     (* SIDE TO MOVE *)
  JNTW  : TW;                     (* MOVES STACK POINTER *)

  (* LETS *)

  FKPSHD : TI;                    (* KING PAWN SHIELD CREDIT *)
  FKSANQ : TI;                    (* KING IN SANCTUARY CREDIT *)
  FMAXMT : TI;                    (* MAXIMUM MATERIAL SCORE *)
  FNODEL : TI;                    (* NODE LIMIT FOR SEARCH *)
  FPADCR : ARRAY [TF] OF TI;      (* PAWN ADVANCE CREDIT BY FILE *)
  FPBLOK : TI;                    (* PAWN BLOCKED PENALTY *)
  FPCONN : TI;                    (* PAWN CONNECTED CREDIT *)
  FPFLNX : TI;                    (* PAWN PHALANX CREDIT *)
  FRDUBL : TI;                    (* DOUBLED ROOK CREDIT *)
  FRK7TH : TI;                    (* ROOK ON SEVENTH CREDIT *)
  FTRADE : TI;                    (* TRADE-DOWN BONUS FACTOR *)
  FTRDSL : TI;                    (* TRADE-DOWN TUNING FACTOR *)
  FTRPOK : TI;                    (* PAWN TRADE-DOWN RELAXATION *)
  FTRPWN : TI;                    (* PAWN TRADE-DOWN FACTOR *)
  FWKING : TI;                    (* KING EVALUATION WEIGHT *)
  FWMAJM : TI;                    (* MAJOR PIECE MOBILITY WEIGHT *)
  FWMINM : TI;                    (* MINOR PIECE MOBILITY WEIGHT *)
  FWPAWN : TI;                    (* PAWN EVALUATION WEIGHT *)
  FWROOK : TI;                    (* ROOK EVALUATION WEIGHT *)
  WINDOW : TI;                    (* SIZE OF ALPHA-BETA WINDOW *)

  (* SWITCHES *)

  SWEC : TB;                      (* ECHO INPUT *)
  SWPA : TB;                      (* PAGING *)
  SWPS : TB;                      (* PRINT PRELIMINARY SCORES *)
  SWRE : TB;                      (* REPLY WITH MOVE *)
  SWSU : TB;                      (* PRINT STATISTICS SUMMARY *)
  SWTR : TB;                      (* TRACE TREE SEARCH *)

  (* COMMAND PROCESSING DATA *)

  ICARD : RJ;                     (* INPUT CARD IMAGE *)
  ILINE : RJ;                     (* CURRENT COMMAND *)
  JNTJ  : TJ;                     (* CURRENT INPUT LINE POSITION *)
  JMTJ  : TJ;                     (* CURRENT COMMAND POSITION *)
```

*Listing 1, continued:*

```
MOVNS : RM;                                (* MOVE MESSAGE *)

(* TRANSLATION TABLES *)

XSPB : ARRAY )TP] QF TB)                   )* TRUE FOR SNEEP PIECES *)
XFPE : ARRAY (TP] QF TE]                   (* FIRST DIRECTION *)
XLLO : ARRAY [AZL..ZAL] QF TQ:             (* DIRECTIQN FOR LARGE BOARD
                                              SQUARE DIFFERENCES *)
XLPE : ARRAY (TP[ OF TE:                   [* LAST DIRECTION *)
XRFS : ARRAY (TF] OF RS:                   (* BIT BOARQ FOR FILES *)
XRRS : ARRAY [TR] QF RS[                   (* BIT BQARQ FOR RANKS *)
XNFS : ARRAY (TF] OF RS:                   (* CONP BIT BQARQ FQR FILES *)
XNRS : ARRAY (TR] OF RS)                   (* COMP BIT BOARD FOR RANKS *]
XRSS : ARRAY (TS] OF RS)                   [* BIT BOARD FOR 8X8 INDEX *)
XROM : ARRAY [TQ] QF RM)                   [* MOVES FOR CASTLE TYPES *)
XSQS : ARRAY [TQ] OF RS]                   )* BIT BOARD FOR CASTLE TYPES *)
XSSX : ARRAY [TS] QF SX)                   )* SET ELEMENT FQR 8X8 INDEX *)
XTBC : ARRAY [TB] OF TC]                   [* CHARACTERS FOR BOOLEANS *]
XTEO : ARRAY [TE] OF TO]                   (* DIRECTION NUMBER TO 10X12
                                              SQUARE DIFFERENCE *)
XTGC : ARRAY [TG] OF TC)                   (* CHARACTERS FOR PRQNQTION *)
XTGNP: ARRAY [TG,TN] QF TP)                [* PIECE FOR PRONQTIQN TYPE
                                              AND CQLOR *)
XTLS ( ARRAY (TL] OF TT:                   (* 8X8 INQEX FQR 10X12 INDEX *)
XTNA : ARRAY [TN] OF RA]                   (* NOROS FOR COLORS *[
XTND : ARRAY )TN] OF TQ)                   (* CASTLE TYPES FOR SIQE *)
XTNV : ARRAY )TN] OF TV;                   )* SCORE FACTOR FOR SIDE *[
XTPC : ARRAY (TP] OF TC;                   (* CHARACTERS FOR PIECES *)
XTPN : ARRAY (TP] OF TN)                   (* SIOES FOR PIECES *)
XTPU : ARRAY [TP] OF TU)                   )* TYPE FOR PIECE *)
XTPV : ARRAY [TP] OF TV;                   )* VALUES OF PIECES *[
XTOA : ARRAY [TQ] OF RA[                   (* NOROS FOR CASTLES *)
XTQS : ARRAY [TQ] OF TS;                   [* TO SQUARES FOR CASTLE TYPES *]
XTRFS: ARRAY )TR,TF] OF TS;                [* 8X8 INQEX FOR RANK AND FILE *)
XTSF : ARRAY (TS] OF TF:                   [* FILES FOR SQUARES *)
XTSL : ARRAY (TS] QF TL:                   [* 10X12 INDEX FOR 8XA INDEX *)
XTSR : ARRAY )TS] OF TR]                   (* RANKS FOR SQUARES *[
XTSX : ARRAY [TS] OF TX[                   [* ELEMENT NUMBER FOR AX8
                                              INDEX *)
XTSY : ARRAY (TS] OF TY)                   (* ARRAY SUBSCRIPT INTO BIT BQARD
                                              FOR 8X8 INDEX *)
XTUC : ARRAY (TU] QF TC]                   (* CHARACTER FQR TYPE *[
XTUMP: ARRAY )TU,TN] OF TP)                (* PIECE FOR TYPE AND SIDE *)

XROSO: ARRAY [TQ] QF RS;                   [* UNOCCUPIEO SQUARES FQR
                                              CASTLING *[
XROSA: ARRAY [TQ] OF RS;                   (* UNATTACKEQ SQUARES FOR
                                              CASTLING *)

EOGE : ARRAY (TE) OF RS;                   )* EQGES IN VARIQUS OIRECTIONS *)
CORNR: RS;                                 [* KING SANCTUARY *)
NULNV: RN)                                 )* NULL NOVE *[
QTHER: ARRAY (TN] OF YN:                   )* OTHER COLOR *)
SYNTX: ARRAY(SYNCF..SYNNL) OF RY:          [* MOVE SYNTAX TABLE *)


FUNCTION MAX(A,B:TI):TI;                   (* LARGER OF TNO NUMBERS *)

BEGIN
  IF A > B THEN
    NAX := A
  ELSE
    NAX := B;
END;  (* NAX *)


FUNCTION NIN(A,B:TI):TI;                   (* SNALLER OF YNO NUMBERS *)

BEGIN
  IF A < B TNEN
    NIN := A
  ELSE
    NIN := B)
END;  [* NIN *]


FUNCTION SIGN[A,B:TI]:TI;                  (* SIGN OF B APPLIEQ TO
                                              ABSOLUTE VALUE QF A *)

BEGIN
  SIGN := TRUNC)B/ABS(B)) * ABS[A[;
END)  [* SIGN *)


PROCEQURE SORTIT                           )* SORT PRELIMINARY SCQRES *]
  (VAR A:RE;                               (* ARRAY OF SCORES *]
   VAR B:RF)                               )* ARRAY OF MOVES *)
   C:TN[)                                  )* NUMBER OF ENTRIES *)

VAR
  INTB : JB;                               )* LOOP EXIT FLAG *)
  INTN : TN)                               )* OUTER LOOP INDEX *[
  INTI : TI;                               (* INNER LOOP INDEX *)
  INTV : TV;                               (* NOLO SCORE *]
  INRN : RN)                               (* HOLD MOVE *[

BEGIN
  FOR INTN := AN+2 YO C DO
  BEGIN
    INTI := INTN - 1;
    INTV := A[INTN];
    INRN := B[INTN]|
    INTB := TRUE;
    WHILE )INTI > AN) ANO INTB DO
      IF INTV < A(INTI] THEN
      BEGIN
        A[INTI+1[ := A)INTI];
        B(INTI+1) := B(INTI))
        INTI := INTI - 1;
      END
      ELSE
        INTB := FALSE:                     (* EXIT *)
    A[INTI+1) := INTV:
    B[INTI+1] := INRN[
  ENQ]
END;  (* SORYIT *)


PROCEOURE ANORS                            [* INTERSECYION OF TNO BIT
                                              BOAROS *)
  (VAR C:RS;                               [* RESULT *)
   A, B:RS))                               [* OPERANOS *)

VAR
  INTY : TY;                               )* BIT BOARO WORD INOEX *)

BEGIN
  FOR INTY := AY TQ ZY DO
    C.RSSS(INTY) := A.RSSS[INTY) * B.RSSS[INTY]:
END;  (* ANORS *)

PROCEOURE CLRRS                            [* REMOVE SQUARE FRON BIT
                                              BOARD *)
  (VAR C:RS;                               (* BIT BOARO *)
   A:TS);                                  (* SQUARE TO REMOVE *)

BEGIN
  C.RSSS[XTSY)A]] := C.RSSS)XTSY[A]) - XSSX[A])
ENQ;  )* CLRRS *)


PROCEOURE CPYRS                            (* COPY OF A BIT BOARO *)
  [VAR C:RS)                               )* RESULT *)
   A:RS);                                  [* OPERANO *)

VAR
  INTY : TY:                               [* BIT BOARO NORO INOEX *)

BEGIN
  FOR INTY := AY YO ZY DO
    C.RSSS[INTY] := A.RSSS[INTY];
END)  [* CPYRS *)


PROCEQURE IORRS                            (* UNION OF TNO BIT BOARDS *)
  (YAR C:RS;                               {* RESULT *)
   A, B:RS);                               [* OPERANOS *)

VAR
  INTY : TY;                               (* BIT BOARO WORO INOEX *)

BEGIN
  FOR INTY := AY TO ZY DO
    C.RSSS[INTY] := A.RSSS[INTY] + B.RSSS(INTY):
END;  [* IORRS *)


PROCEOURE NENRS                            (* CLEAR BIT BOARO *)
  (VAR A:RS);                              (* BIT BOARD TO CLEAR *)

VAR
  INTY : TY;                               (* BIT BOARO HORD INDEX *)

BEGIN
  FOR INTY := AY TO ZY DO
    A.RSSS(INTY) := ();
END;  (* NENRS *)


PROCEOURE NOTRS                            (* CONPLENENY OF A BIT BOARD *)
  (YAR C:RS;                               (* RESULT *)
   A:RS);                                  (* OPERANO *)

YAR
  INTY : TY)                               [* BIT BOARO NORO INOEX *)

BEGIN
  FOR INTY := AY TO ZY DO
    C.RSSS[INTY] := [AX..ZX]-A.RSSS[INTY];
END;  [* NOTRS *)


FUNCTION NXTTS                             [* NEXT ELENENT IN BIT BOARD *)
  (VAR A:RS]                               [* BIT BOARD TO LOCATE FIRST
                                              SOUARE, AND THEN RENOVE *)
   VAR B:TS                                (* SQUARE NUMBER OF FIRST SQUARE
                                              IN BIT BOARD *)
  ):TB;                                    [* TRUE IFF ANY SOUARES WERE SET
                                              INITIALLY *)

LABEL
  11)                                      [* RETURN *[

VAR
  INTX : TX)                               [* BIT BQARD BIT INDEX *)
  INTY : YY:                               (* BIT BOARQ NORD INOEX *)
  X : RK;                                  (* KLUDGE WORD *)

BEGIN
  FOR INTY := ZY QONNTO AY DO              (* LOOP THRU BIT BQARO NOROS *)
    IF A.RSTI(INTY] <> 0 TNEN
    BEGIN

[*** BEGIN COC 6000 OEPENOANT COOE *)
(*** FQLLONING COOE REQUIRES THE 'EXPO' FUNCTION TO RETURN
(*** THE EXPONENT FRON A FLOATING POINY NUMBER.  IT ALSO ASSUMES
(*** THAT FLOATING POINT NUMBERS NAVE 48 BIT COEFFICIENTS RIGNT-
(*** JUSTIFIEQ IN A NQRO, ANQ TNAT SETS ARE RIGNT-JUSTIFIEO IN
[*** A NORO. *)
(*    X.RKTZ := A.RSTI(INTY];               )* FLQAT NORO *)
)*    B := EXPO(X.RXTZ) + INTY * [ZX+1[;
)*                                          )* CONVERT TO SQUARE NUMBER *)
```

*Listing 1, continued:*

```
(*      X.RXTB := X.RXTB - [47];             (* RENOVE MOST SIGNIFICANT BIT *)
(*      A.RSTI(INTY( := TRUNC(X.RXTZ);       (* INTEGERIZE *)
(*      NXTTS := TRUE;                       (* RETURN A BIT SET *)
(*      GOTO 11;                             (* RETURN *)
(*** END CDC 6000 DEPENOANT CODE *)

(*** BEGIN MACNINE INDEPENDENT CODE *)
     FOR INTX := ZX DONNTO AX DO             (* LOOP THROUGN BITS IN NORD OF
                                                SET *)
       IF INTX IN A.RSSS[INTY] THEN
       BEGIN
         B := INTX+INTY*(ZX+1)I              (* RETURN SQUARE NUMBER *)
         A.RSSS)INTYI := A.RSSS[INTT] - [INTX];
                                             (* RENOVE BIT FROM NORD *)
         NXTTS := TRUE;                      (* RETURN A BIT SET *)
         GOTO 11;                            (* RETURN *)
       END;
(*** END NACNINE INDEPENDENT CODE *(

    END;
  NXTTS := FALSE;                            (* ELSE RETURN NO BITS SET *)
11:  (* RETURN *)
END;  (* NXTTS *)



FUNCTION CNTRS                               (* COUNT MENBERS OF A BIT
                                                BOARD *(
  (A:RS):TS;                                 (* BIT BOARD TO COUNT *(

VAR
  INTY : TY;                                 (* BIT BOARD NORD INDEX *)
  INTS : TS;                                 (* TENPORARY *)
  INRS : RS;                                 (* SCRATCN *)
  INTS : TS;                                 (* SCRATCN *)

BEGIN
  INTS := 0;

(*** BEGIN MACHINE INDEPENDENT CODE *)
  CPYRS(INRS,A);
  WNILE NXTTS(INRS,INTS) DO
    INTS := INTS+1;                          (* COUNT SQUARES *)
(*** END NACNINE INDEPENDENT CODE *(

(*** BEGIN CDC 6000 DEPENDENT CODE *(
(*** FOLLONING CODE REQUIRES THE 'CARD' FUNCTION TO
(*** COUNT THE NENBERS IN A SET. *)
(*FOR INTY := AY TO ZY DO
(*  INTS := INTS + CARD(A.RSSS(INTY));
(*** END CDC DEPENDENT CODE *)

  CNTRS := INTS;                             (* RETURN SUN *)
END;  (* CNTRS *)



PROCEDURE SETRS                              (* INSERT SQUARE INTO BIT
                                                BOARD *)
  (VAR C:RS;                                 (* BIT BOARD *(
   A:TS(;                                    (* SQUARE TO INSERT *)
                                             .
BEGIN
  C.RSSS[XTSY[A]] := C.RSSS(XTSY(A(( + XSSX[A(;
END;  (* SETRS *)



PROCEDURE SFTRS                              (* SHIFT BIT BOARD *)
  (VAR A:RS;                                 (* RESULT *)
   B:RS;                                     (* SOURCE *(
   C:TE);                                    (* DIRECTION *)

VAR
  INRS : RS;                                 (* SCRATCN *)
  INTS : TS;                                 (* SCRATCN *(
  INTY : TY;                                 (* BIT BOARD NORD INDEX *)

BEGIN

(*** BEGIN MACHINE INDEPENDENT CODE *)
  NEWRS(A);                                  (* CLEAR NEW BIT BOARD *(
  WHILE NXTTS(B,INTS) DO
    IF XTLS(XTSL)INTS]+XTED(C]I > 0 THEN
                                             (* SHIFT EACH BIT *)
      SETRS(A,XTLS[XTSL[INTS]+XTED(C)]);
(*** END MACHINE INDEPENDENT CODE *)
(*** BEGIN CDC 6000 DEPENDENT CODE *)
(*** FOLLONING CODE ASSUMES THAT NULTIPLICATION DR DIVISION
(*** BY A CONSTANT POWER OF 2 IS DONE NITN A SNIFT INSTRUCTION. *)
(*CASE C OF
(*S1:  BEGIN
(*       FOR INTY := AY TO ZT DO          (* SNIFT ONE PLACE *)
(*       BEGIN
(*         B.RSSS[INTY] := B.RSSS(INTY] - EDGE[S1].RSSS[INTY];
(*         A.RSTI(INTY) := B.RSTI(INTY( DIV 2I
(*       END;
(*     END(
(*S2:  BEGIN
(*       FOR INTY := AY TO ZY DO          (* SNIFT NORDS *)
(*       BEGIN
(*         B.RSSS(INTYI := B.RSSS(INTYI - EDGE[S2].RSSS[INTT];
(*         INRS.RSSS[INTY] := B.RSSS[INTT] * [ZX-7..ZX];
(*         A.RSSS(INTYI := B.RSSS[INTT] - [ZX-7..ZX]
(*         A.RSTI[INTY) := A.RSTI[INTY( * 256
(*       END;
(*       FOR INTY := AY+1 TO ZY DO        (* CARRY BETWEEN NORDS *(
(*         A.RSTI(INTYI := A.RSTI[INTYI + INRS.RSTI[INTY-1] DIV P2X8(
(*     END;
(*S3:  BEGIN
(*       FOR INTY := AY TO ZY DO          (* SNIFT ONE PLACE *)
(*       BEGIN
(*         A.RSSS(INTY) := B.RSSS[INTYI - EDGE[S3].RSSS(INTY];
(*         A.RSTI[INTY( := A.RSTI(INTY) * 2;
(*       END;
(*     END;
(*S4:  BEGIN
(*       FOR INTY := AY TO ZY DO          (* SHIFT NORDS *)
(*       BEGIN
(*         B.RSSS(INTYI := B.RSSS(INTY) - EDGE[S4].RSSS[INTY];
(*         INRS.RSSS)INTY( := B.RSSS(INTY] * [AX..AX+7];
(*         A.RSTI)INTY( := B.RSTI(INTT] DIV 256;
(*       END;
(*       FOR INTY := AY TO ZT-1 DO        (* CARRY BETWEEN NORDS *)
(*         A.RSTI)INTY( := A.RSTI(INTY] + INRS.RSTI(INTY+1( * P2X8;
(*     END;
(*B1:  BEGIN
(*       SFTRS(INRS,B,S1);
(*       SFTRS(A,INRS,S2);
(*     END;
(*B2:  BEGIN
(*       SFTRS(INRS,B,S2);
(*       SFTRS(A,INRS,S3);
(*     END;
(*B3:  BEGIN
(*       SFTRS(INRS,B,S3);
(*       SFTRS(A,INRS,S4);
(*     END;
(*B4:  BEGIN
(*       SFTRS(INRS,B,S4(;
(*       SFTRS(A,INRS,S1);
(*     END;
(*N1:  BEGIN
(*       SFTRS(INRS,B,B1(;
(*       SFTRS(A,INRS,S2);
(*     END(
(*N2:  BEGIN
(*       SFTRS(INRS,B,B2);
(*       SFTRS(A,INRS,S2);
(*     END;
(*N3:  BEGIN
(*       SFTRS(INRS,B,B2);
(*       SFTRS(A,INRS,S3(;
(*     END;
(*N4:  BEGIN
(*       SFTRS(INRS,B,B3);
(*       SFTRS(A,INRS,S3(;
(*     END(
(*N5:  BEGIN
(*       SFTRS(INRS,B,B3];
(*       SFTRS(A,INRS,S4](
(*     END)
(*N6:  BEGIN
(*       SFTRS(INRS,B,B4);
(*       SFTRS(A,INRS,S4);
(*     END;
(*N7:  BEGIN
(*       SFTRS(INRS,B,B4);
(*       SFTRS(A,INRS,S1);
(*     END;
(*N8:  BEGIN
(*       SFTRS(INRS,B,B1);
(*       SFTRS(A,INRS,S1);
(*     END;
(*END;
(*** END CDC 6000 DEPENDENT CODE *)

END;  (* SFTRS *)



FUNCTION INRSTB                              (* SQUARE IN BIT BOARD BOOLEAN *)
  (A:RS;                                     (* BIT BOARD *(
   B:TS(:TB;                                 (* SQUARE IN QUESTION *(

BEGIN
  INRSTB := XSSX(B] <= A.RSSS(XTSY(B)(;
END;  (* INRSTB *)



FUNCTION NULRS                               (* NULL BIT BOARD *)
  (A:RS)                                     (* BIT BOARD TO CHECK *)
  :TB;                                       (* TRUE IF BIT BOARD ENPTY *(

VAR
  INTY : TY;                                 (* BIT BOARD NORD INDEX *(
  INTB : TB(                                 (* TENPORARY VALUE *(

BEGIN
  INTB := TRUE;
  FOR INTY := AY TO ZY DO
    INTB := INTB AND (A.RSTI[INTY] = 0);
  NULRS := INTB;
END;  (* NULRS *)



FUNCTION NULMVB                              (* NULL MOVE BOOLEAN *)
  (A:RM)                                     (* MOVE TO TEST *)
  :TB;                                       (* TRUE IF NULL MOVE *(
BEGIN
  WITH A DO
    NULMVB := RMAC AND RMPR AND (NOT RMCA((
END;  (* NULMVB *)



PROCEDURE INICON)                            (* INITIALIZE GLOBAL CONSTANTS *)

VAR
  INTD : TD;                                 (* DIRECTION INDEX *)
  INTE : TE;                                 (* DIRECTION *)
  INTF : TF(                                 (* FILE INDEX *(
  INTI : TI;                                 (* SCRATCN *)
  INTL : TL;                                 (* LARGE BOARD INDEX *)
  INTQ : TQ;                                 (* CASTLE TYPE INDEX *)
  INTR ( TR;                                 (* RANK INDEX *I
  INTT : TT;                                 (* SQUARE INDEX *(
  INTX : TX;                                 (* SET ELEMENT INDEX *(
  INTY : TY;                                 (* BIT BOARD NORD INDEX *)
  INTI : TI;                                 (* SCRATCN *)
  INRS : RS(                                 (* SCRATCN *)
```

*Listing 1, continued:*

```
 PROCEOURE INISYN                          [* INITIALIZE MOVE SYNTAX
                                              TABLE ENTRY *)
   (A:RA))                                 )* MOVE SYNTAX *]

 BEGIN
   NITN SYNTX[INTI] 00
   BEGIN
     NITN RYLS DO
     BEGIN
       RQPC := TRUE)
       ROSL := A[AA+0] <> " "I
       ROKQ := A[AA+1] <> " ";
       RONB := A[AA+2] <> " ";
       RORK := A[AA+3] <> " ";
     ENO;
     RYCN := A[AA+4])
     NITN RYRS 00
     BEGIN
       ROPC := A[AA+5] <> " "(
       ROSL := A[AA+6] <> " "I
       ROXO := A[AA+7] <> " "]
       RONB := A[AA+8] <> " ";
       RORX := A[AA+9] <> " ";
     ENO;
   ENO;
   INTI := INTI+1;
 ENO;  )* INISYN *)

 PROCEOURE INIXIP                          )* INIIIALIZE PIECE IRANSLATION
                                              TABLES *)
   (A : TP;                                (* PIECE TO BE TRANSLATEO *)
    B : TC;                                (* OISPLAY EOUIVALENT *)
    C : TN;                                )* COLOR OF PIECE *)
    O : TU;                                )* TYPE OF PIECE *)
    E : TB;                                (* TRUE IF SWEEP PIECE *)
    F : TE;                                ]* FIRST OIRECTION OF MOVEMENT *)
    G : TE;                                (* LAST OIRECTION OF MOVEMENT *)
    N : TV)I                               [* VALUE QF PIECE *]

 BEGIN
   XTPC[A] := B]
   XTPM[A] := CI
   XSPB[A] := E;
   XFPE[A] := F]
   XLPEIA] := G;
   XTPU[A] := O;
   XTPV[A] := N;
   IF A <> MT THEN
     XTUNP[O,C] :=' A;
 EMO;  (* INIXTP *)


BEGIN  (* INICON *]

  (** INITIALIZE PIECE CHARACTERISTICS *]

  INIXTP(LP,"A",LITE,EP,FALSE,B1,B2,1*64);
  INIXTP(LR,"B",LITE,ER,TRUE ,S1,S4,5*64);
  INIXTP(LN,"C",LITE,EN,FALSE,N1,N8,3*64);
  INIXTP(LB,"O",LITE,EB,TRUE ,B1,B4,3*64);
  INIXTP(LO,"E",LITE,EO,TRUE ,B1,S4,9*64);
  INIXTP(LK,"F",LITE,EK,FALSE,B1,S4,0);
  INIXTP(OP,"1",OARX,EP,FALSE,B3,B4,-1*64);
  INIXTP(OR,"2",OARX,ER,IRUE ,S1,S4,-5*64);
  INIXTP(ON,"3",OARX,EN,FALSE,N1,N8,-3*64);
  INIXTP(OB,"4",OARX,EB,IRUE ,B1,B4,-3*64))
  INIXTP(OO,"5",OARX,EQ,TRUE ,B1,S4,-9*64);
  INIXTP(OX,"6",OARX,EX,FALSE,B1,S4,0);
  INIXTP(NT,"-",NONE,EP,FALSE,B2,B1,0);

  XIGNP[PO,LITE] := LO;  XTGMP[PO,OARK] := OO;  XTGC[PO] := "O";
  XTGNP[PR,LITE] := LR;  XTGNP[PR,OARK] := OR;  XTGC[PR] := "R";
  XIGNP[PN,LITE] := LN;  XTGNP[PN,OARX] := ON|  XTGC[PN] := "N";
  XTGMP[PB,LITE] := LB;  XTGMP[PB,OARX] := OB;  XTGC[PB] := "B";

  XTUC[EX] := "X";
  XTUC[EO] := "O";
  XTUC[ER] := "R";
  XTUC[EN] := "N";
  XTUC[EB] := "B";
  XTUC[EP] := "P";

  (** INIIIALIZE OTHER CONSTANTS *)

  XTBC[FALSE] := "-";
  XTBC[TRUE ] := "*";

  OTNER[LITE] := OARX;  XTNV[LITE] :=  1;
  OTHER[OARK] := LITE;  XINV[OARX] := -1;
  OTNER[NONE] := NONE;

  XTMA[LITE] := "    WHITE ";
  XTMA[OARX] := "    BLACX ";
  XTNA[NONE] := "   NO ONE "]

  XTQA[LS] := "WHITE KING";
  XTQA[LL] := "WHITE LONG"I
  XTQA[DS] := "BLACK XING")
  XTQA[DL] := "BLACK LONG";

  )** INITIALIZE 10X12 TO 8X8 AND 8X8 TO 10X12 TRANSLATION TABLES *)

  FOR INTL := AL TO ZL DO                  [* LOOP THROUGN LARGE BOARO *)
    XTLS[INTL] := -1]                      )* PRESET ARRAY TO OFF BOARD *]

  INTL := 21]                              (* INDEX OF FIRST SQUARE ON LARGE
                                              BOARO *]
  INTT := -1;                              (* INDEX QF FIRST SQUARE ON SMALL
                                              BQARD *)
  FOR INTR := R1 TO R8 00                  (* LOOP THROUGN RANKS *]
  BEGIN
    FOR INTF := F1 TO FX DO                [* LOOP THROUGH FILES *)
    BECIN
      INTT := INTT+1I                      ]* ADVANCE SMALL BOARD INOEX *]
      XTRFS[INIR,INTF( := INTTI            ]* SET MATRIX TQ VECTOR
                                              TRANSLATION *]
      XTLS[INTL] := INTTI                  (* SET LARGE BOARQ TRANSLATION
                                              TABLE WITN SMALL-BQARQ
                                              INQEX *)
      XTSL[INTT] := INTL;                  (* SET SMALL BQARD TRANSLATION
                                              TABLE WITN LARGE BOARQ
                                              INDEX *]
      XTSR[INTT] := INTR]                  ]* SET RANK OF SQUARE *]
      XTSF[INTT] := INTF)                  (* SET FILE OF SQUARE *]
      INTL := INTL+1;                      (* ADVANCE LARGE BOARD INOEX *)
    ENDI
    INTL := INTL+2I                        [* ADVANCE LARCE BOARD INDEX TO
                                              SKIP BORQER *]
  ENO;

  I** INITIALIZE 8X8 TO BIT BOARO TABLES *]

  INTT := -1;
  FOR INTY := AY TO ZY DO
  BEGIN
    FOR INTX := AX TO ZX 00
    BEGIN
      INTT := INTT+1;
      XTSX[INTT] := INTX;
      XTSY[INT]] := INTY;
      XSSX[INTT] := [INTX];
      NEWRS(XRSS[INTT])I
      XRSS[INT]].RSSS[INTY] := [INTX];
    END;
  ENO;

  )** INITIALIZE CONSTANI BIT BOAROS *)

  FOR INTR := R1 IO R8 00
    NEWRS(XRRS[INTR]);

  FOR INTF := F1 TO F8 00
    NENRS(XRFS[INTF]);

  FOR INTR := R1 TO R8 00
    FOR INTF := F1 TO F8 00
    BEGIN
      SETRS(XRRS[INTR],XTRFS[INTR,INTF]);
      SETRS(XRFS[INTF],XTRFS[INTR,INTF])(
    END)

  FOR INTF := F1 TO F8 00
    NOTRS(XNFS[INTF],XRFS[INTF])I

  FOR INTR := R1 TO R8 00
    NOTRS(XNRS[INTR],XRRS[INTR])I

  (** INITIALIZE EOGES *)

  CPYRS(EOGE[S1],XRFS[F1]))
  CPYRS(EOGE[S2],XRRS[R8]);
  CPYRS(EOGE[S3],XRFS[F8]))
  CPYRS(EOGE[S4],XRRS[R1])I
  IORRS(EOGE[B1],EOGE[S1],EOGE[S2]);
  IORRS(EOGE[B2],EOGE[S2],EOGE[S3]);
  IORRS(EOGE[B3],EOGE[S3],EOGE[S4]);
  IORRS(EOGE[B4],EOGE[S4],EOGE[S1]))
  IORRS(EOGE[N1],EOGE[B1],XRRS[R7])I
  IORRS(EOGE[N2],EOGE[B2],XRRS[R7])I
  IORRS(EDGE[NI],EDGE[B2],XRFS[F7]))
  IORRS(EOGE[N4],EOGE[B3],XRFS[F7])I
  IORRS(EOGE[N5],EDGE[B3],XRRS[R2])I
  IORRS(EOGE[N6],EOGE[B4],XRRS[R2]);
  IORRS(EOGE[N7],EOGE[B4],XRFS[F2]);
  IORRS(EOGE[N8],EOGE[B1],XRFS[F2]))

  I** INITIALIZE CORNER MASX *)

  IORRS(INAS,XRRS[R1],XRRS[R2]);
  IORRS(INRS,INRS,XRRS[R7]);
  IORRS(INRS,INRS,XRRS[R8]);
  IORRS(CORNR,XRFS[F1],XRFS[F2]);
  IORRS(CORNR,CORNR,XRFS[F7]);
  IORRS(CORNR,CORNR,XRFS[F8]);
  ANORS(CORNR,CORNR,INRS);

  (** INITIALIZE OIRECTION TABLE *)

                XTEO[N1]:= 19;                    XTEO[N2]:= 21;
  XTEO[N8]:=  8;XTEO[B1]:=  9;XIEO[S2]:= 10;XTED[B2]:= 11;XIEO[N3]:= 12;
                XIEO[S1]:= -1;                    XTEO[S3]:=  1;
  XTEO[N7]:=-12;XTEO[B4]:=-11;XTEO[S4]:=-10;XTED[B3]:= -9;XTEO[N4]:= -8;
                XTEO[N6]:=-21;                    XTEO[N5]:=-19;

  )** INITIALIZE SOUARE OIFFERENCE TO OIRECTION TABLE *)

  FOR INTI := AZL TO ZAL 00
    XLLO[INTI] := 0;
  FOR INTE := B1 TO S4 00
  BEGIN
    INTO := XTEO[INTE];
    FOR INTI := 1 TO 7 00
      XLLO[INTI*INTO] := INTO;
  ENO;
  FOR INTE := N1 TO N8 00
    XLLO[XTED[INTE]] := XTEO[INTE])

  )** INITIALIZE CASTLING TRANSLATION TABLES *)

  IORRS(XSQS[LS],XRSS[XTRFS[R1,F8]],XRSS[XTRFS[R1,F5]]))
  IORRS(XSQS[LL],XRSS[XTRFS[R1,F1]],XRSS[XTRFS[R1,F5]]))
  IORRS(XSQS[DS],XRSS[XTRFS[R8,F8]],XRSS[XTRFS[R8,F5]]);
  IORRS(XSQS[DL],XRSS[XTRFS[R8,F1]],XRSS[XTRFS[R8,F5]]);

  IORRS(XRQSQ[LS],XRSS[XTRFS[R1,FA]],XRSS[XTRFS[R1,F7]]);
  IORRS(XRQSO[LL],XRSS[XTRFS[R1,F4]],XRSS[XTRFS[R1,F3]]);
  IORRS(XRQSA[LS],XRSS[XTRFS[R1,F5]],XRQSQ[LS]);
  IORRS(XRQSA[LL],XRSS[XTRFS[R1,F5]],XRQSQ[LL]);
  IORRS(XRQSO[LL],XRSS[XTRFS[R1,F2]],XRQSD[LL]);

  IORRS(XRQSO[DS],XRSS[XTRFS[R8,F6]],XRSS[XTRFS[R8,F7]]);
  IORRS(XRQSO[DL],XRSS[XTRFS[R8,F4]],XRSS[XTRFS[R8,F3]]))
```

*Listing 1, continued:*

```
IORRS(XRQSA[DS],XRSS[XTRFS[R8,F5]],XRQSO[DS]);
IORRS(XRQSA[DL],XRSS[XTRFS[R8,F5]],XRQSO[DL]);
IORRS(XRQSQ[DL],XRSS[XTRFS[R8,F2]],XRQSO[DL]);

FOR INTQ := LS TO DL DO
  WITH XRQM[INTQ] DO
  BEGIN
    RMCP := MT;
    RMCA := FALSE;
    RMAC := TRUE;
    RMCH := FALSE;
    RMMT := FALSE;
    RMIL := FALSE;
    RMSU := FALSE;
    RMPR := FALSE;
    RMDO := TRUE;
  END;

XRQM[LS].RMFR := XTRFS[R1,F5]; XRQM[LS].RMTO := XTRFS[R1,F7];
XRQM[LL].RMFR := XTRFS[R1,F5]; XRQM[LL].RMTO := XTRFS[R1,F3];
XRQM[DS].RMFR := XTRFS[R8,F5]; XRQM[DS].RMTO := XTRFS[R8,F7];
XRQM[DL].RMFR := XTRFS[R8,F5]; XRQM[DL].RMTO := XTRFS[R8,F3];

XRQM[LS].RMQS := FALSE;
XRQM[LL].RMQS := TRUE;
XRQM[DS].RMQS := FALSE;
XRQM[DL].RMQS := TRUE;

XTMQ[LITE] := LS;
XTMQ[DARK] := DS;

XTQS[LS] := XTRFS[R1,F8];
XTQS[LL] := XTRFS[R1,F1];
XTQS[DS] := XTRFS[R8,F8];
XTQS[DL] := XTRFS[R8,F1];

(** INITIALIZE NULL MOVE *)

WITH NULMV DO
BEGIN
  RMFR := AS;
  RMTO := AS;
  RMCP := MT;
  RMCA := FALSE;
  RMAC := TRUE;
  RMCH := FALSE;
  RMMT := FALSE;
  RMIL := FALSE;
  RMSU := FALSE;
  RMPR := TRUE;
  RMPP := PB;
END;

(** INITIALIZE COMMAND PROCESSING VARIABLES *)

JNTJ := ZJ;
ICARD[ZJ] := ";";
ILINE[ZJ] := ";";

(** INITIALIZE MOVES SYNTAX TABLE *)

INTI := SYMCF;
INISYM("    *P     ");
INISYM("    *P/  1");
INISYM("/  1*P     ");
INISYM("    *P/ R ");
INISYM("/ R *P     ");
INISYM("    *P/ R1");
INISYM("/ R1*P     ");
INISYM("    *P/KR ");
INISYM("/KR *P     ");
INISYM("    *P/KR1");
INISYM("/KR1*P     ");
INISYM("/  1*P/  1");
INISYM("/ R *P/ R ");
INISYM("/  1*P/ R ");
INISYM("/ R *P/  1");
INISYM("/ R1*P/  1");
INISYM("/  1*P/ R1");
INISYM("/ R1*P/ R ");
INISYM("/ R *P/ R1");
INISYM("/KR *P/  1");
INISYM("/  1*P/KR ");
INISYM("/KR *P/ R ");
INISYM("/ R *P/KR ");
INISYM("/  1*P/KR1");
INISYM("/KR1*P/  1");
INISYM("  R *P/KR1");
INISYM("/KR1*P/ R ");
INISYM("/ R1*P/ R1");
INISYM("/KR *P/ R1");
INISYM("/ R1*P/KR ");
INISYM("/KR *P/KR ");
INISYM("/KR1*P/ R1");
INISYM("/ R1*P/KR1");
INISYM("/KR1*P/KR ");
INISYM("/KR *P/KR1");
INISYM("/KR1*P/KR1");

INISYM("     -   R1");
INISYM("     -  KR1");
INISYM("/  1-   R1");
INISYM("/ R -   R1");
INISYM("/  1-  KR1");
INISYM("/ R -  KR1");
INISYM("/ R1-   R1");
INISYM("/KR -   R1");
INISYM("/ R1-  KR1");
INISYM("/KR -  KR1");
INISYM("/KR1-  KR1");

(** INITIALIZE LETS *)

FKPSMO := 10;
FKSANQ := 150;
  FMAXMT := 256;
  FMODEL := 10;
  FPADCR[F1] := 0;
  FPADCR[F2] := 0;
  FPADCR[F3] := 5;
  FPADCR[F4] := 10;
  FPADCR[F5] := 15;
  FPADCR[F6] := 5;
  FPADCR[F7] := 0;
  FPADCR[F8] := 0;
  FPBLOK := 20;
  FPCONN := 5;
  FPFLNX := 12;
  FRDUBL := 60;
  FRK7TH := 120;
  FTRADE := 30;
  FTRDSL := 5156;
  FTRPOK := 2;
  FTRPWN := 8;
  FWKING := 50;
  FWMAJM := 1;
  FWMINM := 200;
  FWPAWN := 100;
  FWROOK := 2;
  WINDOW := 30;

  (** INITIALIZE SWITCHES *)

  SWEC := TRUE;
  SWPA := TRUE;
  SWPS := FALSE;
  SWRE := TRUE;
  SWSU := FALSE;
  SWTR := FALSE;

  (** INITIALIZE MAIN LOOP CONTROL VARIABLES *)

  GOING := 0;

END;  (* INICON *)


PROCEDURE INITAL(VAR A:RB);                (* INITIALIZE FOR A NEW GAME *)

VAR
  INTF : TF;                               (* FILE INDEX *)
  INTR : TR;                               (* RANK INDEX *)

BEGIN
  WITH A DO
  BEGIN
    RBTM := LITE;                          (* SIDE TO MOVE *)
    RBTS := -1;                            (* NO ENPASSANT SQUARE *)
    RBTI := 0;                             (* GAME HAS NOT STARTED *)
    RBSQ := [LS,LL,DS,DL];                 (* ALL CASTLING MOVES LEGAL *)
    FOR INTF := F1 TO F8 DO                (* LOOP THROUGH ALL FILES *)
    BEGIN
      RBIRF[R2,INTF] := LP;                (* SET LIGHT PAWNS ON BOARD *)
      FOR INTR := R3 TO R6 DO              (* LOOP THRU MIDDLE OF BOARD *)
        RBIRF[INTR,INTF] := MT;            (* SET MIDDLE OF BOARD EMPTY *)
      RBIRF[R7,INTF] := DP;                (* SET DARK PAWNS ON BOARD *)
    END;
    RBIRF[R1,F1] := LR;                    (* SET REMAINDER OF PIECES ON
                                              BOARD *)
    RBIRF[R1,F2] := LN;
    RBIRF[R1,F3] := LB;
    RBIRF[R1,F4] := LQ;
    RBIRF[R1,F5] := LK;
    RBIRF[R1,F6] := LB;
    RBIRF[R1,F7] := LN;
    RBIRF[R1,F8] := LR;
    RBIRF[R8,F1] := DR;
    RBIRF[R8,F2] := DN;
    RBIRF[R8,F3] := DB;
    RBIRF[R8,F4] := DQ;
    RBIRF[R8,F5] := DK;
    RBIRF[R8,F6] := DB;
    RBIRF[R8,F7] := DN;
    RBIRF[R8,F8] := DR;

    MOVMS := " ENTER MOVE OR TYPE GO.         ";
    WRITELN(MOVMS);
    LSTMV := NULMV;                        (* INITIALIZE PREVIOUS MOVE *)
  END;
END;  (* INITAL *)


PROCEDURE PAUSER;                          (* PAUSE FOR CARRIAGE RETURN *)

BEGIN
  IF SWPA THEN
  BEGIN
    WRITELN(" PAUSING ");
    READLN;
  END;
END;  (* PAUSER *)


PROCEDURE PRIMOV(A:RM);                    (* PRINT A MOVE *)

BEGIN
  WITH A DO
  BEGIN
    WRITE(" FROM ",RMFR:2," TO ",RMTO:2);
    IF NULMVB(A) THEN
      WRITE(", NULL MOVE")
    ELSE
    BEGIN
      IF RMCA THEN
        WRITE(", CAPTURE ",XTPC[RMCP],",")
      ELSE
        WRITE(", SIMPLE,");
      IF NOT RMAC THEN
        WRITE(" NO");
      WRITE(" ACS");
      IF RMCH THEN
```

*Listing 1, continued:*

```
        WRITE(', CHECK');
      IF RNMT THEN
        WRITE(', MATE');
      IF RNIL THEN
        WRITE(', ILLEGAL');
      IF RNSU THEN
        WRITE(', SEARCHED');
      CASE RNPR OF
      FALSE:  (* NOT PROMOTION *)
        CASE RNOO OF
        FALSE:  (* NOT CASTLE *)
          IF RNEP THEN
            WRITE(', ENPASSANT');
        TRUE:  (* CASTLE *)
          BEGIN
            WRITE(', CASTLE ');
            IF RNQS THEN
              WRITE('LONG')
            ELSE
              WRITE('SHORT');
          END;
        END;
       TRUE:   (* PROMOTION *)
        BEGIN
          WRITE(', PROMOTE TO ');
          CASE RNPP OF
          PQ:  WRITE('QUEEN');
          PR:  WRITE('ROOK');
          PB:  WRITE('BISHOP');
          PN:  WRITE('KNIGHT');
          END;
        END;
      END;
    END;
  END;
  WRITELN('.');
END;  (* PRINOV *)


PROCEDURE PRINTB(A:RC);                     (* PRINT A BOARD *)

VAR
  INTR : TR;                                (* RANK INDEX *)
  INTF : TF;                                (* FILE INDEX *)

BEGIN
  WRITELN;                                  (* WRITE A BLANK LINE *)
  FOR INTR := R8 DOWNTO R1 DO               (* LOOP DOWN THROUGH RANKS *)
  BEGIN
    WRITE (' ',ORD(INTR)+1:1,' ');          (* OUTPUT RANK LABEL *)
    FOR INTF := F1 TO F8 DO                 (* LOOP ACROSS THROUGH FILES *)
      WRITE (XTPC[A[XTRFS[INTR,INTF]]]);
                                            (* OUTPUT CONTENTS OF SQUARE *)
    WRITELN;                                (* WRITE OUT A RANK *)
  END;
  WRITELN ('  W RNBQKBNR');                 (* WRITE OUT BOTTOM LABEL *)
END;  (* PRINTB *)


PROCEDURE PRINBB(A:FS);                     (* PRINT A BIT BOARD *)

VAR
  INTR : TR;                                (* RANK INDEX *)
  INTF : TF;                                (* FILE INDEX *)

BEGIN
  WRITELN;                                  (* WRITE OUT A BLANK LINE *)
  FOR INTR := R8 DOWNTO R1 DO               (* LOOP DOWN THROUGH RANKS *)
  BEGIN
    WRITE (' ',ORD(INTR)+1:1,' ');          (* OUTPUT RANK LABEL *)
    FOR INTF := F1 TO F8 DO                 (* LOOP ACROSS THROUGH FILES *)
      WRITE (XTBC[INRSTB(A,XTRFS[INTR,INTF])]);
                                            (* OUTPUT CONTENTS OF SQUARE *)
    WRITELN;                                (* WRITE OUT A RANK *)
  END;
  WRITELN ('  W RNBQKBNR');                 (* WRITE OUT BOTTOM LABEL *)
END;  (* PRINBB *)


PROCEDURE PRINAM(A:FX);                     (* PRINT ATTACK MAP *)

VAR
  INTR, JNTR : TR;                          (* RANK INDICES *)
  INTF, JNTF : TF;                          (* FILE INDICES *)

BEGIN
  WRITELN;
  FOR INTR := R8 DOWNTO R1 DO
  BEGIN
    FOR JNTR := R8 DOWNTO R1 DO
    BEGIN
      FOR INTF := F1 TO F8 DO
      BEGIN
        WRITE(' ');
        FOR JNTF := F1 TO F8 DO
        BEGIN
          WRITE(XTBC[INRSTB(A[XTRFS[INTR,INTF]],XTRFS[JNTR,JNTF])]);
        END;
        WRITE(' ');
      END;
      WRITELN;
    END;
    WRITELN;
    IF INTR IN [R1,R3,R5,R7] THEN PAUSER;
  END;
END;  (* PRINAM *)


PROCEDURE PRISWI(A:FA;B:TB);                (* PRINT A SWITCH *)

BEGIN
  WRITE(' ',A[AA],A[AA+1]);
  IF B THEN
    WRITELN(' ON')
  ELSE
    WRITELN(' OFF');
END;  (* PRISWI *)

PROCEDURE MBEVAL;                          (* EVALUATE MATERIAL BALANCE *)

VAR
  INTI : TI;                               (* COUNT PAWNS OF WINNING SIDE *)

BEGIN
  IF MBLTE <> 0 THEN
    IF MBLTE > 0 THEN
      INTI := MBPWN[LITE]
    ELSE
      INTI := MBPWN[DARK]
  ELSE
    INTI := 0;

  MBVAL[JNTK] := SIGN(MIN(MIN(FMAXMT,ABS(MBLTE))
      +FTRADE*ABS(MBLTE)*(FTRDSL-MBTOT)*(4*INTI+FTRPOK)
      DIV (4*INTI+FTRPWN) DIV 262144,16320),MBLTE);

END;  (* MBEVAL *)


PROCEDURE MBCAPT                           (* EVALUATE MATERIAL AFTER
                                              CAPTURE *)
  (A:TP);                                  (* PIECE CAPTURED *)

BEGIN
  MBTOT := MBTOT - ABS(XTPV[A]);           (* TOTAL MATERIAL ON BOARD *)
  IF XTPU[A] = EP THEN
    MBPWN[XTPM[A]] := MBPWN[XTPM[A]] - 1;
                                           (* REMOVE PAWN IF NECESSARY *)
  MBLTE := MBLTE - XTPV[A];                (* LITE ADVANTAGE *)
  MBEVAL;                                  (* EVALUATE MATERIAL *)
END;  (* MBCAPT *)


PROCEDURE MBTPAC                           (* REMOVE CAPTURE FROM
                                              MATERIAL BALANCE DATA.  THIS
                                              IS THE INVERSE OF MBCAPT *)
  (A:TP);                                  (* PIECE UNCAPTURED *)

BEGIN
  MBTOT := MBTOT + ABS(XTPV[A]);
  IF XTPU[A] = EP THEN
    MBPWN[XTPM[A]] := MBPWN[XTPM[A]] + 1;
  MBLTE := MBLTE + XTPV[A];
END;  (* MBTPAC *)


PROCEDURE MBPROM                           (* EVALUATE MATERIAL BALANCE
                                              CHANGE DUE TO PAWN
                                              PROMOTION *)
  (A:TP);                                  (* PIECE TO PROMOTE TO *)

BEGIN
  MBTOT := MBTOT + ABS(XTPV[A]-XTPV[XTUMP[EP,XTPM[A]]]);
                                           (* TOTAL MATERIAL ON BOARD *)
  MBPWN[XTPM[A]] := MBPWN[XTPM[A]] - 1;(* COUNT PAWNS *)
  MBLTE := MBLTE + XTPV[A]-XTPV[XTUMP[EP,XTPM[A]]];
  MBEVAL;                                  (* EVALUATE RESULT *)
END;  (* MBPROM *)


PROCEDURE MBMORP                           (* REMOVE PAWN PROMOTION
                                              FROM MATERIAL BALANCE DATA.
                                              THIS IS THE INVERSE
                                              OF MBPROM *)
  (A:TP);                                  (* PIECE PROMOTED TO *)

BEGIN
  MBTOT := MBTOT - ABS(XTPV[A]-XTPV[XTUMP[EP,XTPM[A]]]);
  MBPWN[XTPM[A]] := MBPWN[XTPM[A]] + 1;
  MBLTE := MBLTE - (XTPV[A]-XTPV[XTUMP[EP,XTPM[A]]]);
END;  (* MBMORP *)


PROCEDURE ADDATK                           (* ADD ATTACKS OF PIECE TO DATA
                                              BASE *)
  (A:TS);                                  (* SQUARE OF PIECE TO ADD
                                              ATTACK *)

VAR
  INTB : TB;                               (* LOOP CONTROL BOOLEAN *)
  INTD : TD;                               (* CURRENT DIRECTION OFFSET *)
  INTE : TE;                               (* CURRENT DIRECTION INDEX *)
  INTM : TM;                               (* COLOR OF CURRENT PIECE *)
  INTP : TP;                               (* CURRENT PIECE *)
  INTT : TT;                               (* RUNNING SQUARE *)

BEGIN
  INTP := MBORD[A];                        (* PIECE OF INTEREST *)
  INTM := XTPM[INTP];                      (* COLOR *)
  FOR INTE := XFPE[INTP] TO XLPE[INTP] DO
  BEGIN
    INTT := A;                             (* INITIALIZE RUNNING SQUARE *)
    INTB := XSPB[INTP];                    (* TRUE IF SWEEP PIECE *)
    INTD := XTED[INTE];                    (* OFFSET *)
    REPEAT
      INTT := XTLS[XTSL[INTT] + INTD]; (* STEP IN PROPER DIRECTION *)
      IF INTT >= 0 THEN
      BEGIN
        SETRS(ATKFR[A],INTT);
        SETRS(ATKTO[INTT],A);
        SETRS(ALATK[INTM],INTT);
        IF MBORD[INTT] <> MT THEN
          INTB := FALSE;
```

*Listing 1, continued:*

```
      END
      ELSE
        INTB := FALSE;
    UNTIL NOT INTB;
  END;
END;  (* ADDATK *)


PROCEDURE ADDLOC                        (* ADD PIECE TO DATA BASE *)
  (A:TS;                                (* SQUARE WITH NEW PIECE ON IT *)
   B:TP);                               (* NEW PIECE TO ADD *)


BEGIN
  CLRRS(TPLOC[MT],A);                   (* BIT BOARD OF EMPTY SQUARES *)
  SETRS(TPLOC[B],A);                    (* BIT BOARD OF ALL SAME PIECE *)
  SETRS(TMLOC[XTPM[B]],A);              (* BIT BOARD OF ALL SAME COLOR *)
  SETRS(ALLOC[JNTK],A);                 (* BIT BOARD OF ALL PIECES *)
  NBORD[A] := B;                        (* SET NEW PIECE ON BOARD *)
END;  (* ADDLOC *)


PROCEDURE CLSTAT;                       (* CLEAR POSITION STATUS *)

BEGIN
  WITH BOARD DO
  BEGIN
    RBTM := LITE;                       (* WHITE TO MOVE *)
    RBTS := -1;                         (* NO ENPASSANT *)
    RBSQ := [];                         (* NO CASTLING LEGAL *)
  END;
END;  (* CLSTAT *)


PROCEDURE CUTATK                        (* CUT ATTACKS THROUGH SQUARE *)
  (A:TS);                               (* SQUARE *)

VAR
  INRS : RS;                            (* ATTACKING PIECES *)
  INTS : TS;                            (* ATTACKING PIECE SQUARE *)
  INRS : RS;                            (* SCRATCH *)
  INTD : TD;                            (* STEP SIZE *)
  INTM : TM;                            (* ATTACKING PIECE SIDE *)
  INTL : TL;                            (* NO LONGER ATTACKED SQUARE *)
  INTT : TT;                            (* NO LONGER ATTACKED SQUARE *)

BEGIN
  CPYRS(INRS,ATKTO[A]);                 (* ALL PIECES ATTACKING SQUARE *)
  WHILE NXTTS(INRS,INTS) DO
    IF XSPB[NBORD[INTS]] THEN           (* IF SWEEP PIECE *)
    BEGIN
      INTD := XLLD[XTSL[A]-XTSL[INTS]];
                                        (* STEP SIZE ON 10 X 12 BOARD *)
      INTM := XTPM[NBORD[INTS]];        (* SIDE OF ATTACKING PIECE *)
      INTL := XTSL[A]+INTD;             (* FIRST SQUARE BEYOND PIECE *)
      INTT := XTLS[INTL];               (* FIRST SQUARE BEYOND PIECE ON
                                           8X8 BOARD *)
      WHILE INTT > AT DO                (* WHILE ON BOARD *)
      BEGIN
        CLRRS(ATKFR[INTS],INTT);        (* CLEAR ATTACK MAP *)
        CLRRS(ATKTO[INTT],INTS);
        ANDRS(INRS,ATKTO[INTT],TMLOC[INTM]);
                                        (* OTHER ATTACKS ON SQUARE BY
                                           SAME SIDE *)
        IF NULRS(INRS) THEN             (* IF NO ATTACKS BY THAT SIDE *)
          CLRRS(ALATK[INTM],INTT);      (* CLEAR ATTACKS BY SIDE *)
        IF NBORD[INTT] = MT THEN
        BEGIN
          INTL := INTL+INTD;            (* STEP BEYOND SQUARE *)
          INTT := XTLS[INTL];
        END
        ELSE
          INTT := AT;                   (* STOP SCAN *)
      END;
    END;
END;  (* CUTATK *)


PROCEDURE DELATK                        (* DELETE ATTACKS FROM SQUARE *)
  (A:TS);                               (* SQUARE TO REMOVE PIECE *)

VAR
  INRS : RS;                            (* SQUARES ATTACKED BY PIECE ON
                                           SQUARE *)
  INRS : RS;                            (* SCRATCH *)
  INTS : TS;                            (* SQUARE ATTACKED BY PIECE ON
                                           SQUARE *)
  INTM : TM;                            (* SIDE OF PIECE ON SQUARE *)
BEGIN
  CPYRS(INRS,ATKFR[A]);                 (* SQUARES ATTACKED BY PIECE
                                           ON SQUARE *)
  NEWRS(ATKFR[A]);                      (* CLEAR ATTACKS FROM SQUARE *)
  INTM := XTPM[NBORD[A]];               (* SIDE OF PIECE ON SQUARE *)
  WHILE NXTTS(INRS,INTS) DO             (* LOOP THROUGH ALL ATTACKS BY
                                           PIECE *)
  BEGIN
    CLRRS(ATKTO[INTS],A);               (* CLEAR ATTACK TO OTHER
                                           SQUARE *)
    ANDRS(INRS,ATKTO[INTS],TMLOC[INTM]);
                                        (* OTHER ATTACKS BY SAME SIDE *)
    IF NULRS(INRS) THEN
      CLRRS(ALATK[INTM],INTS);          (* CLEAR ATTACKS BY SIDE *)
  CLRRS(TPLOC[NBORD[A]],A);             (* CLEAR PIECE *)
  CLRRS(TMLOC[INTM],A);                 (* CLEAR PIECE FROM SIDE *)
  CLRRS(ALLOC[JNTK],A);                 (* CLEAR PIECE FROM ALL PIECES *)
  SETRS(TPLOC[MT],A);                   (* SET EMPTY *)
  NBORD[A] := MT;
  END;
END;  (* DELATK *)


PROCEDURE PRPATK                        (* PROPAGATE ATTACKS THROUGH
                                           SQUARE *)
  (A:TS);                               (* SQUARE *)

VAR
  INRS : RS;                            (* ATTACKING PIECES *)
  INTS : TS;                            (* ATTACKING PIECE SQUARE *)
  INTD : TD;                            (* STEP SIZE *)
  INTM : TM;                            (* ATTACKING PIECE SIDE *)
  INTL : TL;                            (* NEW ATTACKED SQUARE *)
  INTT : TT;                            (* NEW ATTACKED SQUARE *)

BEGIN
  CPYRS(INRS,ATKTO[A]);                 (* ALL PIECES ATTACKING SQUARE *)
  WHILE NXTTS(INRS,INTS) DO
    IF XSPB[NBORD[INTS]] THEN           (* IF SWEEP PIECE *)
    BEGIN
      INTD := XLLD[XTSL[A]-XTSL[INTS]];
                                        (* STEP SIZE ON 10 X 12 BOARD *)
      INTM := XTPM[NBORD[INTS]];        (* SIDE OF ATTACKING PIECE *)
      INTL := XTSL[A]+INTD;             (* FIRST SQUARE BEYOND PIECE *)
      INTT := XTLS[INTL];               (* FIRST SQUARE BEYOND PIECE ON
                                           8X8 BOARD *)
      WHILE INTT >= 0 DO                (* WHILE ON BOARD *)
      BEGIN
        SETRS(ATKFR[INTS],INTT);        (* SET ATTACK MAP *)
        SETRS(ATKTO[INTT],INTS);
        SETRS(ALATK[INTM],INTT);        (* SET ATTACKS BY SIDE *)
        IF NBORD[INTT] = MT THEN
        BEGIN
          INTL := INTL+INTD;            (* STEP BEYOND SQUARE *)
          INTT := XTLS[INTL];
        END
        ELSE
          INTT := -1;                   (* STOP SCAN *)
      END;
    END;
END;  (* PRPATK *)


PROCEDURE GAINIT                        (* UNPROCESS CAPTURE MOVE *)
  (A:RM);                               (* CAPTURE MOVE *)

BEGIN
  WITH A DO
  BEGIN
    ADDLOC(RMFR,NBORD[RMTO]);           (* PUT PIECE ON ORIGINAL
                                           SQUARE *)
    ADDATK(RMFR);
    CUTATK(RMFR);                       (* STOP ATTACKS AT THIS SQUARE *)
    DELATK(RMTO);                       (* REMOVE THEM FROM
                                           DESTINATION SQUARE *)
    ADDLOC(RMTO,RMCP);                  (* REPLACE CAPTURED PIECE *)
    ADDATK(RMTO);
    NBTPAC(NBORD[RMTO]);                (* UPDATE SCORE *)
  END;
END;  (* GAINIT *)


PROCEDURE LOSEIT                        (* PROCESS CAPTURE MOVE *)
  (A:RM);                               (* CAPTURE MOVE *)

BEGIN
  WITH A DO
  BEGIN
    NBCAPT(NBORD[RMTO]);                (* UPDATE SCORE *)
    DELATK(RMTO);                       (* DELETE ATTACKS OF CAPTURED
                                           PIECE *)
    ADDLOC(RMTO,NBORD[RMFR]);           (* ADD PIECE TO DESTINATION
                                           SQUARE *)
    DELATK(RMFR);                       (* DELETE ATTACKS OF MOVING
                                           PIECE *)
    PRPATK(RMFR);                       (* PROPAGATE ATTACKS THROUGH
                                           FROM SQUARE *)
    ADDATK(RMTO);                       (* ADD ATTACKS OF MOVING PIECE *)
  END;
END;  (* LOSEIT *)


PROCEDURE MOVEIT                        (* PROCESS ORDINARY MOVE *)
  (A:RM);                               (* ORDINARY MOVE *)

BEGIN
  WITH A DO
  BEGIN
    ADDLOC(RMTO,NBORD[RMFR]);           (* ADD PIECE TO NEW SQUARE *)
    CUTATK(RMTO);                       (* CUT ATTACKS THROUGH NEW
                                           SQUARE *)
    DELATK(RMFR);                       (* DELETE ATTACKS FROM OLD
                                           SQUARE *)
    PRPATK(RMFR);                       (* PROPAGATE ATTACKS THROUGH OLD
                                           SQUARE *)
    ADDATK(RMTO);                       (* ADD ATTACKS FROM NEW SQUARE *)
  END;
END;  (* MOVEIT *)


PROCEDURE RTRKIT                        (* UNPROCESS ORDINARY MOVE *)
  (A:RM);                               (* THE MOVE TO RETRACT *)

BEGIN
  WITH A DO
  BEGIN
    ADDLOC(RMFR,NBORD[RMTO]);           (* PUT PIECE ON ORIGINAL
                                           SQUARE *)
    CUTATK(RMFR);                       (* CUT ATTACKS THROUGH ORIGINAL
                                           SQUARE *)
    DELATK(RMTO);                       (* DELETE ATTACKS FROM
                                           DESTINATION SQUARE *)
    PRPATK(RMTO);                       (* PROPAGATE ATTACKS THROUGH
                                           DESTINATION SQUARE *)
    ADDATK(RMFR);                       (* ADD ATTACKS FROM ORIGINAL
                                           SQUARE *)
  END;
END;  (* RTRKIT *)
```

*Listing 1, continued:*

```
PROCEDURE PAWNIT                           (* UNPROMOTE A PAWN *)
  (A:RM);                                  (* PROMOTION MOVE *)

BEGIN
  WITH A DO
  BEGIN
    MBMORP(MBORD(RMTO));                   (* UPDATE SCORE *)
    MBORD(RMTO) := XTUMP(EP,XTPM(MBORD(RMTO)));
  END;
END;  (* PAWNIT *)


PROCEDURE PROACA                           (* PROCESS CASTLE STATUS
                                              CHANGES *)
  (A:TS);                                  (* SQUARE *)

VAR
  INRS : RS;                               (* SCRATCH *)
  INRS : RS;                               (* SCRATCH *)

BEGIN
  CLRRS(CSTAT(JNTK),A);                    (* CLEAR THIS SQUARE *)
  ANDRS(INRS,CSTAT(JNTK),KRRS(XTSR(A)));
                                           (* CASTLE BITS FOR THIS SIDE *)
  IF NOT INRSTB(INRS,XTRFS(XTSR(A),F5)) THEN
                                           (* IF KING MOVE *)
    ANDRS(CSTAT(JNTK),CSTAT(JNTK),XNRS(XTSR(A)));
                                           (* CLEAR ALL CASTLE MOVES FOR
                                              SIDE *)
  ANDRS(INRS,INRS,XRFS(F8));               (* KING ROOK SQUARE *)
  ANDRS(INRS,INRS,KRFS(F1));               (* QUEEN ROOK SQUARE *)
  IORRS(INRS,INRS,INRS);                   (* BOTH ROOK SQUARES *)
  IF NULRS(INRS) THEN                      (* IF BOTH ROOKS GONE *)
    ANDRS(CSTAT(JNTK),CSTAT(JNTK),XNRS(XTSR(A)));
END;  (* PROACA *)


PROCEDURE PROACS                           (* PROCESS MOVES AFFECTING CASTLE
                                              STATUS *)
  (A:RM);                                  (* MOVE WITH RMAC *)

BEGIN
  WITH A DO
  BEGIN
    IF INRSTB(CSTAT(JNTK),RMFR) THEN       (* FROM SQUARE *)
      PROACA(RMFR);
    IF INRSTB(CSTAT(JNTK),RMTO) THEN       (* TO SQUARE *)
      PROACA(RMTO);
  END;
END;  (* PROACS *)


PROCEDURE PROMOT                           (* PROCESS PROMOTION *)
  (A:RM);                                  (* PROMOTION MOVE *)

BEGIN
  WITH A DO
  BEGIN
    MBPROM(XTGMP(RMPP,JNTM));              (* UPDATE SCORE *)
    MBORD(RMFR) := XTGMP(RMPP,JNTM);
  END;
END;  (* PROMOT *)


PROCEDURE CREATE;                          (* CREATE GLOBAL DATA BASE *)

VAR
  INRS : RS;                               (* SCRATCH BIT BOARD *)
  INTM : TM;                               (* COLOR INDEX *)
  INTP : TP;                               (* PIECE INDEX *)
  INTQ : TQ;                               (* CASTLE TYPE INDEX *)
  INTS : TS;                               (* SQUARE INDEX *)

BEGIN
  WITH BOARD DO
  BEGIN

    JNTW := AW+1;                          (* INITIALIZE MOVES STACK
                                              POINTER *)
    JNTK := AK;                            (* PLY INDEX *)
    JNTM := RBTM;                          (* SIDE TO MOVE *)

    NODES := 0;                            (* INITIALIZE TOTAL NODES *)

    LINDX(JNTK) := JNTW;                   (* MOVES ARRAY LIMIT *)
    SRCHM(JNTK) := M0;                     (* SEARCH MODE *)

    FOR INTS := AS TO ZS DO
    BEGIN
      NEWRS(ATKFR(INTS));                  (* CLEAR ATTACKS FROM *)
      NEWRS(ATKTO(INTS));                  (* CLEAR ATTACKS TO *)
      MBORD(INTS) := MT;                   (* CLEAR LOOKAHEAD BOARD *)
    END;

    NEWRS(ALLOC(JNTK));                    (* CLEAR ALL PIECE LOCATIONS *)

    FOR INTP := LP TO MT DO
      NEWRS(TPLOC(INTP));                  (* CLEAR PIECE LOCATIONS *)

    FOR INTM := LITE TO NONE DO
    BEGIN
      NEWRS(TMLOC(INTM));                  (* CLEAR COLOR LOCATIONS *)
      NEWRS(ALATK(INTM));                  (* CLEAR COLOR ATTACKS *)
    END;

    MBTOT := 0;
    MBPWN(LITE) := 0;
    MBPWN(DARK) := 0;
    MBLTE := 0;

    FOR INTS := AS TO ZS DO
      IF RBIS(INTS) <> MT THEN
      BEGIN
        ADDLOC(INTS,RBIS(INTS));
        MBTPAC(RBIS(INTS));
      END
      ELSE
        SETRS(TPLOC(MT),INTS);

    MBEVAL;                                (* EVALUATE MATERIAL *)

    CPYRS(INRS,ALLOC(JNTK));               (* COPY BIT BOARD OF ALL
                                              PIECES *)
    WHILE NXTTS(INRS,INTS) DO
      ADDATK(INTS);                        (* ADD ATTACKS OF ALL PIECES *)

    NEWRS(CSTAT(JNTK));                    (* INITIALIZE CASTLING SQUARES *)
    FOR INTQ := LS TO DL DO
      IF INTQ IN RBSQ THEN
        IORRS(CSTAT(JNTK),CSTAT(JNTK),XSQS(INTQ));

    NEWRS(ENPAS(JNTK));                    (* INITIALIZE ENPASSANT SQUARE *)
    IF RBTS >= 0 THEN
      SETRS(ENPAS(JNTK),RBTS);

    CPYRS(GENPN(JNTK),TPLOC(XTUMP(EP,JNTM)));
    NOTRS(GENTO(JNTK),TMLOC(JNTM));
    NOTRS(INRS,GENPN(JNTK));
    ANDRS(GENFR(JNTK),TMLOC(JNTM),INRS);
  END;
END;  (* CREATE *)

PROCEDURE DNDATE                           (* DOWNDATE DATA BASE TO BACK
                                              OUT A MOVE *)
  (A:RM);                                  (* THE MOVE TO RETRACT *)

VAR
  INTS : TS;                               (* SCRATCH *)
  INTR : TR;                               (* ROOK RANK FOR CASTLING *)
  INTF : TF;                               (* ROOK FILE FOR CASTLING *)

  RKFR : TS;                               (* ROOK FROM SQUARE *)
  RKTO : TS;                               (* ROOK TO SQUARE *)

BEGIN
  WITH A DO
  BEGIN
    CASE ORD(RMCA)*4 + ORD(RMAC)*2 + ORD(RMPR) OF
      0:  (* ORDINARY MOVE *)
        RTRKIT(A);
      1:  (* PAWN MOVE AND PROMOTE *)
        BEGIN
          PAWNIT(A);
          RTRKIT(A);
        END;
      2:  (* MISCELLANEOUS ACS *)
        IF RMOO THEN
        BEGIN  (* CASTLE *)
          IF RMQS THEN
            INTF := F1                     (* ROOK ON QUEEN ROOK FILE *)
          ELSE
            INTF := F8;                    (* ROOK ON KING ROOK FILE *)
          INTR := XTSR(RMFR);              (* ROOK FILE *)
          RKFR := XTRFS(INTR,INTF);        (* ROOK FROM SQUARE *)
          RKTO := (RMFR+RMTO) DIV 2;       (* ROOK TO SQUARE *)
          ADDLOC(RKFR,MBORD(RKTO));        (* REPLACE ROOK *)
          DELATK(RKTO);
          PRPATK(RKTO);
          ADDATK(RKFR);
          RTRKIT(A);                       (* RETRACT KING MOVE *)
        END
        ELSE  (* NOT CASTLE *)
          RTRKIT(A);
      3:  (* NULL MOVE *)
      4:  (* CAPTURE *)
        IF RMEP THEN
        BEGIN  (* CAPTURE ENPASSANT *)
          INTS := XTRFS(XTSR(RMFR),XTSF(RMTO));
          ADDLOC(INTS,RMCP);
          CUTATK(INTS);
          ADDATK(INTS);
          RTRKIT(A);                       (* RETRACT PAWN MOVE *)
          MBTPAC(MBORD(INTS));             (* ADD PIECE TO SCORE *)
        END
        ELSE  (* CAPTURE NOT ENPASSANT *)
          GAINIT(A);
      5:  (* CAPTURE AND PROMOTE *)
        BEGIN
          PAWNIT(A);                       (* UNPROMOTE *)
          GAINIT(A);                       (* UNCAPTURE *)
        END;
      6:  (* CAPTURE ACS *)
        GAINIT(A);                         (* UNCAPTURE *)
      7:  (* CAPTURE ROOK ACS, PROMOTE *)
        BEGIN
          PAWNIT(A);
          GAINIT(A);
        END;
    END;
    JNTW := LINDX(JNTK);                   (* RESET MOVE GENERATION
                                              POINTER *)
    JNTK := JNTK-1;                        (* BACK UP PLY INDEX *)
    JNTM := OTHER(JNTM);                   (* SWITCH SIDE TO MOVE *)
  END;
END;  (* DNDATE *)


FUNCTION UPDATE                            (* UPDATE DATA BASE FOR A MOVE *)
  (VAR A:RM)                               (* THE MOVE *)
  :TB;                                     (* RETURNS TRUE IF MOVE IS
                                              LEGAL *)

VAR
  INRS : RS;                               (* SCRATCH *)
  INRS : RS;                               (* SCRATCH *)
  INTS : TS;                               (* SCRATCH *)
  INTF : TF;                               (* ROOK FILE FOR CASTLING *)
```

*Listing 1, continued:*

```
  INTR : TR;                          (* ROOK RANK FOR CASTLING *)
  RXTO : TS;                          (* ROOK DESTINATION SQUARE *)
  RXFR : TS;                          (* ROOK ORIGIN SQUARE *)

BEGIN
  WITH A DO
  BEGIN
    JNTK := JNTK+1;                   (* ADVANCE PLY INDEX *)
    NEWRS(ENPAS(JNTK));               (* CLEAR ENPASSANT BIT BOARD *)
    CPYRS(CSTAT(JNTK),CSTAT(JNTK-1)); (* INITIALIZE CASTLE STATUS *)
    CPYRS(ALLOC(JNTK),ALLOC(JNTK-1)); (* INITIALIZE ALL LOCATIONS *)
    MBVAL(JNTK) := MBVAL(JNTK-1);     (* INITIALIZE MATERIAL SCORE *)
    LINDX(JNTK) := JNTN;              (* MOVES ARRAY LIMIT *)
    CASE ORD(RMCA)*4 + ORD(RMAC)*2 + ORD(RMPR) OF
     0:  (* ORDINARY MOVE *)
      IF RMEP THEN
      BEGIN                           (* PAWN MOVE 2 SPACES *)
        SFTRS(INRS,XRSS(RMTO),S1);
        SFTRS(INRS,XRSS(RMTO),S3);
        IORRS(INRS,INRS,INRS);        (* SQUARES NEXT TO DESTINATION *)
        ANDRS(INRS,INRS,TPLOC(XTUMP(EP,OTHER(JNTM))));
                                      (* INTERSECT WITH ENEMY PAWNS *)
        IF NOT NULRS(INRS) THEN
          SETRS(ENPAS(JNTK),(RMTO+RMFR) DIV 2);
                                      (* SET ENPASSANT SQUARE *)
        MOVEIT(A);                    (* MOVE PAWN *)
      END
      ELSE
        MOVEIT(A);                    (* MOVE PIECE *)
     1:  (* MOVE AND PROMOTE *)
      BEGIN
        PROMOT(A);                    (* PROMOTE PAWN *)
        MOVEIT(A);                    (* MOVE PROMOTED PIECE *)
      END;
     2:  (* MISCELLANEOUS ACS *)
      BEGIN
        IF RMOO THEN
        BEGIN  (* CASTLE *)
          IF RMOS THEN
            INTF := F1
          ELSE
            INTF := F8;               (* ROOK ON QUEEN ROOK FILE *)
          INTR := XTSR(RMFR);         (* ROOK ON KING ROOK FILE *)
          RXFR := XTRFS(INTR,INTF);   (* ROOK ON KINGS RANK *)
          RXTO := (RMFR+RMTO) DIV 2;  (* ROOK ORIGIN SQUARE *)
          ANDRS(CSTAT(JNTK),CSTAT(JNTK),XNRS(INTR));
                                      (* ROOK DESTINATION SQUARE *)
                                      (* DISALLOW FURTHER CASTLING
                                         BY THIS SIDE *)
          ADDLOC(RXTO,NBORD(RXFR));   (* PUT ROOK ON NEW SQUARE *)
          ADDATK(RXTO);               (* ADD ITS ATTACKS *)
          DELATK(RXFR);               (* DELETE FROM ORIGINAL SQUARE *)
          MOVEIT(A);                  (* MOVE KING *)
        END
        ELSE  (* NOT CASTLE *)
        BEGIN
          PROACS(A);                  (* PROCESS CASTLE STATUS MODS *)
          MOVEIT(A);                  (* MOVE TO OR FROM KING OR ROOK
                                         SQUARE *)
        END;
      END;
     3: (* NULL MOVE *)
     4:  (* CAPTURE *)
      IF RMEP THEN
      BEGIN  (* CAPTURE ENPASSANT *)
        INTS := XTRFS(XTSR(RMFR),XTSF(RMTO));
                                      (* CAPTURED PAWN SQUARE *)
        MBCAPT(NBORD(INTS));          (* UPDATE SCORE *)
        DELATK(INTS);                 (* DELETE CAPTURED PAWN
                                         ATTACKS *)
        PRPATK(INTS);                 (* PROPAGATE ATTACKS THROUGH
                                         PAWN *)
        MOVEIT(A);                    (* MOVE CAPTURING PAWN *)
      END
      ELSE  (* CAPTURE NOT ENPASSANT *)
        LOSEIT(A);                    (* PROCESS CAPTURE *)
     5:  (* CAPTURE AND PROMOTE *)
      BEGIN
        PROMOT(A);                    (* PROMOTE PAWN *)
        LOSEIT(A);                    (* PROCESS CAPTURE WITH PROMOTED
                                         PIECE *)
      END;
     6:  (* CAPTURE ACS *)
      BEGIN
        PROACS(A);                    (* PROCESS CASTLE STATUS MODS *)
        LOSEIT(A);                    (* PROCESS ROOK CAPTURE *)
      END;
     7:  (* CAPTURE ROOK ACS, PROMOTE *)
      BEGIN
        PROMOT(A);                    (* PROMOTE PAWN *)
        PROACS(A);                    (* CHANGE CASTLE STATUS *)
        LOSEIT(A);                    (* PROCESS ROOK CAPTURE *)
      END;
  END;

  (* INITIALIZE MOVE GENERATION *)

  JNTM := OTHER(JNTM);                (* SWITCH SIDE TO MOVE *)
  CPYRS(GENPN(JNTK),TPLOC(XTUMP(EP,JNTM)));
  NOTRS(GENTO(JNTK),TMLOC(JNTM));
  NOTRS(INRS,GENPN(JNTK));
  ANDRS(GENFR(JNTK),TMLOC(JNTM),INRS);

  (* DETERMINE IF MOVE LEAVES KING IN CHECK, OR MOVES
     KING INTO CHECK *)

  ANDRS(INRS,TPLOC(XTUMP(EK,JNTM)),ALATK(OTHER(JNTM)));
  RMCH := NOT NULRS(INRS);
  ANDRS(INRS,TPLOC(XTUMP(EK,OTHER(JNTM))),ALATK(JNTM));
  RMIL := NOT NULRS(INRS);
  UPDATE := NOT RMIL;
  IF NOT RMIL THEN
    NVSEL(JNTK-1) := NVSEL(JNTK-1) + 1;
                                      (* COUNT LEGAL MOVES *)
  (* INITIALIZE MOVE SEARCHING *)

  SRCHM(JNTK) := H1;
```

```
    NODES := NODES+1;                 (* COUNT NODES SEARCHED *)
  END;
END;  (* UPDATE *)


PROCEDURE GENONE                      (* STACK ONE GENERATED MOVE *)
  (A:TT;                              (* FROM SQUARE *)
   B:TS);                             (* TO SQUARE *)

VAR
  INRS : RS;                          (* SCRATCH *)

BEGIN
  WITH MOVES(JNTN) DO
  BEGIN
    RMFR := A;                        (* FROM SQUARE *)
    RMTO := B;                        (* TO SQUARE *)
    RMCP := NBORD(B);                 (* CAPTURED PIECE *)
    RMCA := (NBORD(B) <> MT);         (* CAPTURE *)
    IORRS(INRS,XRSS(A),XRSS(B));
    ANDRS(INRS,INRS,CSTAT(JNTK));
    RMAC := NOT NULRS(INRS);          (* AFFECTS CASTLE STATUS *)
    RMCH := FALSE;                    (* CHECK *)
    RMMT := FALSE;                    (* MATE *)
    RMIL := FALSE;                    (* ILLEGAL *)
    RMSU := FALSE;                    (* SEARCHED *)
    RMPR := FALSE;                    (* PROMOTION *)
    RMOO := FALSE;                    (* CASTLE *)
    RMEP := FALSE;                    (* ENPASSANT *)
  END;
  VALUE(JNTN) := 0;                   (* CLEAR VALUE *)
  IF JNTN < ZW THEN
    JNTN := JNTN+1;                   (* ADVANCE MOVES STACK POINTER *)
END;  (* GENONE *)


PROCEDURE PWNPRO;                     (* GENERATE ALL PROMOTION
                                         MOVES *)

VAR
  INTG : TG;                          (* PROMOTION TYPE *)

BEGIN
  MOVES(JNTN-1).RMPR := TRUE;         (* SET PROMOTION *)
  MOVES(JNTN-1).RMPP := PQ;           (* PROMOTE TO QUEEN FIRST *)
  FOR INTG := PR TO PB DO             (* GENERATE OTHER PROMOTIONS *)
  BEGIN
    MOVES(JNTN) := MOVES(JNTN-1);     (* COPY LAST MOVE *)
    MOVES(JNTN).RMPP := INTG;         (* CHANGE PROMOTE TO PIECE *)
    JNTN := JNTN+1;                   (* ADVANCE MOVE INDEX *)
  END;
END;  (* PWNPRO *)


PROCEDURE GENPWN                      (* GENERATE PAWN MOVES *)
  (A:RS;                              (* PAWNS TO MOVE *)
   B:RS);                             (* VALID DESTINATION SQUARES *)

VAR
  INRS, IMRS : RS;                    (* SCRATCH *)
  INTS : TS;                          (* DESTINATION SQUARE *)

BEGIN
  IF JNTM = LITE THEN
  BEGIN                               (* WHITE PAWNS *)
    SFTRS(IMRS,A,S2);                 (* ADVANCE ONE RANK *)
    ANDRS(IMRS,TPLOC(MT),IMRS);       (* ONLY TO EMPTY SQUARES *)
    CPYRS(IMRS,INRS);                 (* SAVE FOR 2 SQUARE MOVES *)
    ANDRS(IMRS,B,IMRS);               (* ONLY VALID DESTINATION
                                         SQUARES *)
    WHILE NXTTS(IMRS,INTS) DO
    BEGIN
      GENONE(XTLS(XTSL(INTS)-XTED(S2)),INTS);
                                      (* GENERATE SIMPLE PAWN MOVES *)
      IF INTS >= XTRFS(R8,F1) THEN
        PWNPRO;                       (* PROCESS PROMOTION *)
    END;
    ANDRS(INRS,INRS,XRRS(R3));        (* TAKE ONLY PAWNS ON THIRD *)
    SFTRS(INRS,INRS,S2);              (* ADVANCE ONE MORE RANK *)
    ANDRS(INRS,INRS,TPLOC(MT));       (* ONLY TO EMPTY SQUARES *)
    ANDRS(INRS,INRS,B);               (* ONLY VALID DESTINATION
                                         SQUARES *)
    WHILE NXTTS(INRS,INTS) DO
    BEGIN
      GENONE(XTLS(XTSL(INTS)-2*XTED(S2)),INTS);
                                      (* GENERATE DOUBLE PAWN MOVES *)
      MOVES(JNTN-1).RMEP := TRUE;     (* FLAG AS TWO SQUARES *)
    END;

    SFTRS(INRS,A,B1);                 (* TRY CAPTURES TO THE LEFT *)
    IORRS(IMRS,TMLOC(OTHER(JNTM)),ENPAS(JNTK));
                                      (* OPPONENT PIECES + EP SQUARE *)
    ANDRS(IMRS,IMRS,B);               (* VALID DESTINATION SQUARES *)
    ANDRS(INRS,IMRS,INRS);            (* CAPTURE MOVES TO LEFT *)
    WHILE NXTTS(INRS,INTS) DO
    BEGIN
      GENONE(XTLS(XTSL(INTS)-XTED(B1)),INTS);
                                      (* GENERATE CAPTURE MOVE *)
      MOVES(JNTN-1).RMCA := TRUE;     (* FLAG CAPTURE *)
      MOVES(JNTN-1).RMEP := INRSTB(ENPAS(JNTK),INTS);
                                      (* FLAG ENPASSANT CAPTURE *)
      IF MOVES(JNTN-1).RMEP THEN
        MOVES(JNTN-1).RMCP := BP;     (* SET CAPTURED PIECE TYPE *)
      IF INTS >= XTRFS(R8,F1) THEN
        PWNPRO;                       (* PROCESS PROMOTION *)
    END;

    SFTRS(INRS,A,B2);                 (* TRY CAPTURES TO THE RIGHT *)
    IORRS(IMRS,TMLOC(OTHER(JNTM)),ENPAS(JNTK));
                                      (* OPPONENT PIECES + EP SQUARE *)
    ANDRS(IMRS,IMRS,B);               (* VALID DESTINATION SQUARES *)
    ANDRS(INRS,IMRS,INRS);            (* CAPTURE MOVES TO LEFT *)
    WHILE NXTTS(INRS,INTS) DO
    BEGIN
      GENONE(XTLS(XTSL(INTS)-XTED(B2)),INTS);
                                      (* GENERATE CAPTURE MOVE *)
```

*Listing 1, continued:*

```
      MOVES(JNTN-1).RNCA := TRUE;       (* FLAG CAPTURE *)
      MOVES(JNTN-1).RNEP := INRSTB(ENPAS(JNTK),INTS));
                                        (* FLAG ENPASSANT CAPTURE *)

      IF MOVES(JNTN-1).RNEP THEN
        MOVES(JNTN-1).RNCP := OP;       (* SET CAPTURED PIECE TYPE *)
      IF INTS >= XTRFS(R8,F1) THEN
        PNNPRO;                         (* PROCESS PROMOTION *)
    END;
  END
  ELSE
  BEGIN                                 (* BLACK PAWNS *)
    SFTRS(INRS,A,S4);                   (* ADVANCE ONE RANK *)
    ANDRS(INRS,TPLOC[NT],INRS);         (* ONLY TO EMPTY SQUARES *)
    CPYRS(INRS,INRS);                   (* SAVE FOR 2 SQUARE MOVES *)
    ANDRS(INRS,B,INRS);                 (* ONLY VALID DESTINATION
                                           SQUARES *)

    WHILE NXTTS(INRS,INTS) DO
    BEGIN
      GENONE(XTLS(XTSL(INTS)-XTED(S4)),INTS);
                                        (* GENERATE SIMPLE PAWN MOVES *)

      IF INTS <= XTRFS(R1,F8) THEN
        PNNPRO;                         (* PROCESS PROMOTION *)
    END;
    ANDRS(INRS,INRS,XRRS(R6));          (* TAKE ONLY PAWNS ON THIRD *)
    SFTRS(INRS,INRS,S4);                (* ADVANCE ONE MORE RANK *)
    ANDRS(INRS,INRS,TPLOC(MT));         (* ONLY TO EMPTY SQUARES *)
    ANDRS(INRS,INRS,B);                 (* ONLY VALID DESTINATION
                                           SQUARES *)

    WHILE NXTTS(INRS,INTS) DO
    BEGIN
      GENONE(XTLS(XTSL(INTS)-2*XTED(S4)),INTS);
                                        (* GENERATE DOUBLE PAWN MOVES *)
      MOVES(JNTN-1).RNEP := TRUE;       (* FLAG AS TWO SQUARES *)
    END;

    SFTRS(INRS,A,B3);                   (* TRY CAPTURES TO THE LEFT *)
    IORRS(INRS,TNLOC(OTHER[JNTN]),ENPAS(JNTK));
                                        (* OPPONENT PIECES + EP SQUARE *)
    ANDRS(INRS,INRS,B);                 (* VALID DESTINATION SQUARES *)
    ANDRS(INRS,INRS,INRS);              (* CAPTURE MOVES TO LEFT *)
    WHILE NXTTS(INRS,INTS) DO
    BEGIN
      GENONE(XTLS(XTSL(INTS)-XTED(B3)),INTS);
                                        (* GENERATE PAWN CAPTURE MOVE *)
      MOVES(JNTN-1).RNCA := TRUE;       (* FLAG CAPTURE *)
      MOVES(JNTN-1).RNEP := INRSTB(ENPAS(JNTK),INTS);
                                        (* FLAG ENPASSANT CAPTURE *)

      IF MOVES(JNTN-1).RNEP THEN
        MOVES(JNTN-1).RNCP := LP;       (* SET CAPTURED PIECE TYPE *)
      IF INTS <= XTRFS(R1,F8) THEN
        PNNPRO;                         (* PROCESS PROMOTION *)
    END;

    SFTRS(INRS,A,B4);                   (* TRY CAPTURES TO THE RIGHT *)
    IORRS(INRS,TNLOC(OTHER[JNTN]),ENPAS[JNTK]);
                                        (* OPPONENT PIECES + EP SQUARE *)
    ANDRS(INRS,INRS,B);                 (* VALID DESTINATION SQUARES *)
    ANDRS(INRS,INRS,INRS);              (* CAPTURE MOVES TO LEFT *)
    WHILE NXTTS(INRS,INTS) DO
    BEGIN
      GENONE(XTLS[XTSL(INTS]-XTED(B4)],INTS);
                                        (* GENERATE PAWN CAPTURE MOVE *)
      MOVES(JNTN-1].RNCA := TRUE;       (* FLAG CAPTURE *)
      MOVES(JNTN-1).RNEP := INRSTB(ENPAS(JNTK),INTS);
                                        (* FLAG ENPASSANT CAPTURE *)

      IF MOVES[JNTN-1].RNEP THEN
        MOVES(JNTN-1).RNCP := LP;       (* SET CAPTURED PIECE TYPE *)
      IF INTS <= XTRFS[R1,F8] THEN
        PNNPRO;                         (* PROCESS PROMOTION *)
    END;
  END;
END;  (* GENPNN *)


PROCEDURE GENFSL                        (* GENERATE ALL MOVES FROM
                                           A SET OF SQUARES *)
  (A:RS);                               (* ORIGIN SET OF SQUARES *)

VAR
  INRS : RS;                            (* OUTER LOOP BIT BOARD *)
  INRS : RS;                            (* INNER LOOP BIT BOARD *)
  IPRS : RS;                            (* PAWN ORIGIN BIT BOARD *)
  INTS : TS;                            (* OUTER LOOP SQUARE NUMBER *)
  INTS : TS;                            (* INNER LOOP SQUARE NUMBER *)

BEGIN
  ANDRS(INRS,A,GENFR[JNTK]);            (* ONLY VALID FROM SQUARES *)
  NOTRS(INRS,A);
  ANDRS(GENFR[JNTK],GENFR[JNTK],INRS);  (* REMOVE ORIGIN SQUARES *)
  ANDRS(IPRS,A,GENPN(JNTK));            (* VALID PAWN FROM SQUARES *)
  ANDRS(GENPN(JNTK),GENPN(JNTK),INRS);  (* REMOVE PAWNS *)

  WHILE NXTTS(INRS,INTS) DO             (* LOOP THROUGH ORIGINS *)
  BEGIN
    ANDRS(INRS,ATXFR[INTS],GENTO(JNTK));
                                        (* GET UNPROCESSED DESTINATION
                                           SQUARES *)

    WHILE NXTTS(INRS,INTS) DO           (* LOOP THROUGH DESTINATIONS *)
      GENONE(INTS,INTS);                (* GENERATE MOVE *)
  END;
  GENPNN(IPRS,GENTO(JNTX));             (* GENERATE PAWN MOVES *)
END;  (* GETFSL *)


PROCEDURE GENTSL                        (* GENERATE ALL MOVES TO A
                                           SET OF SQUARES *)
  (A:RS);                               (* TARGET SET OF SQUARES *)

VAR
  INRS : RS;                            (* OUTER LOOP BIT BOARD *)
  INRS : RS;                            (* INNER LOOP BIT BOARD *)
  IPRS : RS;                            (* PAWN BIT BOARD *)
  INTS : TS;                            (* OUTER LOOP SQUARE NUMBER *)
  INTS : TS;                            (* INNER LOOP SQUARE NUMBER *)

BEGIN
  ANDRS(INRS,A,GENTO(JNTK));            (* ONLY VALID TO SQUARES *)
  NOTRS(INRS,A);
  ANDRS(GENTO[JNTK],GENTO[JNTK],INRS);  (* REMOVE DESTINATION SQUARES *)
  CPYRS(IPRS,INRS);                     (* SAVE FOR PAWN MOVES *)

  WHILE NXTTS(INRS,INTS) DO             (* LOOP THROUGH DESTINATIONS *)
  BEGIN
    ANDRS(INRS,ATKTO(INTS),GENFR(JNTK));
                                        (* GET PIECES OF SIDE TO MOVE *)
    WHILE NXTTS(INRS,INTS) DO           (* LOOP THROUGH ORIGINS *)
      GENONE(INTS,INTS);                (* GENERATE MOVE *)
  END;
  GENPNN(GENPN(JNTK),IPRS);             (* GENERATE PAWN MOVES *)
END;  (* GENTSL *)


PROCEDURE GENCAP;                       (* GENERATE CAPTURE MOVES *)

VAR
  INRS : RS;                            (* DESTINATION SQUARES *)

BEGIN
  IORRS(INRS,ENPAS(JNTK),TNLOC(OTHER[JNTN]));
  GENTSL(INRS);                         (* GENERATE MOVES TO
                                           ENEMY SQUARES *)
END;  (* GENCAP *)


PROCEDURE GENCAS;                       (* GENERATE CASTLE MOVES *)

VAR
  INTO : TO;                            (* CASTLE TYPE INDEX *)
  INRS : RS;                            (* OCCUPIED SQUARES TEST *)
  INRS : RS;                            (* ATTACKED SQUARES TEST *)

BEGIN
  FOR INTO := XTMO(JNTN) TO SUCC(XTMO(JNTN)) DO
   IF INRSTB(CSTAT(JNTK),XTOS(INTO)) THEN
                                        (* IF CASTLING IS LEGAL *)
    BEGIN
      ANDRS(INRS,XROSO(INTO),ALLOC(JNTK));
                                        (* CHECK OCCUPIED SQUARES *)
      ANDRS(INRS,XROSA[INTO],ALATK(OTHER(JNTN)));
                                        (* CHECK ATTACKED SQUARES *)
      IF NULRS(INRS) AND NULRS(INRS) THEN
                                        (* IF CASTLING IS LEGAL AND
                                           POSSIBLE *)
      BEGIN
        MOVES[JNTN] := XRON(INTO);      (* GENERATE CASTLING MOVE *)
        VALUE[JNTN] := 0;
        JNTN := JNTN+1;
      END;
    END;
END;  (* GENCAS *)


PROCEDURE GENALL;                       (* GENERATE ALL LEGAL MOVES *)

BEGIN
  GENFSL(ALLOC(JNTK));                  (* GENERATE SIMPLE MOVES *)
  GENCAS;                               (* GENERATE CASTLE MOVES *)
END;  (* GENALL *)


PROCEDURE LSTMOV;                       (* LIST LEGAL PLAYERS MOVES *)

VAR
  INTN : TN;                            (* MOVES INDEX *)

BEGIN
  CREATE;                               (* CREATE DATA BASE *)
  GENALL;                               (* GENERATE ALL MOVES *)
  FOR INTN := AN+1 TO JNTN-1 DO
  BEGIN
    IF UPDATE(MOVES(INTN)) THEN;        (* SET ILLEGAL FLAG *)
    DNDATE(MOVES(INTN));
  END;
END;  (* LSTMOV *)


PROCEDURE THEMOV                        (* MAKE THE MOVE FOR REAL *)
  (A:RM);                               (* THE MOVE TO MAKE *)

VAR
  INTB : TB;                            (* SCRATCH *)
  INRS : RS;                            (* SCRATCH *)
  INTO : TO;                            (* CASTLE TYPE INDEX *)
  INTS : TS;                            (* SCRATCH *)

BEGIN
  LSTMV := A;                           (* SAVE AS PREVIOUS MOVE *)
  INTB := UPDATE(A);                    (* UPDATE THE DATA BASE *)
  WITH BOARD DO                         (* AND COPY ALL THE RELEVANT DATA
                                           BACK DOWN *)
   BEGIN
    RBTM := JNTN;                       (* SIDE TO MOVE *)
    CPYRS(INRS,ENPAS(JNTK));
    IF NXTTS(INRS,INTS) THEN            (* FIND ENPASSANT SQUARE *)
      RBTS := INTS
    ELSE
      RBTS := AT;
    IF JNTM = DARX THEN
      RBTI := RBTI+1;                   (* ADVANCE MOVE NUMBER *)
    FOR INTO := LS TO DL DO
      IF INRSTB(CSTAT(JNTK),XTQS(INTO)) THEN
        RBSQ := RBSQ+[INTO]             (* CASTLE LEGAL *)
      ELSE
        RBSQ := RBSQ-[INTO];            (* CASTLE NOT LEGAL *)
    FOR INTS := AS TO ZS DO
      RB[S](INTS] := NBORD(INTS);       (* COPY POSITION *)
   END;
END;  (* THEMOV *)
```

# Creating Chess Player

## Part 3: Chess 0.5 (continued)

**Peter Frey**
**Larry Atkin**

*In Part 3 we conclude the listing and commentary of Chess 0.5 begun in Part 2. The program was written by Larry Atkin, who is coauthor with David Slate of the world championship chess program, Chess 4.6. The program is readily adaptable to personal computers having Pascal systems such as the UCSD Pascal project software. Part 4 concludes the series with a discussion of chess strategy and tactics.*

### Evaluating Terminal Positions

Another important aspect of any chess program is the function which provides a static evaluation of terminal positions in the look-ahead tree. In the present program, this routine also doubles as a preliminary scoring function for sorting moves at the first ply, at the beginning of the look-ahead search. Since the evaluation function is used repetitively in the search, efficiency demands that it be carefully engineered. We have left this task as an exercise for the reader. Our function presently includes only a few basic essentials.

The most important feature is material. We employ essentially the same function for this that is used by Chess 4.5. A trade-down bonus is also incorporated, ie: trade pieces but not pawns when ahead in material. A second feature which is considered is piece mobility. The mobility of Knights and Bishops is weighted more heavily than that for Rooks and Queens. Special credit is given to a King which is located in one of the four corner squares in each corner of the board, ie: 16 squares total. This encourages early castling. Pawn structure is considered by providing a bonus for advancing the pawns in the four center files, for having a pawn near the King, and for having a pawn adjacent to or defended by another pawn. This indirectly penalizes isolated or backward pawns. There is a direct penalty if the square in front of a pawn is occupied. The position of the Rooks is considered by providing a bonus for placing a Rook on the seventh rank and for attacking another Rook of the same color (ie: doubled Rooks). The executive routine for these assessments is EVALU8.

### The Look-Ahead Procedure

The look-ahead procedure is controlled by an executive routine called SEARCH. Several subprocedures are also defined which handle specific tasks. NEWBST keeps track of the move which is currently thought to be best, and dynamically reorders the moves at the first ply level each time a new best-move is selected. MINMAX determines whether the move under consideration will produce an $\alpha$-$\beta$ cutoff. SCOREM is called into action when the program can find no legal moves at a node. It determines whether the position should be scored as a checkmate or as a stalemate. SELECT is responsible for move ordering at each node. It determines whether there are any more moves to be searched and if so, makes sure that they are generated in the correct order (ie: captures, killers, castling moves, and then the remaining moves).

SEARCH incorporates a number of important features which make the look-ahead search more efficient. These include staged move generation, preliminary ordering scores, setting a narrow $\alpha$-$\beta$ window at the beginning of the search, conducting the search in an iterative fashion, and dynamically recording moves at the first ply as the search proceeds. Because of these features, the full-width search takes a long time instead of taking forever.

### User Commands

For the user's convenience, the program should be able to respond to a few simple commands. Inputs to the program are processed by a lengthy routine, READER, which has many component subprocedures. The translation of the input string is handled by a group of routines: RDRERR, RDRGNT, RDRSFT, RDRCMP, RDLINE, RDRMOV and RDRNUM. Each of the commands is executed by a separate routine.

When the human player wishes to terminate the game before it has reached its conclusion (eg: when he is hopelessly lost and does not want to stay around to be crushed), he can simply type an END command and the ENDCMD routine will terminate the program. If the user simply wishes to start a new game, he can type INIT and the INICMD routine will set up for a new game. If the user would like to set up a specific position from the previous game or some other game, he can call the BOACMD routine, which will set up any position he desires. To use this instruction, the pieces are designated in the standard way (eg: K, Q, R, B, N and P) and the colors are designated by L for light and D for dark. The board is described by starting at the lower lefthand corner and listing, row by row, the 64 squares. Numbers are used to represent consecutive empty squares. The command to set up the position after 1. P-K4, P-K4, 2. N-KB3, N-QB3 is: BOARD, LRNBQKB1 RPPPP1PPP5N24P34DP33N4PPPP1PPPR1B QKBNR.

If the human player is lazy or simply wishes to test the program, he or she can type GO and the machine will select a move. By repeatedly typing GO the user can sit back and watch the machine play against itself. The routine that handles this is GONCMD. To specify a value for selected program parameter variables, the player can use LETCMD. For example, the amount of time the machine spends calculating a move can be controlled by specifying a limit for the number of nodes to be searched. The command LET FNODEL = 1000 will cause the machine to set a target value of 1000 for the number of nodes to be searched. In this case it will not start another iteration if it has already searched 1000 nodes. If the user is confused about the current board configuration, the command PRINT will activate PRICMD which calls PRINTB for a representation (8 by 8 array) of the board. For diagnostic purposes the user can also ask for other information. The routine PAMCMD is activated by PB and provides an 8 by 8 attack map for each of the 64 squares. The routine POPCMD is activated by PO and gives information concerning the side to move (White or Black), the en passant status after the last move, the present castle status and the move number. If the user types PM, the routine PMVCMD will provide a list of all moves which are legal for the side to move in the current position. The command PL activates PLECMD which prints the value of a designated variable; for example, the user can determine the present limit for the number of nodes to be searched by typing PL FNODEL.

The user also has control over several switches. He can ask the machine to repeat (echo) each entry, to pause after 20 lines of output, and to reply automatically each time the opponent enters a move. These switches are set by the switch commands (eg: SW EC OFF), and are processed by SWICMD. If the user wishes to manually alter one or more of the status conditions (eg: side to move, move number, en passant, castling), this can be done by activating STACMD.

### Notes on Notation

The program also processes standard chess notation. This is not strictly necessary. Many programs use their own convention for entering and reporting moves. A common procedure is to denote the squares using a number (1 through 8) for each row and a letter (A through H) for each column. A move is defined by listing the present square of the piece and then the destination square. For example, the common opening move, P-K4, would be E2E4. Moving the White Knight on the kingside from its original square to KB3 would be G1F3. This convention works nicely but it forces an experienced chess player to learn a new system. Most would prefer standard chess notation.

Because there are multiple ways to express the same move in standard notation, the translation routine needs to be fairly sophisticated. Consider a position in which the White Queen's Rook is on its original square and the neighboring Knight and Bishop have been moved. A move which places the Rook on the Queen Bishop file can be designated as R-B1, R-QB1, R/1-B1, R/1-QB1, R/R1-B1, or R/R1-QB1. It is important that the program recognize that each of these character strings represents the same move. How is this done?

One way is to have the machine generate a list of all legal moves and then compare each of these with the move entered by the player. If his move matches one on the list, that move is noted. The rest of the list is then checked and if no more matches are found, the noted move is assumed to be the correct one. If no match is found, the machine prints "illegal move." If a second match is found (eg: P-B3 matches both P-KB3 and P-QB3), the machine prints "ambiguous move." The process of translating the opponent's move into machine compatible form and checking its legality or ambiguity is done by YRMOVE. The process of translating the machine's move into standard notation is handled by MYMOVE. Both of these procedures call MINENG, which is responsible for constructing the appropriating character strings.

### Final Thoughts

This completes our listing of our demonstration chess program. Despite the program's length, there are many desirable features which have been omitted. The reader with an interest in chess and programming should use this listing as a starting point for developing a program. The time required for move calculation can be reduced by writing machine dependent code for some of the frequently used routines. There are also features which can be added to improve the level of play.

One useful addition would be an opening library. An effective technique for this is described by Slate and Atkin in their chapter in *Chess Skill in Man and Machine* (P W Frey, editor, Springer-Verlag, New York, 1977). An opening library provides the user with a challenging set of opening moves and directs the game into situations which are familiar to the experienced chess player. By including various options at the early choice points and using a random selection procedure, the programmer can insure that the machine will not always select the same move sequence. The programmer can also give the user the option of specifying a particular opening against which he would like to practice. For important matches, the programmer can prepare surprise openings for the machine in order to gain a psychological edge on the opponent.

A second and somewhat more challenging project would be to develop a transposition table for the program. This requires the availability of unused memory (at least 8 K bytes and preferably 16 K or 32 K bytes), an efficient hashing scheme, and a set of decision rules to select among positions when a collision occurs (ie: two positions hash to the same address in the table). Another problem is that the use of a staged evaluation process and the $\alpha$-$\beta$ algorithm often provides an imprecise evaluation score (ie: the machine has determined that a position was not optimal but has not invested the time to find out exactly how bad it was). If the programmer succeeds with the transposition table, however, move calculation will take 30 to 50 per cent less time in most middle game positions and 60 to 90 per cent less time in many end game positions.

A third area for improvement is the evaluation function. Our program presently has only a rudimentary function. The reader should compare it with the one used by Chess 4.5 which is described in detail by Slate and Atkin. Their evaluation function provides an excellent starting point for revising our present function. In part 4 we will discuss the advantages of using a conditional evaluation function, ie: one that changes depending on the stage of the game and on the presence of special features. One implementation of this strategy is the special end game program described by Monroe Newborn in *Chess Skill in Man and Machine.*

It is appropriate for us to add two important disclaimers at this juncture. Although we have carefully tested each of the routines in the program and played several chess games, it is still possible that there are a few minor bugs in the program. If you find one, a letter to one of us or to BYTE would be appreciated. Secondly, our chess program was written primarily for pedagogical purposes. For this reason it is not a production program and does not run very efficiently. If you are the competitive type, our program should provide many useful ideas, but you should not expect it to compete successfully in tournament play unless you make extensive modifications and additions.

A chess program has a tendency to grow and change its personality as the programmer becomes more familiar with each of its many limitations. It provides a constant challenge for those of us who are too compulsive to tolerate obvious weaknesses. In fact one must be careful not to become totally obsessed with this project. We do not wish any of you to lose your job or your spouse because of a chess program.■

*Listing 1: The second half of Chess 0.5, written in Pascal. This portion of the program covers evaluation of terminal nodes, the look-ahead procedure and user commands.*

```
PROCEOURE EVALU8;                            )* EVALUATE CURRENT POSITION *)

VAR
  INTV : TV;                                 (* SCORE *)


  FUNCTION EVKING                            (* EVALUATE KING *)
    (A:RS;                                   (* KING BIT BOARD *)
     B:RS):TV;                               (* FRIENOLY PAWN BIT BOARD *)

  VAR
    INTS : TS;                               (* SCRATCN *)
    INRS : RS;                               (* SCRATCN *)
    INTV : TV;                               (* SCRATCN *)

  BEGIN
    ANORS(INRS,A,CORNR);
    IF NULRS(INRS) THEN                      (* KING NOT IN CORNER *)
      INTV := 0
    ELSE
      INTV := FKSANQ;                        (* KING SAFELY IN CORNER *)

    INRS := A;
    IF NXTTS(INRS,INTS) THEN
    BEGIN
      ANORS(INRS,ATKFR(INTS),B);             )* FINO PAWNS NEKT TO RING *)
      INTV := INTV + CNTRS(INRS)*FKPSNO;
                                             (* CREOIT EACH CLOSE PAWN *)
    ENO;

    EVKING := INTV;                          (* RETURN KING SCORE *)
  END;  (* EVKING *)


  FUNCTION EVNOBL                            (* EVALUATE MOBILITY *)
    (A,B:TP):TV;                             (* PIECE TYPES TO EVALUATE *)

  VAR
    INRS : RS;                               (* SCRATCN *)
    INTS : TS;                               (* SCRATCN *)
    INTV : TV;                               (* SCRATCN *)

  BEGIN
    IORRS(INRS,TPLOC[A],TPLOC[B]);           (* NERGE PIECE TYPES *)
    INTV := 0;                               (* INITIALIZE COUNT *)
    WHILE NXTTS(INRS,INTS) DO                (* COUNT ATTACKS *)
      INTV := INTV + CNTRS(ATKFR[INTS]);
    EVNOBL := INTV;                          (* RETURN TOTAL ATTACKS *)
  ENO;  (* EVNOBL *)


  FUNCTION EVPAWN                            (* EVALUATE PANNS *)
    (A:RS;                                   (* LOCATION OF PAWNS *)
     B:TE;                                   (* PAWN FORWARO OIRECTION *)
     C:TR):TV;                               (* PANN NONE RANK *)

  VAR
    INRS : RS;                               (* SCRATCH *)
    INRS : RS;                               )* SCRATCN *)
    INTS : TS;                               (* SCRATCN *)
    INTV : TV;                               (* SCRATCN *)

  BEGIN
    SFTRS(INRS,A,S1);
    ANORS(INRS,INRS,A);                      (* BIT SET FOR SIDE BY SIOE *)
    INTV := CNTRS(INRS)*FPFLNX;              (* SCORE PNALANK *)

    SFTRS(INRS,A,B1);
    ANORS(INRS,INRS,A);                      (* BIT SET FOR PANN OEFENSE *)
    INTV := INTV + CNTRS(INRS)*FPCONN;       (* CREOIT CONNECTEO PAWNS *)

    SFTRS(INRS,A,B2);
    ANORS(INRS,INRS,A);
    INTV := INTV + CNTRS(INRS)*FPCONN;       (* ANO OTNER CONNECTEO PAWNS *)

    SFTRS(INRS,A,B);                         (* NOVE FORWARO *)
    NOTRS(INRS,TPLOC[NT]);                   (* OCCUPIEO SQUARES *)
    ANORS(INRS,INRS,INRS);                   (* BLOCKEO PANNS *)
    INTV := INTV - CNTRS(INRS)*FPBLOK;       (* PENALIZE OLOCKEO PAWNS *)

    CPYRS(INRS,A);
    WNILE NXTTS(INRS,INTS) DO                (* FOR EACN PAWN *)
      INTV := INTV +(ABS(ORO(C)-ORO(KTSR[INTS]))*FPAOCR[KTSF[INTS]];
                                             (* CREOIT PAWN AOVANCEMENT *)

    EVPAWN := INTV;                          (* RETURN PAWN SCORE *)
  ENO;  (* EVPAWN *)


  FUNCTION EVROOK                            (* EVALUATE ROORS *)
    (A:RS;                                   (* ROOK LOCATIONS *)
     B:RS):TV;                               (* SEVENTN RANK *)

  VAR
    INTV : TV;                               (* SCRATCN *)
    INTI : TI;                               (* SCRATCN *)
    INTS : TS;                               (* SCRATCN *)
    INRS : RS;                               (* SCRATCN *)

  BEGIN
    INTV := 0;                               )* INITIALIZE *)
    INRS := A;
    IF NKTTS(INRS,INTS) THEN                 (* LOCATE FIRST ROOK *)
    BEGIN
      ANORS(INRS,A,ATKFR[INTS]);
      IF NOT NULRS(INRS) THEN                )* ROOK ATTACKS FRIENOLY ROOK *)
        INTV := INTV + FROUBL;               (* GIVE OOUBLEO ROOK CREOIT *)
    ENO;

    ANORS(INRS,A,B);                         (* ROOKS ON SEVENTN *)
    INTI := CNTRS(INRS);
    EVROOK := INTV + INTI*INTI*FRX7TH;       (* CREOIT ROOKS ON SEVENTH *)
  ENO;  (* EVROOK *)



BEGIN
  IF XTNV[JNTH]*NBVAL[JNTK] + NAKPS <= BSTVL[JNTK-2] TNEN
                                             (* MOVE WILL PRUNE ANYWAY *)
    INTV := KTHV[JNTH] * NBVAL[JNTK]
  ELSE
  BEGIN
    INTV :=(   FWPAWN*(EVPAWN(TPLOC[LP],S2,R2)-EVPAWN(TPLOC[OP],S4,R7))
             + FWNINN*(EVNOBL(LB,LN)            -EVNOBL(DB,ON))
             + FWMAJN*(EVNOBL(LR,LQ)            -EVNOBL(OR,OQ))
             + FWROOK*(EVROOK(TPLOC[LR],RRRS[R7])
                      -EVROOK(TPLOC[OR],RRRS[R2]))
             + FWKING*(EVKING(TPLOC[LK],TPLOC[LP])
                      -EVKING(TPLOC[OK],TPLOC[OP]))
           ) OIV 64;
    NAKPS := NAK(NAKPS,ABS(INTV));
    INTV := XTNV[JNTN]*(NBVAL[JNTK]+INTV);
  ENO;
  IF SWTR TNEN
  BEGIN
    WRITE(" EVALU8",JNTK,JNTM,INOEX[JNTK],INTV);
    PRINOV(NOVES[INOEK[JNTK]]);
  ENO;
  VALUE[INDEX[JNTK]] := INTV;                (* RETURN SCORE *)
ENO;  (* EVALU8 *)



FUNCTION SEARCN                              (* SEARCH LOOK-ANEAO TREE *)
  :TN;                                       (* RETURNS TNE BEST NOVE *)

LABEL
  11,                                        (* START NEW PLY *)
  12,                                        (* TRY OIFFERENT FIRST NOVE *)
  13,                                        (* FLOAT VALUE BACK UP *)
  14,                                        (* FINO ANOTHER HOVE *)
  15,                                        (* BACK UP A PLY *)
  16;                                        (* EKIT SEARCH *)


  PROCEOURE NEWBST                           (* SAVE BEST NOVE INFORNATION *)
    (A:TK);                                  (* PLY OF BEST NOVE *)

  VAR
    INTW : TN;                               (* NOVES INOEX *)
    INRN : RN;                               (* SCRATCH *)

  BEGIN
    BSTMV[A] := INOEX[A+1];                  (* SAVE BEST NOVE *)
    IF A = AK THEN                           (* AT FIRST PLY *)
    BEGIN
      INRN := NOVES[BSTHV[A]];               (* SAVE BEST NOVE *)
      FOR INTN := BSTHV[A]-1 DOWNTO AW+1 DO
        MOVES[INTN+1] := NOVES[INTN];        (* NOVE OTHER NOVES OOWN *)
      MOVES[AW+1] := INRM;                   (* PUT BEST AT BEGINNING *)
      BSTHV[AK] := AW+1;                     )* POINTS TO BEST MOVE *)
    ENO
    ELSE
      IF NOT NOVES[BSTNV[A]].RMCA THEN
        KILLR[JNTK] := NOVES[BSTNV[A]];      (* SAVE KILLER NOVE *)
  ENO;  (* NEWBST *)



  FUNCTION MINNAK                            (* PERFORM MINIMAX OPERATION *)
    (A:TR)                                   (* PLY TO MINIMAR AT *)
    :TB;                                     (* TRUE IF REFUTATION *)

  BEGIN
    MINNAK := FALSE;                         (* DEFAULT IS NO PRUNING *)
    IF SWTR THEN
      WRITE(" MINMAR",A,-BSTVL[A-1],BSTVL[A],-BSTVL[A+1]);
    IF -BSTVL[A+1] > BSTVL[A] THEN
    BEGIN
      BSTVL[A] := -BSTVL[A+1];
      NEWBST[A];                             (* SAVE BEST MOVE *)
      MINMAR := BSTVL[A+1] <= BSTVL[A-1];
                                             )* RETURN TRUE IF REFUTATION *)
      IF SWTR THEN
        WRITE(" NEW BEST. PRUNE: ",BSTVL[A+1] <= BSTVL[A-1]);
    END;
    IF SWTR THEN
      WRITELN;                               (* PRINT TRACE LINE *)
  END;  (* NINNAK *)



PROCEOURE SCOREN;                            (* SCORE NATE *)

BEGIN
  MOVES[INOEX[JNTR]].RMMT := TRUE;           (* INDICATE MATE *)
  IF MOVES[INDEK[JNTK]].RMCN THEN            (* CHECKMATE *)
    VALUE[INOEX[JNTR]] :=  64*JNTR - ZV
  ELSE                                       )* STALEMATE *)
```

```
    VALUE[INDEX!JNTK[[ := 0!
  IF SMTR THEN
    WRITELN(" SCOREN",JHTK,JNTM,INDEX[JNTK],VALUE[INDEK!JNTK)][!
EHD!  (* SCONEN *(


FUNCTION SELECT                          (* SELECT NEXT MOVE TO SEARCH *(
   :TB!                                  (* TRUE IF MOVE RETURNEO *(

LABEL
  21,                                    (* NEH SEARCN NODE *(
  22!                                    !* EXIT SELECT *)

VAN
  INTB : TB!                             (* RETUNH VALUE *)
  INTK : TK!                             (* SCRATCH *(
  INTM : TM!                             !* MOVE INDEK *)
  INTM : TM!                             (* SCRATCN *)
  INTV : TV!                             (* SCRATCN *(


  PROCEOURE SELOON!                      (* SELECT EXIT - OONE.
                                            CALLEO WHEN NO FURTNER
                                            MOVES ARE TO BE SEARCHEO
                                            FROM THIS POSITION.
                                            THE CURRENT POSITION MUST
                                            HAVE BEEN EVALUATED. *]

  BEGIN
    INTB := FALSE(                       (* RETURH HO MOVE SELECTED *)
    IF SMTR THEN
      WRITELN!" SELECT",JNTK," ENO."(!
    GOTO 22!                             (* EKIT SELECT *]
  EHD!  (* SELOON *)



  PNOCEOURE SELMOV                       (* SELECT EXIT - SEARCN.
                                            CALLED WHEN A MOVE TO
                                            BE SEARCHEO NAS BEEN
                                            FOUNO. *]
    (A:TM(]                              (* INOEX TO SELECTED MOVE *)

  BEGIN
    INTB := TRUE;                        (* RETURN MOVE SELECTEO *(
    INOEK(JHTK+1( := A;                  (* POINT TO SELECTED MOVE *)
    MOVES[A].RHSU := TRUE!               (* FLAG MOVE AS SEARCNED *)
    IF SNTR TNEN
    BEGIN
      WRITE)" SELECT",JMTK,ORO(SRCNM[JMTK](,A(!
      PRIMOV(MOVES!A[](
    END!
    GOTO 22;                             (* EXIT SELECT *)
  EHD(  (* SELMOV *(


  PROCEOURE SELNXT                       (* SELECT EXIT - NEW NODE.
                                            CALLED WHEN A NEW SEARCH
                                            MODE IS TO BE SELECTED *(
    (A:TH)!                              (* NEW SEARCH MOOE *]

  BEGIN
    (NDEX(JN!K+1) := LINOK[JNTK]-1;      (* RESET MOVES POINTER *]
    SRCHM(JMTK( := A;                    (* CHANGE SEARCH MODE *)
    GOTO 21!                             (* EKECUTE HEXT MOOE *]
  ENO;  (* SELHXT *]



  PROCEOURE SELANY;                      (* SEARCH ALREAOY GENERATED
                                            ANO NOT ALREAOY SEARCHEO *(

  VAR
    (NTM : TM;                           (* MOVES INOEX *(

  BEGIN
    FOR (NTM := IHDEX(JMTK+1]+1 TO JNTM-1 OO
      (F HOT MOVES((HTM).RNSU THEN
        SELMOV(INTM);
  EHD;  )* SELANY *(


BEGIN
21!  (* NEW SEARCH NODE *]
  CASE SRCHM[JMTK] OF

    M0!  (* IN(TIALIZE FOR NEW MOVE *]
         BEGIN
           MVSEL)JHTK] := 0;             (* CLEAR MOVES SEARCNED *)
           (HTV := BSTVL[JNTK-2)!        )* SAVE ALPHA *(
           BSTVL(JNTK-2( ):= -IV!        (* INNIBIT PRUNING IN EVALUB *)
           MAXPS := 0!                   (* INITIALIIE MAXIMUN POSITIONAL
                                            SCORE *)
           GENALL!                       (* GENERATE ALL MOVES *)
           FOR INTM := AM+1 TO JNTM-1 OO
           BEGIN
             IF UPDATE(MOVES[INTN]] THEN
             BEGIN
               INOEX[JNTK] := INTN;      !* POINT TO CURRENT MOVE *(
               EVALUB!                   !* SCORE POSITION *)
             EHD!
             ONOATE)MOVES[INTM]) !
           EHD!
           BSTVL[JNTK-2! := INTV(        (* RESTORE ALPNA *(
           SORTIT)VALUE,MOVES,JNTM-1)(
                                         !* SORT PRELIMINARY SCORES *(
           FON INTK := AK TO ZK OO
             KILLN((NTK) ):= NULMV!      (* CLEAR KILLER TABLE *)

       IF SMTR OR SMPS THEN
         FOR INTM := AM+1 TO JNTM-1 DO
         BEGIN
           WRITE(" PRELIN",INTN,VALUE[INTN](!
           PRIMOV(MOVES!INTM]]!  (* PRINT PRELIMINARY SCORES *)
           IF INTM/LPP = INTM DIV LPP THEN
             PAUSER!
           END!
         SELNXT(M6(]                     !* SEARCH ALL MOVES *)
       END!

    M1!  (* INITIALIZE AT NEW OEPTN *}
         BEGIN
           MVSEL[JMTK] ):= 0T            (* CLEAR MOVES SEARCHEO *}
           IF JHTK = JMTK THEN
           BEGIN
             EVALUA(                     (* EVALUATE CURRENT POSITION *(
             INDEX[JNTK+1] := AM!
             BSTVL[JNTK+1( := -VALUE!INDEX(JNTK)]!
             IF MINMAX(JMTK) OR (JHTK = ZK) THEN
               SELOON!                   (* TNIS MOVE PRUNES *)
             SRCHM(JNTK( := N2!          (* CAPTUNE SEARCH *)
           EHO
           ELSE
             SRCNM(JNTK( := N3!          (* CAPTURES IN FULL SEARCH *)
           GENCAP!                       (* GENERATE CAPTURES *]
           SELNXT(SRCHM!JNTK((!          (* CHANGE SEARCH MOOE *(
         EHD!

    H2!  (* CAPTURE SEARCH *(
         BEGIN
           INTM := AM!                   (* BEST MOVE POINTER *(
           INTV := AV!                   (* BEST VALUE *(
           FOR (NTN (= LINOX!JNTK( TO JNTM-1 DO
             WITN MOVES[INTM] OO
               IF HOT RMSU TNEN
                 IF ABS!KTPV(RNCP]) > INTV TNEN
                 BEG(N
                   INTV := ABS!XTPV(RMCP!)!

                   INTN := INTM!
                 EHO!
           IF INTM <> AM THEH            )* MOVE FOUNO *(
             SELNOV(INTM(                (* SELECT BIGGEST CAPTURE *(
           ELSE
             SELOON!                     (* QUIT *]
         END!

    H3!  (* FULL WIOTH SEARCH - CAPTURES *)
         BEGIN
           INTM := AM!                   !* BEST MOVE POINTER *]
           INTV := AV!                   (* BEST VALUE *!
           FOR INTM := LINOX(JNTK( TO JNTM-1 OO
             WITN MOVES(INTM) OO
               IF MOT RNSU THEN
                 IF ABS(KTPV(RNCP() > INTV THEN
                 BEGIN
                   INTV := ABS(X!PV!RMCP(]!

                   INTN := INTM!
                 ENO!
           IF INTM <> AM THEH            (* MOVE FOUNO *(
             SELNOV(INTM(                (* SELECT BIGGEST CAPTURE *(
           ELSE
             IF NOT HULNVB(KILLR[JHTK)] TNEN
             BEGIN
               INTM := JHTM!             )* SAVE CURRENT MOVES IHOEX *(
               GENFSL!KRSS(KILLR[JHTK].RMFR]]!
                                         (* GENERATE MOVE BY KILLER *)
               SRCHM)JHTK] := M4]        (* SET NEXT SEARCN MODE *)
               FOR INTM := INTM TO JNTM-1 OO
                                         )* LOOK AT MOVES BY KILLER *(
                 IF KILLN(JNTK].RNTO = MOVES(IN!MI.RNTO THEN
                   SELNOV(INTM)!         !* SELECT KILLER MOVE *)
             EHO!
           SELNXT)M4]!                   (* GO TO NEKT STATE *]
         END(

    H4!  (* IHITIALIZE SCAN OF CASTLE MOVES AND OTHER MOVES
            BY KILLER PIECE *)
         BEGIN
           GENCAS!                       )* GENERATE CASTLE MOVES *)
           SELNXT(MS]!                   (* GO TO NEXT STATE *)
         END!

    M5!  )* FULL WIOTH SEARCH - CASTLES AHO OTHER MOVES BY XILLER
            PIECE *)
         BEG(N
           SELANY;                       (* SELECT ANY MOVE *]
           GEMFSL!ALLOC(JNTK))(          (* GENERATE RENAIMING MOVES *)
           SELNKT!H6)!                   !* NEXT SEARCH MOOE *(
         EHD;

    M6!  !* FULL WIOTH SEARCH - REMAINING MOVES *)
         BEGIH
           SELANY;                       (* SELECT ANYTHING ON L(ST *)
           (F MVSEL[JNTK] = 0 THEN
             SCOREM:                     (* SCORE MATE *]
           SELOOH;                       (* EXIT SELECT *]
         END!

    M7!  (* RESEARCH F(RST PLY *)
         BEGIN
           JNTM := LIHOK[AK+1]!          )* POINT TO ALREAOY GENERATED
                                            MOVES *)
           MVSEL(AK) := 0(               )* RESET MOVES SEARCHEO *)
           FOR INTM := AM+1 TO JNTM-1 DO
             MOVES[INTMI.RMSU := FALSE!
                                         !* CLEAR SEARCHEO BIT *]
           IF SNTR THEN
             WRITELN!" REOO  ",JNTK,BSTVL[AK-2],BSTVL(AK-1]!]
           SELNXT!M6]!                   !* SEARCH ALL MOVES *]
         END!
  END!



  22)  (* SELECT EXIT *(
    SELECT := INTB!                      (* RETURN VALUE *!
  END!  (* SELECT *)

BEGIN  (* SEARCH *(
  BSTMV[AK! := AM!                       !* INITIALIZE MOVE *)
  INOEK(JNTK! := AM!                     (* INITIALIZE TREE *)
```

*Listing 1, continued:*

```
  MOVES[AN] := LSTMV;                  (* INITIALIZE MOVE *)
  EVALU;                               (* INITIAL GUESS AT SCORE *)
  BSTVL[AK-2] := VALUE[AN] - WINDOW;   (* INITIALIZE ALPHA-BETA
                                          WINDOW *)
  BSTVL[AK-1] := - VALUE[AN] - WINDOW;
  JNTK := AK+1;                        (* INITIALIZE ITERATION NUMBER *)
  WHILE (NODES < FNODEL) AND (JNTK = MAX(ZK DIV 2, ZK-8)) DO
  BEGIN

11:  (* START NEW PLY *)
    BSTVL[JNTK] := BSTVL[JNTK-2];      (* INITIALIZE ALPHA *)

12:  (* DIFFERENT FIRST MOVE *)
    IF NOT SELECT THEN
    BEGIN
      BSTVL[JNTK] := VALUE[INDEX[JNTK]];
      NEWBST(JNTK);
    END
    ELSE
    BEGIN
      IF UPDATE(MOVES[INDEX[JNTK+1]]) THEN
        GOTO 11                        (* START NEW PLY *)
      ELSE
      BEGIN
        DNDATE(MOVES[INDEX[JNTK]]);
        GOTO 12;                       (* FIND ANOTHER MOVE *)
      END;

13:  (* FLOAT VALUE BACK *)
     IF MINMAX(JNTK) THEN
       GOTO 15;                        (* PRUNE *)

14:  (* FIND ANOTHER MOVE AT THIS PLY *)
     IF SELECT THEN
       IF UPDATE(MOVES[INDEX[JNTK+1]]) THEN
         GOTO 11                       (* START NEW PLY *)
       ELSE
       BEGIN
         DNDATE(MOVES[INDEX[JNTK]]);
         GOTO 14;                      (* FIND ANOTHER MOVE *)
       END;
    END;

15:  (* BACK UP A PLY *)
    IF JNTK > AK THEN
    BEGIN (* NOT DONE WITH ITERATION *)
      DNDATE(MOVES[INDEX[JNTK]]);      (* RETRACT MOVE *)
      GOTO 13;
    END;

     (* DONE WITH ITERATION *)
    IF (BSTVL[AK] <= BSTVL[AK-2]) OR (BSTVL[AK] >= -BSTVL[AK-1]) THEN
    BEGIN  (* NO MOVE FOUND *)
      IF MVSEL[AK] = 0 THEN
      BEGIN  (* NO LEGAL MOVES *)
        GOTO 16;                       (* GIVE UP *)
      END;
      BSTVL[AK-2] := -ZV;              (* SET ALPHA-BETA WINDOW LARGE *)
      BSTVL[AK-1] := -ZV;
      SRCHM[AK] := H7;
      JNTK := AK+1;
      GOTO 11;                         (* TRY AGAIN *)
    END;
    BSTVL[AK-2] := BSTVL[AK] - WINDOW; (* SET ALPHA BETA WINDOW *)
    BSTVL[AK-1] := - BSTVL[AK] - WINDOW;
    JNTK := JNTK+1;                    (* ADVANCE ITERATION NUMBER *)
    SRCHM[AK] := H7;
  END;

16:  (* EXIT SEARCH *)
  SEARCH := BSTMV[AK];                 (* RETURN BEST MOVE *)
END;  (* SEARCH *)



PROCEDURE READER;                      (* READ INPUT FROM USER *)

LABEL
  11;                                  (* COMMAND FINISHED EXIT *)

VAR
  INRA : RA;                           (* SCRATCH TOKEN *)
  INTJ : TJ;                           (* ECHO COMMAND INDEX *)



  PROCEDURE RDRERR(A:RN);              (* PRINT DIAGNOSTIC AND EXIT *)

  VAR
    INTJ : TJ;                         (* STRING INDEX *)
    INTN : TN;                         (* MESSAGE INDEX *)

  BEGIN
    IF NOT SWEC THEN                   (* ECHO LINE IF NOT ALREADY
                                          DONE *)
    BEGIN
      WRITE(" ");
      FOR INTJ := AJ TO ZJ-1 DO
        WRITE(ILINE[INTJ]);            (* WRITE INPUT LINE *)
      WRITELN;
    END;
    FOR INTJ := AJ TO JNTJ DO
      WRITE(" ");                      (* LEADING BLANKS BEFORE ARROW *)
    WRITELN("^");                      (* POINTER TO ERROR *)
    FOR INTN := AN TO ZN DO
      WRITE(A[INTN]);                  (* WRITE DIAGNOSTIC *)
    WRITELN;
    GOTO 11;                           (* COMMAND EXIT *)
  END;  (* RDRERR *)

FUNCTION RDRGNT(VAR A:RA):TB;          (* GET NEXT TOKEN FROM COMMAND
                                          RETURNS TOKEN IN A.
                                          RETURNS TRUE IF NON-EMPTY
                                          TOKEN.
                                          A TOKEN IS ANY CONSECUTIVE
                                          COLLECTION OF ALPHANUMERIC
                                          CHARACTERS.
                                          LEADING SPECIAL CHARACTERS
                                          IGNORED. *)

VAR
  INTJ : TJ;                           (* STRING INDEX *)

BEGIN
  WHILE (JNTJ < ZJ) AND (ORD(ILINE[JNTJ]) >= ORD("+")) DO
    JNTJ := JNTJ+1;
  A := "          ";
  INTJ := AA;
  WHILE (JNTJ < ZJ) AND (INTJ < ZA) AND (ILINE[JNTJ] IN ["A".."9"]) DO
  BEGIN
    A[INTJ] := ILINE[JNTJ];            (* COPY CHARACTER TO TOKEN *)
    INTJ := INTJ+1;                    (* ADVANCE POINTERS *)
    JNTJ := JNTJ+1;
  END;
  RDRGNT := INTJ <> AA;                (* RETURN TRUE IF ANYTHING
                                          MOVED *)
  WHILE (JNTJ < ZJ) AND (ILINE[JNTJ] IN ["A".."9"]) DO
    JNTJ := JNTJ+1;                    (* SKIP REST OF TOKEN *)
END;  (* RDRGNT *)



PROCEDURE RDRSFT;                      (* SKIP FIRST TOKEN IN COMMAND
                                          LINE *)

VAR
  INRA : RA;                           (* SCRATCH *)
  INTB : TB;                           (* SCRATCH *)

BEGIN
  JNTJ := AJ;                          (* INITIALIZE SCAN *)
  INTB := RDRGNT(INRA);                (* THROW AWAY FIRST TOKEN *)
END;  (* RDRSFT *)



PROCEDURE RDRCMD                       (* TEST FOR AND EXECUTE COMMAND
                                          EXITS TO COMMAND EXIT IF
                                          COMMAND IS PROCESSED. *)

  (A:RA;                               (* POTENTIAL COMMAND KEYWORD *)
   PROCEDURE XKKCMD);                  (* PROCEDURE TO EXECUTE
                                          COMMAND *)

BEGIN
  IF INRA = A THEN
  BEGIN
    XKKCMD;                            (* EXECUTE COMMAND *)
    GOTO 11;                           (* EXIT *)
  END;
END;  (* RDRCMD *)



PROCEDURE RDLINE;                      (* GET NEXT INPUT LINE FROM
                                          USER *)

VAR
  INTC : TC;                           (* SCRATCH *)
  INTJ : TJ;                           (* STRING INDEX *)

BEGIN
  READLN;                              (* ADVANCE TO NEXT LINE *)
  INTJ := AJ;
  WHILE NOT EOLN AND (INTJ < ZJ) DO
  BEGIN
    READ(ICARD[INTJ]);                 (* COPY INPUT LINE *)
    INTJ := INTJ+1;
  END;
  WHILE NOT EOLN DO
    READ(INTC);                        (* SKIP REST OF INPUT LINE *)
  WHILE INTJ < ZJ DO
  BEGIN
    ICARD[INTJ] := " ";                (* BLANK REST OF LINE *)
    INTJ := INTJ+1;
  END;
  ICARD[ZJ] := ";";                    (* SET END OF COMMAND *)
  JNTJ := AJ;                          (* RESET INPUT LINE POINTER *)
END;  (* RDLINE *)



FUNCTION RDRNOV:TB;                    (* EXTRACT NEXT COMMAND
                                          FROM INPUT LINE.
                                          RETURNS TRUE IF NON-EMPTY
                                          COMMAND. *)

VAR
  INTJ : TJ;                           (* STORING POINTER *)

BEGIN
  WHILE (JNTJ < ZJ) AND (ICARD[JNTJ] = " ") DO
    JNTJ := JNTJ+1;                    (* SKIP LEADING BLANKS *)
  INTJ := AJ;
  WHILE (JNTJ < ZJ) AND (ICARD[JNTJ] <> ";") DO
  BEGIN
    ILINE[INTJ] := ICARD[JNTJ];
    INTJ := INTJ+1;
    JNTJ := JNTJ+1;
  END;
  IF (ICARD[JNTJ] = ";") AND (JNTJ < ZJ) THEN
    JNTJ := JNTJ+1;                    (* SKIP SEMI-COLON *)
  RDRNOV := INTJ <> AJ;                (* RETURN TRUE IF NON-EMPTY *)
  WHILE INTJ < ZJ DO
  BEGIN
    ILINE[INTJ] := " ";                (* BLANK FILL LINE *)
```

```
    INTJ := INTJ+1;
  ENO;
  ILINE[ZJ] := ";";                          (* STORE CONNANO TERMINATOR *(
  JNTJ :* AJ;                                (* PRESET COMMANO SCAN *)
ENO(  (* RORROV *)


FUNCTION RORNUN:TI;                          (* CRACK NURBER FROM COMMANO
                                                LIRE.  RETURNS NUMBER IF NO
                                                ERROR.  EKITS TO COMRANO EXIT
                                                IF ERROR. *(


VAR
  INTB : TB;                                 (* SIGN *)
  INTI : TI;                                 (* VALUE *(

BEGIN
  NHILE (JNTJ < ZJ) AND (ILINE[JNTJ) = " ") OO
    JNTJ (= JRTJ+1;                          (* SKIP LEAOING BLANKS *)
  IF ILINE(JNTJ) = "-" THEN
  BEGIN
    INTB := TRUE;                            (* NUMBER IS NEGATIVE *)
    JNTJ := JNTJ+1;                          (* AOVANCE CHARACTER POINTER *)
  ENO
  ELSE
  BEGIN
    INTB := FALSE;                           (* NURBER IS POSITIVE *)
    IF ILIRE(JNTJ) = "+" THEN
      JNTJ := JNTJ+1;                        (* SKIP LEAOING + *)
  ENO(
  INTI := 0;
  NHILE ILINE[JNTJ] IN ["0".."9"] OO
  BEGIN
    IF INTI < NAXINT/10 THEN
      IRTI := 10*INTI+ORD(ILINE[JNTJ])-ORO("0")
    ELSE
      RORERR(" NUNBER TOO LARGE              ");
    JNTJ := JNTJ+1(                          (* AOVANCE *)
  ENO;
  (F ILINE(JNTJ) IN ["A".."Z"] THEN
    RORERR(" OIGIT EXPECTEO                ");
  IF INTB TNEN
    INTI := -INTI(                           (* CORPLENENT IF NEGATIVE *)
  RORNUN := IRTI;                            (* RETURN RUMBER *)
ENO(  (* RORNUR *(


PROCEDURE BOACNO;                            (* COMMARO - SET UP POSITIOR *(

VAR
  INTN : TN;                                 (* COLOR *)
  INTS : TS(                                 (* POSITIOR ON BOARO *)

   PROCEOURE BOAAOV(A:TI);                    (* AOVANCE R FILES *)

   BEGIN
     IF IRTS+A < ZS THEN
       IRTS := IRTS+A
     ELSE
       IRTS := ZS;
   ENO;  (* BOAAOV *)



   PROCEOURE BOASTD(A:TP);                   (* STORE PIECE ON BOARO *)

   BEGIN
     BOARO.RBIS(IRTS) := A;
     IF INTS < ZS THEN
       INTS := INTS+1;
   ENO;  (* BOASTO *)



 BEGIR  (* BOACMD *)
   CLSTAT;                                   (* CLEAR STATUS FLAGS *(
   LSTNV := NULNV;                           (* CLEAR PREVIOUS NOVE *)
   FOR INTS := AS TC ZS OO
     BOARD.RBIS(IR(S) := NT;                 (* CLEAR BOARO *)
   INTN := LITE(
   INTS := B;
   REPEAT
     IF ILINE[JNTJ] IN ("P","R","N","B","O","K","L","O","1".."A"( TRER
     CASE ILINE(JNTJ( OF
       "P": BOASTO(XTUMP(EP,INTN))(
       "R": BOASTO(XTUMP(ER,INTN));
       "N": BOASTO(XTUMP(EN,INTN();
       "B": BOASTO(XTUMP(EB,INTN))(
       "O": BOASTO(XTUMP(EO,INTN();
       "K": BOASTO(XTUMP(EK,INTN));
       "L": INTN := LITE(
       "O": INTN := OARK(
       "1","2","I","4","5","6","7","A":
            BOAAOV(ORO(ILINE(JNTJ])-ORO("0")((
     END
     ELSE
       IF ILINE(JNTJ) IN ["A".."9"] THEN
       BEGIN
         FOR INTS := AS TO ZS DO
           BOARD.RBIS(INTS) := NT;
         CLSTAT;                             (* CLEAR STATUS *)
         RORERR(" ILLEGAL BOARD OPTION          ");
       END;
     JNTJ := JNTJ+1;
   UNTIL JNTJ = ZJ;
END;  (* BOACND *)


PROCEDURE ENDCNO;                            (* CONNANO - ENO PROGRAN *)
BEGIN
  GOTO 9;
END;  (* ENOCNO *)                           (* ENO PROGRAN *(


PROCEDURE GONCNO;                            (* CONNANO - GO N ROVES *)
```

```
BEGIN
  GOING := RORNUN;                           (* CRACK RUNBER *)
  IF GOING <= 0 THEN
    GOING := 1;
  GOTO II                                    (* EXECUTE NACRINES NOVE *(
ENO;  (* GONCMO *I


PROCEOURE IRICNO;                            (* COMMANO - INITIALIZE FOR A NEW
                                                GARE *)

BEGIN
  GOTO 1;                                    (* IRITIALIIE FOR A RER GARE *;
ERO;  (* INICMD *;



PROCEOURE LETCRO;                            (* COMMARO - CNANGE VARIABLE *)

LABEL
  21;                                        (* LET CORMAND EXIT *)

PROCEOURE LETONE                             (* TEST FOR ANO SET ONE
                                                VARIABLE *(
  (A:RA(                                     (* VARIABLE NANE *(
   VAR B:TI);                                (* VARIABLE *;

BEGIN
  IF A = INRA THEN
  BEGIN
    B (= RORNUM;                             (* GET VALUE *;
    GOTO 21(                                 (* EXIT *)
  ERO;
ENO;  (* LETONE *;


BEGIN
  IF RORGNT(INRA) THEN
  BEGIN
    LETONE("FKPSMO    ",FKPSMO);
    LETONE("FKSARO    ",FKSANO);
    LETONE("FMAXNT    ",FNAXNT);
    LETONE("FNOOEL    ",FNOOEL);
    LETORE("FPAOOR    ",FPADCR[F1(((
    LETORE("FPAOON    ",FPADCR[F2]);
    LETONE("FPAOOB    ",FPADCR[F3(((
    LETONE("FPAOOF    ",FPADCR[F4])(
    LETONE("FPAOKF    ",FPADCR(F5I)(
    LETONE("FPAOKB    ",FPADCR(F6]);
    LETORE("FPAOKN    ",FPADCR(F7();
    LETORE("FPAOKR    ",FPADCR[F8((;
    LETONE("FPBLOK    ",FPBLOK)I
    LETONE("FPCONN    ",FPCONN)(
    LETONE("FPFLNX    ",FPFLNK)I
    LETONE("FRDUBL    ",FRDUBL)I
    LETORE("FRK7TN    ",FRK7TN(I
    LETONE("FTRAOE    ",FTRAOE)I
    LETONE("FTROSL    ",FTROSL);
    LETONE("FTRPOK    ",FTRPOK)(
    LETONE("FTRPNR    ",FTRPWR);
    LETONE("FWKING    ",FWKING);
    LETONE("FNMAJR    ",FNRAJR)(
    LETONE("FNMINN    ",FWRINN);
    LETONE("FNPAWR    ",FMPANR);
    LETONE("FWROOK    ",FWROOK((
    LETONE("WINOON    ",WINOON);
    RORERR(" ILLEGAL LET VARIABLE NANE     "((
  ENO(
21:  (* LET COMMANO EXIT *I
ENO;  (* LETCMD *)


PROCEOURE PLECMO;                            (* COMMAND - PRINT VARIABLE *)

LABEL
  21;                                        (* PRINT LET COMMAND EXIT *(

PROCEOURE PRIONE                             (* TEST FOR ARO PRIRT VARIABLE *)
  (A:RA(                                     (* TEST VARIABLE RARE *)
   B:TI);                                    (* VARIABLE *I

BEGIN
  IF INRA = A THEN
  BEGIN
    RRITELN(A,B(;
    GOTO 21;                                 (* EXIT *(
  ENO;
ENO;  (* PRIONE *;


BEGIN  (* PLECND *;
  NHILE RORGNT(INRA) OO
  BEGIR
    PRIONE("FKPSMO    ",FKPSHO);
    PRIONE("FKSANO    ",FKSARO);
    PRIONE("FNAXRT    ",FRAKRT)(
    PRIONE("FNOOEL    ",FNOOEL(;
    PRIONE("FPAOOR    ",FPADCR[F1()(
    PRIORE("FPAOQN    ",FPADCR[F2]);
    PRIONE("FPAOQB    ",FPADCR[F3]);
    PRIORE("FPAOOF    ",FPADCR[F4])(
    PRIORE("FPAOKF    ",FPADCR[F5])I
    PRIORE("FPAOKB    ",FPAOCR(F6()(
    PRIONE("FPAOKN    ",FPADCR[F7I);
    PRIORE("FPAOKR    ",FPADCR[FA]);
    PRIONE("FPBLOK    ",FPBLOK);
    PRIONE("FPCONN    ",FPCORN);
    PRIONE("FPFLNX    ",FPFLNX);
    PRIONE("FRDUBL    ",FROUBL((
    PRIONE("FRK7TH    ",FRK7TH);
    PRIONE("FTRAOE    ",FTRAOE)(
    PRIONE("FTROSL    ",FTROSL(;
    PRIONE("FTRPOK    ",FTRPOK);
    PRIONE("FTRPNN    ",FTRPNN);
    PRIORE("FNKING    ",FNKING);
```

*Listing 1, continued:*

```
      PRIONE("FNMAJN     ",FNMAJN);
      PRIONE("FNMINN     ",FNMINN);
      PRIONE("FNPANN     ",FNPANN);
      PRIONE("FNROOX     ",FNROOK);
      PRIONE("NINOON     ",NINOON);
      RORERR(" ILLEGAL VARIABLE NAME          ");

21:  (* PRINT LET CONNANO EXIT *)
  END(
END;  (* PLECNO *)


PROCEDURE PRICNO;                        (* CONNANO - PRINT BOARO *)

BEGIN
  IF RORGNT(INRA) THEN
    PRINTB(NBORO)
  ELSE
    PRINTB(BOARO.RBIS);
END;  (* PRICNO *)


PROCEDURE PANCNO;                        (* CONNANO - PRINT ATTACK MAP *)

BEGIN
  WHILE RORGNT(INRA) OO
    IF INRA[AA] = "T" THEN
      PRINAN(ATKTO)
    ELSE
      IF INRA[AA] = "F" THEN
        PRINAN(ATKFR)
      ELSE
        RORERR(" ATTACK MAP NOT 'TO' OR 'FROM'");
END;  (* PANCNO *)


PROCEDURE POPCNO;                        (* CONNANO - PRINT OTHER STUFF *)

VAR
  INTQ : TQ;                             (* CASTLE TYPE INOEX *)

BEGIN
  WITH BOARO OO
  BEGIN
    WRITELN(XTNA(RBTN)," TO MOVE.");
    WRITELN(RBTS," ENPASSANT.");
    WRITELN("MOVE NUMBER",RBTI);
    FOR INTQ := LS TO OL OO
      IF INTQ IN RBSQ THEN
        WRITELN(XTQA(INTQ)," SIDE CASTLE LEGAL.");
  END;
END;  (* POPCNO *)


PROCEDURE PMVCNO;                        (* CONNANO - PRINT MOVE LIST *)

VAR
  INTW : TW;                             (* MOVES LIST INOEX *)

BEGIN
  LSTMOV;                                (* LIST LEGAL MOVES *)
  FOR INTW := AW TO JNTW-1 DO
  BEGIN
    WRITE(INTW:4," ");
    PRINOV(MOVES[INTW]);
    IF INTW/LPP = INTW DIV LPP THEN
      PAUSER;
  END;
END;  (* PMVCNO *)


PROCEDURE SNICNO;                        (* CONNANO - FLIP SWITCH *)

LABEL
  21;                                    (* SWITCH OPTION EXIT *)


  PROCEDURE SNIONE                       (* PROCESS ONE SWITCH *)
    (A:RA;                               (* SWITCH NAME *)
     VAR B:TB);                          (* SWITCH *)

  VAR
    INTJ : TJ;                           (* SAVE CONNANO INOEX *)

  BEGIN
    IF INRA = A THEN
    BEGIN
      INTJ := JNTJ;                      (* SAVE CURRENT POSITION *)
      IF RORGNT(INRA) THEN
      BEGIN
        IF INRA = "ON          " THEN
          B := TRUE                      (* TURN SWITCH ON *)
        ELSE
          IF INRA = "OFF         " THEN
            B := FALSE                   (* TURN SWITCH OFF *)
          ELSE
            JNTJ := INTJ;                (* RESTORE CURRENT POSITION *)
        PRISNI(A,B);                     (* PRINT SWITCH VALUE *)
      END
      ELSE
        PRISNI(A,B);
      GOTO 21;                           (* SWITCH OPTION EXIT *)
    END;
  END;  (* SNIONE *)

BEGIN  (* SNICNO *)
21:  (* SWITCH OPTION EXIT *)
  WHILE RORGNT(INRA) DO
  BEGIN
    SNIONE("EC          ",SWEC);
    SNIONE("PA          ",SWPA);
    SNIONE("PS          ",SWPS);
    SNIONE("RE          ",SWRE);
    SNIONE("SU          ",SWSU);
    SNIONE("TR          ",SWTR);
    RORERR(" INVALIO SWITCH OPTION          ")
  END;
END;  (* SNICNO *)


PROCEDURE STACNO;                        (* CONNANO - STATUS CHANGES *)

LABEL
  21;                                    (* STATUS CONNANO OPTION EXIT *)
VAR
  INRA : RA;                             (* CURRENT TOKEN *)
  INTN : TN;                             (* SIDE BEING PROCESSEO *)


  PROCEDURE STAEPF                       (* PROCESS EP FILE *)
    (A:RA;                               (* TEST TOKEN *)
     B:TF);                              (* EQUIVALENT FILE *)

  BEGIN
    IF A = INRA THEN
    BEGIN
      IF INTN = LITE THEN
        BOARO.RBTS := XTRFS[R6,B]
      ELSE
        BOARO.RBTS := XTRFS[R3,B];
      GOTO 21;                           (* EXIT STATUS OPTION *)
    END;
  END;  (* STAEPF *)


  PROCEDURE STACAK;                      (* ALLOW CASTLE KING SIDE *)

  BEGIN
    IF INTN = LITE THEN
      BOARO.RBSQ := BOARO.RBSQ + [LS]
    ELSE

      BOARO.RBSQ := BOARO.RBSQ + [OS];
  END;  (* STACAK *)


  PROCEDURE STACAQ;                      (* ALLOW CASTLE QUEEN SIDE *)

  BEGIN
    IF INTN = LITE THEN
      BOARO.RBSQ := BOARO.RBSO + [LL]
    ELSE
      BOARO.RBSO := BOARO.RBSO + [OL];
  END;  (* STACAQ *)


  PROCEDURE STAORK;                      (* SET BLACK OPTIONS *)

  BEGIN
    INTN := OARK;
  END;  (* STAORK *)


  PROCEDURE STAENP;                      (* SET ENPASSANT FILE *)

  BEGIN
    IF NOT RORGNT(INRA) THEN
    BEGIN
      CLSTAT;                            (* CLEAR STATUS *)
      RORERR(" ENPASSANT FILE OMITTEO         ");
    END;

    STAEPF("OR          ",F1);
    STAEPF("QN          ",F2);
    STAEPF("QB          ",F3);
    STAEPF("Q           ",F4);
    STAEPF("K           ",F5);
    STAEPF("KB          ",F6);
    STAEPF("KN          ",F7);
    STAEPF("KR          ",F8);
    CLSTAT;                              (* CLEAR STATUS *)
    RORERR(" ILLEGAL ENPASSANT FILE         ");
  END;  (* STAENP *)


  PROCEDURE STAGOS;                      (* SET SIOE TO MOVE *)

  BEGIN
    BOARO.RBTN := INTN;
    JNTN := INTN;
  END;  (* STAGOS *)


  PROCEDURE STALIT;                      (* SET WHITE OPTIONS *)

  BEGIN
    INTN := LITE;
  END;  (* STALIT *)


  PROCEDURE STANUM;                      (* SET MOVE NUMBER *)

  BEGIN
    BOARO.RBTI := RORNUM;
  END;  (* STANUM *)
```

```
PROCEDURE STAOPT                            (* TEST STATUS OPTION *)
  (A:RA;                                    (* TEST OPTION *)
   PROCEDURE STAXXX);                       (* PROCEDURE TO EXECUTE IF
                                               EQUAL *)

BEGIN
  IF INRA = A THEN
  BEGIN
    STAXXX;                                 (* EXECUTE PROCEDURE *)
    GOTO 21;                                (* EXIT STATUS OPTION *)
  END;
END;  (* STAOPT *)


BEGIN  (* STACMD *)
  CLSTAT;                                   (* CLEAR STATUS *)
  INTN := LITE;                             (* DEFAULT SIDE WHITE *)
21:  (* STATUS OPTION EXIT *)
  WHILE RDRGNT(INRA) DO
  BEGIN
    STAOPT('D         ',STADRK);
    STAOPT('EP        ',STAENP);
    STAOPT('G         ',STAGOS);
    STAOPT('L         ',STALIT);
    STAOPT('M         ',STAMUN);
    STAOPT('OO        ',STACAK);
    STAOPT('OOO       ',STACAQ);
    CLSTAT;
    RDRERR(' INVALID STATUS OPTION          ');
  END;
END;  (* STACMD *)


PROCEDURE WHACMD;                           (* COMMAND - WHAT? *)

BEGIN
  WRITELN(MOVMS);                           (* PRINT LAST MESSAGE *)
END;  (* WHACMD *)


BEGIN  (* READER *)
11: (* COMMAND EXIT *)
  WHILE NOT RDRMOV DO
    RDLINE;
  IF SWEC THEN
  BEGIN                                     (* ECHO LINE *)
    WRITE(' ');
    FOR INTJ := AJ TO ZJ-1 DO
      WRITE(ILINE[INTJ]);
    WRITELN;
  END;
  IF ILINE[AJ+1] IN ['A'..'M','Y','Z'] THEN
  BEGIN
    INRA := '          ';                   (* EXTRACT KEYWORD *)
    INRA[AA] := ILINE[AJ];
    INRA[AA+1] := ILINE[AJ+1];
    RDRSFT;                                 (* SKIP FIRST TOKEN *)
    RDRCMD('BO        ',BOACMD);
    RDRCMD('EN        ',ENDCMD);
    RDRCMD('GO        ',GONCMD);
    RDRCMD('IN        ',INICMD);
    RDRCMD('LE        ',LETCMD);
    RDRCMD('PB        ',PAMCMD);
    RDRCMD('PO        ',POPCMD);
    RDRCMD('PL        ',PLECMD);
    RDRCMD('PM        ',PMVCMD);
    RDRCMD('PR        ',PRICMD);
    RDRCMD('ST        ',STACMD);
    RDRCMD('SW        ',SWICMD);
    RDRCMD('WH        ',WHACMD);
    RDRERR(' INVALID COMMAND                ');
  END;
END;  (* READER *)


PROCEDURE MINENG                            (* GENERATE MINIMUM
                                               ENGLISH NOTATION *)
  (A:RM;                                    (* MOVE TO NOTATE *)
   B:RA);                                   (* LEADING COMMENT *)

VAR
  INTN : TN;                                (* MESSAGE INDEX *)

  PROCEDURE ADDCHR                          (* ADD CHARACTER TO MESSAGE *)
    (A:TC);                                 (* CHARACTER *)

  BEGIN
    MOVMS[INTN] := A;                       (* ADD CHARACTER *)
    IF INTN < ZN THEN
      INTN := INTN+1;                       (* ADVANCE POINTER *)
  END;  (* ADDCHR *)


  PROCEDURE ADDSQR                          (* ADD SQUARE TO MESSAGE *)
    (A:TS;                                  (* SQUARE TO ADD *)
     B:RD);                                 (* SQUARE SYNTAX *)

  BEGIN
    WITH B DO
    BEGIN
      IF RDPC THEN
        ADDCHR(XTUC[XTPU[NBORD[A]]]);
      IF RDSL THEN
        ADDCHR('/');
      IF RDKQ THEN
        IF XTSF[A] IN [F1..F4] THEN
          ADDCHR('Q')
        ELSE
          ADDCHR('K');
      IF RDNB THEN
        CASE XTSF[A] OF
          F1,F8: ADDCHR('R');
          F2,F7: ADDCHR('N');
```

```
          F3,F6: ADDCHR('B');
          F4   : ADDCHR('Q');
          F5   : ADDCHR('K');
        END;
      IF RDRK THEN
        IF JNTN = LITE THEN
          CASE XTSR[A] OF
            R1: ADDCHR('1');
            R2: ADDCHR('2');
            R3: ADDCHR('3');
            R4: ADDCHR('4');
            R5: ADDCHR('5');
            R6: ADDCHR('6');
            R7: ADDCHR('7');
            R8: ADDCHR('8');
          END
        ELSE
          CASE XTSR[A] OF
            R1: ADDCHR('8');
            R2: ADDCHR('7');
            R3: ADDCHR('6');
            R4: ADDCHR('5');
            R5: ADDCHR('4');
            R6: ADDCHR('3');
            R7: ADDCHR('2');
            R8: ADDCHR('1');
          END;
    END;
  END;  (* ADDSQR *)


  PROCEDURE ADDWRD                          (* ADD WORD TO MESSAGE *)
    (A:RA;                                  (* TEXT OF WORD *)
     B:TA);                                 (* LENGTH OF WORD *)

  VAR
    INTA : TA;                              (* CHARACTER INDEX *)

  BEGIN
    FOR INTA := AA TO B DO
      ADDCHR(A[INTA]);
  END;  (* ADDWRD *)


FUNCTION DIFFER                             (* COMPARE MOVES *)
  (A,B:RM)                                  (* MOVES TO COMPARE *)
  :TB;                                      (* TRUE IF MOVES ARE DIFFERENT *)

VAR
  INTB : TB;                                (* SCRATCH *)

BEGIN
  INTB := (A.RMFR <> B.RMFR) OR
          (A.RMTO <> B.RMTO) OR
          (A.RMCP <> B.RMCP);
  IF A.RMPR = B.RMPR THEN
    IF A.RMPR THEN
      DIFFER := INTB OR (A.RMPP <> B.RMPP)
    ELSE
      IF A.RMOO = B.RMOO THEN
        IF A.RMOO THEN
          DIFFER := INTB OR (A.RMQS <> B.RMQS)
        ELSE
          DIFFER := INTB
      ELSE
        DIFFER := TRUE
  ELSE
    DIFFER := TRUE;
END;  (* DIFFER *)


PROCEDURE SETSQD                            (* DEFINE SPECIFIC SQUARE
                                               DESCRIPTOR *)
  (A:TS;                                    (* SQUARE TO DESCRIBE *)
   B:RD;                                    (* SYNTAX TO USE *)
   VAR C:SR;                                (* SET OF POSSIBLE RANKS *)
   VAR D:SF);                               (* SET OF POSSIBLE FILES *)

BEGIN
  C := [R1..R8];                            (* INITIALIZE TO DEFAULTS *)
  D := [F1..F8];
  WITH B DO
  BEGIN
    IF RDKQ AND RDNB THEN
      D := [XTSF[A]];
    IF (NOT RDKQ) AND RDNB THEN
      CASE XTSF[A] OF
        F1,F8: D := [F1,F8];
        F2,F7: D := [F2,F7];
        F3,F6: D := [F3,F6];
        F4   : D := [F4];
        F5   : D := [F5];
      END;
    IF RDRK THEN
      C := [XTSR[A]];
  END;
END;  (* SETSQD *)


PROCEDURE MINGEN                            (* PRODUCE MINIMUM
                                               ENGLISH NOTATION FOR
                                               MOVES AND CAPTURES *)
  (A:RM;                                    (* MOVE OR CAPTURE *)
   B:TI;                                    (* FIRST SYNTAX TABLE ENTRY *)
   C:TI);                                   (* LAST SYNTAX TABLE ENTRY *)

LABEL
  21,                                       (* EXIT AMBIGUOUS MOVE SCAN *)
  22;                                       (* EXIT MINGEN *)

VAR
  INTG : TG;                                (* PROMOTION PIECE *)
  INTI : TI;                                (* SYNTAX TABLE INDEX *)
```

*Listing 1, continued:*

```
    INTN : TN;                             (* MOVES INDEX *)
    INLR : SR;                             (* RANKS DEFINED ON LEFT *)
    INRR : SR;                             (* RANKS DEFINED ON RIGHT *)
    INLF : SF;                             (* FILES DEFINED ON LEFT *)
    INRF : SF;                             (* FILES DEFINED ON RIGHT *)

  BEGIN
    FOR INTI := B TO C DO                  (* FOR EACH SYNTAX ENTRY *)
      WITH SYNTX(INTI) DO
      BEGIN
        IF A.RMPR THEN
          INTG := A.RMPP
        ELSE
          INTG := PB;
        SETSQQ(A.RMFR,RYLS,INLR,INLF); (* SET SQUARE SETS *)
        SETSQQ(A.RMTO,RYRS,INRR,INRF);
        FOR INTN := AN+1 TO JNTN-1 DO
          IF DIFFER(MOVES(INTN),A) THEN
            IF (NBORD(A.RMFR) = NBORD(MOVES(INTN).RMFR)) AND
                (A.RMCP = MOVES(INTN).RMCP) THEN
              WITH MOVES(INTN) DO
                IF (XTSR(RMFR) IN INLR) AND
                   (XTSR(RMTO) IN INRR) AND
                   (XTSF(RMFR) IN INLF) AND
                   (XTSF(RMTO) IN INRF) AND
                  ((RMPR AND (INTG = RMPP)) OR (NOT RMPR)) THEN
                  GOTO 21;                 (* ANOTHER MOVE LOOKS THE SAME *)

        (* NO OTHER MOVE LOOKS THE SAME *)
        ADDSQR(A.RMFR,RYLS);               (* ADD FROM SQUARE *)
        ADDCHR(RYCH);                      (* ADD MOVE OR CAPTURE *)
        ADDSQR(A.RMTO,RYRS);               (* ADD TO SQUARE *)
        GOTO 22;                           (* EXIT MINGEN *)
  21:   (* TRY NEXT SYNTAX *)
      END;
  22:   (* EXIT MINGEN *)
  END;  (* MINGEN *)


BEGIN  (* MINENG *)
  MOVMS := "                               ";
                                           (* CLEAR MESSAGE *)
   INTM := AN+1;                           (* INITIALIZE MESSAGE INDEX *)
   ADDWRD(B,ZA);                           (* ADD INITIAL COMMENT *)
   ADDWRD("-          ",2);
   WITH A DO
   BEGIN
     IF RMOO THEN                          (* CASTLE *)
     BEGIN
       ADDWRD("O-O        ",3);
       IF RMQS THEN
         ADDWRD("-O        ",2);
     END
     ELSE                                  (* NOT CASTLE *)
       IF RMCA THEN                        (* CAPTURE *)
         MINGEN(A,SYNCF,SYNCL)
       ELSE                                (* SIMPLE MOVE *)
         MINGEN(A,SYNMF,SYNML);
     IF RMPR THEN                          (* PROMOTION *)
     BEGIN
       ADDCHR("=");
       ADDCHR(XTGC(RMPP));
     END;
     ADDWRD(".         ",3);
     IF RMCH THEN                          (* CHECK *)
     BEGIN
       ADDWRD("CHECK     ",5);
       IF RMMT THEN                        (* CHECKMATE *)
         ADDWRD("MATE      ",4);
       ADDCHR(".");
     END
     ELSE
       IF RMMT THEN                        (* STALEMATE *)
         ADDWRD("STALEMATE.",10);
   END;
 END;  (* MINENG *)


 PROCEDURE MYMOVE;                         (* MAKE MACHINES MOVE *)

 VAR
   INRM : RM;                              (* THE MOVE *)

 BEGIN
   CREATE;                                 (* INITIALIZE DATA BASE *)
   INRM := MOVES(SEARCH);                  (* FIND THE BEST MOVE *)
   IF INRM.RMIL THEN
   BEGIN                                   (* NO MOVE FOUND *)
     GOING := 0;
     IF LSTMV.RMCH THEN                    (* CHECKMATE *)
       WRITELN(" CONGRATULATIONS.")
     ELSE                                  (* STALEMATE *)
       WRITELN(" DRAWN. ")
   END
   ELSE
   BEGIN
     MINENG(INRM,"  MY MOVE ");            (* TRANSLATE MOVE TO ENGLISH *)
     WRITELN(MOVMS);                       (* TELL THE PLAYER *)
     THEMOV(INRM);                         (* MAKE THE MOVE *)
     IF SWSU THEN
       WRITELN(BOARD.RBTI,".",NODES," NODES.",RSTVL(AK));
   END;
 END;  (* MYMOVE *)


 PROCEDURE YRMOVE;                         (* MAKE PLAYERS MOVE *)

 LABEL
   11, 12, 13, 14, 15,                     (* SYNTAX NODES *)
   16,                                     (* SYNTAX ERROR *)
   17,                                     (* AMBIGUOUS MOVE *)
   18;                                     (* NORMAL EXIT *)

 VAR
   INTB : TB;                              (* VALID MOVE FOUND *)
   INTC : TC;                              (* CURRENT CHARACTER *)
   INTN : TJ;                              (* MOVES INDEX *)

   INTP : TP;                              (* MOVING PIECE *)
   INCP : TP;                              (* CAPTURED PIECE *)
   IFCA : TO;                              (* CAPTURE *)
   IFPR : TO;                              (* PROMOTION *)
   IFOO : TO;                              (* CASTLE *)
   IFOS : TO;                              (* QUEEN SIDE CASTLE *)
   INTG : TG;                              (* PROMOTION TYPE *)
   IFMV : TB;                              (* MOVE FOUND *)

   IFLD : TB;                              (* R, N, OR B ON LEFT *)
   IFLF : TO;                              (* K OR Q ON LEFT *)
   IFRD : TO;                              (* R, N, OR B ON RIGHT *)
   IFRF : TB;                              (* K OR Q ON RIGHT *)

   INLF : SF;                              (* FILES ON LEFT *)
   INLR : SR;                              (* RANKS ON LEFT *)
   INRF : SF;                              (* FILES ON RIGHT *)
   INRR : SR;                              (* RANKS ON RIGHT *)

   INRM : RM;                              (* THE MOVE *)

   FUNCTION NCHIN                          (* DETERMINE IF NEXT INPUT
                                              CHARACTER IS NOT IN A GIVEN
                                              SET *)
     (A:SC;                                (* SET OF CHARACTERS TO CHECK *)
      PROCEDURE YRMXXX)                    (* SEMANTICS ROUTINE TO CALL
                                              IF NEXT CHARACTER IS IN SET *)
     :TO;                                  (* TRUE IF CHARACTER IS NOT IN
                                              SET *)

   VAR
     INTO : TO;                            (* SCRATCH *)

   BEGIN
     INTO := NOT (INTC IN A);
     IF NOT INTO THEN
     BEGIN
       YRMXXX;                             (* EXECUTE SEMANTICS ROUTINE *)
       JNTJ := JNTJ+1;                     (* ADVANCE PAST CHARACTER *)
       WHILE (JNTJ < ZJ)
         AND ((ILINE(JNTJ) = " ") OR (ORD(ILINE(JNTJ)) > ORD(ZC))) DO

        JNTJ := JNTJ+1;                    (* SKIP BLANKS *)
      INTC := ILINE(JNTJ);                 (* NEXT CHARACTER *)
      IF (INTC = ".") OR (INTC = ";") THEN
        GOTO 18;                           (* EXIT SCAN *)
    END;
    NCHIN := INTO;                         (* RETURN TRUE IF CHARACTER IS
                                              NOT IN STRING *)
  END;  (* NCHIN *)


  PROCEDURE YRMHIT;                        (* FOUND A MOVE.  EXITS
                                              TO AMBIGUOUS MOVE IF THIS
                                              IS THE SECOND POSSIBLE MOVE.
                                              SAVES THE MOVE IN INRM
                                              OTHERWISE.  *)

  BEGIN
    IF IFMV THEN GOTO 17;                  (* SECOND POSSIBLE MOVE *)
    IFMV := TRUE;                          (* FIRT POSSIBLE MOVE *)
    INRM := MOVES(INTN);                   (* SAVE MOVE *)
  END;  (* YRMHIT *)


  PROCEDURE YRMCOM;                        (* COMPARE SQUARES.  CALLS YRMHIT
                                              IF MOVES(INTN) MOVES THE
                                              RIGHT TYPE OF PIECE, CAPTURES
                                              THE RIGHT TYPE OF PIECE, AND
                                              MOVES TO AND FROM POSSIBLE
                                              SQUARES *)

  BEGIN
    WITH MOVES(INTN) DO
      IF (XTSR(RMFR) IN INLR) AND
         (XTSF(RMFR) IN INLF) AND
         (XTSR(RMTO) IN INRR) AND
         (XTSF(RMTO) IN INRF) AND
         (NOT RMIL) AND
         (BOARD.RBIS(RMFR) = INTP) THEN
        IF RMCA = IFCA THEN
          IF RMCA THEN
            IF RMCP = INCP THEN
              YRMHIT
            ELSE
          ELSE
            YRMHIT;
  END;  (* YRMCOM *)


  PROCEDURE YRMCAP;                        (* SEMANTICS - CAPTURE *)

  BEGIN
    IFCA := TRUE;
  END;  (* YRMCAP *)


  PROCEDURE YRMCAS;                        (* SEMANTICS - CASTLE *)

  BEGIN
    IFOO := TRUE;
  END;  (* YRMCAS *)


  PROCEDURE YRMCPC;                        (* SEMANTICS - CAPTURED PIECE *)
```

```
BEGIN
  CASE INTC OF
   "P": INCP I= KTUMP(EP,OTHER(JNTN((]
   "R": INCP 1= XTUMP(ER,OTHER(JNTN]](
   "N": INCP I= XTUMP(EN,OTHER(JNTN((]
   "B": INCP I= KTUMP(EB,OTHER(JNTN(](
   "Q": INCP I= XTUMP(EO,OTHER(JNTN(((
  END;
END;  (* YRNCPC *)


PROCEOURE YRNCOS(                        (* SENANTICS - CASTLE LONG *(

BEGIN
  IFOS I= TRUE(
END;  (* YRNCOS *)


PROCEDURE TRNLKO;                        (* SENANTICS - K OR O ON LEFT *(

BEGIN
  CASE INTC OF
   "K": INLF I= (FS..F8( * INLF(       (* KING SIOE *(
   "Q": INLF I= (F1..F4( * INLF(       (* QUEEN SIDE *(
  END;
  IFLF I= TRUE;
END(  (* YRNLKO *)


PROCEOURE YRNLRB(                        (* SENANTICS - R, N, ON B ON
                                            LEFT *(

BEGIN
  CASE INTC OF
   "R":  INLF I= (F1,F8] * INLF(       (* ROOK FILE *)
   "N":  INLF I= (F2,F7( * INLF(       (* KNIGHT FILE *(
   "B":  INLF I= (F3,F6( * INLF;       (* BISHOP FILE *I
  END;
  IFLO I= TRUE;
END;  (* YRNLRB *I


PROCEOURE TRNLRK(                        (* SENANTICS - RANK ON LEFT *)

BEGIN
  IF JNTN = LITE THEN

    CASE INTC OF
     "1": INLR I= (R1(;
     "2": INLR I= (R2(;
     "3": INLR I= (R3]]
     "4": INLR I= IR4]]
     "5": INLR I= IR5]]
     "6": INLR I= IR6]]
     "7": INLR I= ]R7](
     "8": INLR I= (R8((
    END
  ELSE
    CASE INTC OF
     "1": INLR I= ]R8]]
     "2": INLR I= IR7]]
     "3": INLR I= (R6((
     "4": INLR I= IR5]]
     "5": INLR I= (R4]]
     "6": INLR I= IR3]]
     "7": INLR I= (R2((
     "8": INLR I= (R1]]
    END(
END(  (* TRNLRK *)


PROCEOURE YRNNUL;                        (* SENANTICS - NULL *(

BEGIN
END(  (* YRNNUL *)


PROCEDURE YRNPCN;                        (* SENANTICS - PIECE NOVEO *(

BEGIN
  CASE INTC OF
   "P": INTP I= XTUMP(EP,JNTN]]         (* PANN *(
   "R": INTP I= XTUMP(ER,JNTN](         (* ROOK *(
   "N": INTP I= XTUMP(EN,JNTN((         (* KNIGNT *(
   "B": INTP I= XTUMP(EB,JNTN]]         (* BISNOP *(
   "Q": INTP I= XTUMP(EO,JNTN(]         (* QUEEN *)
   "K": INTP I= XTUMP(EK,JNTN((         (* KING *(
  END;
END(  (* YRMPCN *)


PROCEOURE YRNPRO(                        (* SENANTICS - PRONOTION *(

BEGIN
  CASE INTC OF
   "R": INTG I= PR(                     (* ROOK *(
   "N": INTG I= PN(                     (* KNIGHT *I
   "B": INTG I= PB(                     (* BISHOP *(
   "Q": INTG I= PQ;                     (* QUEEN *)
  END(
  IFPR I= TRUE;
END(  (* YRNPRO *(


PROCEOURE YRNRKO(                        (* SENANTICS - K OR O ON RIGHT *(

BEGIN
  CASE INTC OF
   "K": INRF I= (FS..F8( * INRF(       (* KING SIDE *)
   "Q": INRF I= (F1..F4( * INRF(       (* QUEEN SIDE *)
  END(
    IFRF I= TRUE;
  END;  (* YRNLKO *(


  PROCEDURE TRNRRB;                      (* SENANTICS - R, N, OR B ON
                                            RIGNT *I

  BEGIN
    CASE INTC OF
     "R":  INRF I= [F1,F8( * INRF(     (* ROOK FILE *(
     "N":  INRF I= [F2,F7( * INRF;     (* KNIGNT FILE *)
     "B":  INRF I= [F3,F6( * INRF;     (* BISNOP FILE *(
    END(
    IFRO I= TRUE;
  END;  (* YRNLRB *)


  PROCEOURE YRNRRK;                      (* SENANTICS - RANK ON RIGNT *(

  BEGIN
    IF JNTN = LITE TNEN
      CASE INTC OF
       "1": INRR I= (R1((
       "2": INRR I= (R2](
       "3": INRR I= (R3(;
       "4": INRR I= [R4((
       "5": INRR I= (R5(;
       "6": INRR I= [R6];
       "7": INRR I= [R7(;
       "8": INRR I= [R8(;
      END
    ELSE
      CASE INTC OF
       "1": INRR I= (R8(;
       "2": INRR I= [R7(;
       "3": INRR I= [R6(;
       "4": INRR I= (R5];
       "5": INRR I= [R4(;
       "6": INRR I= [R3(;
       "7": INRR I= [R2];
       "8": INRR I= (R1(;
      END;
  END;  (* YRMLRK *)



BEGIN  (* YRNOVE *).
  INTB I= FALSE;
  WHILE NOT INTB OO
  BEGIN
    READER(                              (* READ NEXT NOVE *(
    LSTNOV;                              (* LIST LEGAL NOVES *I
    IFCA I= FALSE(
    IFPR I= FALSE(
    IFOO I= FALSE;
    IFQS I= FALSE(
    IFLO I= FALSE;
    IFLF I= FALSE(
    IFRO I= FALSE;
    IFRF I= FALSE;
    INTP I= NT;
    INCP I= NT;
    INLF I= (F1..F8((
    INRF I= IF1..F8];
    INLR I= (R1..R8(;
    INRR I= (R1..R8(;

    INTC I= ILINE(JNTJ](

    IF      NCHIN(["P","R","N","B","Q","K"],TRNPCN( THEN GOTO 14(
    IF      NCHIN(["/"(                  ,YRNNUL( THEN GOTO 11(
    IF      NCHIN(["K","Q"(              ,YRNLKO( THEN(
    IF      NCHIN(["R","N","B"(          ,TRNLRB( THEN(
    IF      NCHIN(["1".."8"(             ,TRNLRK( THEN;
11:  (* LEFT SIDE DONE *(
    EF NOT NCHIN(["-"]                   ,TRNNUL( THEN GOTO 12;
    IF      NCHIN(["*","K"(              ,TRNCAP( THEN GOTO 18(
    IF      NCHIN(["P","R","N","B","Q"(  ,YRMCPC( THEN GOTO 18(
    IF      NCHIN(["/"(                  ,TRNNUL( THEN GOTO 13(
12:  (* RIGHT SIOE SQUARE *)
    IF      NCNIN(["K","O"(              ,YRNRKO( THEN(
    IF      NCHIN(["R","N","B"]          ,TRNRRB( THEN;
    IF      NCHIN(["1".."8"(             ,YRNRRK( THEN(
13:  (* PRONOTION *(
    IF      NCNIN(["="]                  ,YRNNUL( THEN GOTO 15(
    IF      NCHIN(["R","N","B","Q"(      ,YRMPRO( THEN GOTO 18(
    GOTO 15(

14:  (* CASTLING *(
    IF      NCHIN(["O","8"(              ,YRNNUL( THEN GOTO 18(
    IF      NCNIN(["-"(                  ,YRNNUL( THEN GOTO 18;
    IF      NCHIN(["O","8"]              ,YRNCAS( THEN GOTO 18(
    IF      NCHIN(["-"(                  ,YRNCQS( THEN GOTO 15(
    IF      NCNIN(["O","8"(              ,YRNNUL( THEN GOTO 16(
15:  (* SYNTAX CORRECT *)

    IF IFRF AND NOT IFRO THEN
      INRF I= INRF * [F4,F5((             (* SELECT K OR O FILE *)
    IF IFLF AND NOT IFLO THEN
      INLF I= INLF * (F4,F5];             (* SELECT K OR O FILE *)
    IFNV I= FALSE(                        (* NO NOVE FOUNO YET *(
    INTN I= AN;                           (* INITIALIZE INOEX *)
    WHILE INTN < JNTN OO
      WITH NOVES(INTN( OO
      BEGIN
        IF RNPR = IFPN THEN
          IF RNPR THEN
            IF RMPP = INTG THEN            (* CORRECT PRONOTION TYPE *)
              YRMCON                       (* CONPARE SQUARES ANO PIECES *(
            ELSE
          ELSE                             (* NOT PRONOTION *)
            IF RNOO = IFOO THEN
              IF RMOO THEN                 (* CASTLING *(
                IF RNOS = IFOS THEN        (* CASTLING SANE WAY *)
                  YRNWIT
```

*Listing 1, continued:*

```
            ELSE
          ELSE                              (* NOT CASTLING *)
            YRNCOM;                         (* COMPARE SQUARES AND PIECES *)
        INTN := INTN+1;                     (* ADVANCE MOVES INDEX *)
      END;
    IF IFMV THEN                            (* ONE MOVE FOUND *)
    BEGIN
      MINENG(INRM,"YOUR MOVE ");            (* CONVERT TO OUR STYLE *)
      WRITELN(MOVMS);                       (* PRINT MOVE *)
      THEMOV(IMRM);                         (* MAKE THE MOVE *)
      INTB := TRUE;                         (* EXIT YRMOVE *)
    END
    ELSE                                    (* NO MOVES FOUND *)
      WRITELN(" ILLEGAL MOVE.");
    GOTO 18;                                (* EXIT *)

16:  (* SYNTAX ERROR *)
    WRITELN(" SYNTAX ERROR.");
    GOTO 18;                                (* EXIT *)

17:  (* AMBIGUOUS MOVE *)
    WRITELN(" AMBIGUOUS MOVE.");
18:  (* EXIT *)
  END;
END;  (* YRMOVE *)


BEGIN  (* THE PROGRAM *)
  WRITELN(" HI.  THIS IS CHESS .5");
  INICON;                                   (* INITIALIZE CONSTANTS *)

1:  (* INITIALIZE FOR A NEW GAME *)
  INITAL (BOARD);                           (* INITIALIZE FOR A NEW GAME *)
  REPEAT
    REPEAT
      YRMOVE;                               (* EXECUTE PLAYERS MOVE *)
    UNTIL SWRE;

2:  (* EXECUTE MACHINES MOVE *)
    REPEAT
      MYMOVE;
      IF GOING > 0 THEN
        GOING := GOING-1;
    UNTIL GOING = 0;
  UNTIL FALSE;

9:  (* END OF PROGRAM *)
END.
```

# Creating a Chess Player

## Part 4: Thoughts on Strategy

**Peter W Frey**
**Larry R Atkin**

The chess program that we have presented in parts 2 and 3 of this series (November 1978 and December 1978 BYTE, pages 162[1] and 140[2], respectively) represents a modern implementation of the basic type A strategy described by Shannon in 1950 (see references). If run on a powerful computer, this type of program can play a reasonably good game of chess. Its major weakness lies in its inability to engage in long-range planning. In many middle and end game positions, it will make seemingly aimless moves. Once it attains a position which optimizes the general heuristic goals of its evaluation function, it is faced with the prospect of finding a move which alters the position as little as possible. If the opponent is skillful in developing a long-range attack while not providing any immediate targets, the machine may simply shuffle its pieces back and forth until its position becomes hopeless. The absence of reasonable goal directed behavior is a common limitation of problem solving techniques which are based solely on forward search. The solution of this problem would have important implications for a wide variety of artificial intelligence tasks.

To play a strong game of chess, it is necessary to have a plan. To have a plan, however, the program must recognize specific patterns and relate them to appropriate goals. This, in turn, requires that the program have access to the detailed kind of chess knowledge which is characteristic of the skilled human player. Thus, we seem to have come round in a circle. In order to avoid selective searching, we have adopted a strategy which does not require very much chess knowledge. In examining the weaknesses of this approach, we discover that the forward search can only be truly successful if we have a clear idea of what we are looking for. To know what we are looking for, however, we must have more knowledge about chess.

So where do we go from here? The highly skilled players who are familiar with the chess programming literature (notably, Berliner, Botvinnik and Levy) are unanimous in their enthusiasm for a selective search strategy. Berliner (see references), for example, advocates a procedure in which very small (for a computer) look-ahead trees are generated, eg: 200 to 500 nodes. His idea is that the program should make an intensive analysis at each node "in order to ascertain the truth about each issue dealt with." Chess knowledge should play a primary role in directing the tree search. The search itself would discover additional relevant information and this would provide an even more knowledgeable focus for the search. This procedure is analogous to the progressive deepening technique which de Groot discovered in the human grandmaster and is the exact antithesis of the brute force (type A) strategy (see October 1978 BYTE, "Creating a Chess Player, An Essay on Human and Computer Chess Skill," page 182[3]).

The efforts of the last decade have demonstrated that the selective search strat-

1. Page 117 of this edition.
2. Page 131 of this edition.
3. Page 107 of this edition.

egy is harder to implement than the full-width approach. In addition, full-width searching has consistently produced superior chess. Despite this, there is hardly anyone familiar with chess programming who does not believe that further progress depends on increasing the amount of chess knowledge in the program. The key question is not whether this should be done but how to do it. Since the selective search approach has not led to notable progress, perhaps it is time to consider a different approach.

We believe that a viable alternative exists which combines the proven virtues of the full-width procedure with the potential advantage of a goal-directed search. The central idea is the development of a unique evaluation function for each position. In addition to the general heuristics which are presently employed, evaluations should consider features which are germane to appropriate goals.

According to this plan, move selection would involve two separate stages. In the first phase, a static analysis of the position would be made in an attempt to discover key patterns. This process would involve a hierarchical analysis in which the features of the position would be compared with a general set of library patterns. Highly specific features would be identified and relevant chess-specific knowledge would be accessed. This information, including appropriate short term and long term goals, would be used to construct a conditional evaluation function which would assess the usual general features (eg: material, mobility, King safety, etc) and also other features which are meaningful only in specific situations. Once the conditional evaluation function has been constructed, the second phase of analysis would begin, a conventional full-width tree search employing the special evaluation function.

The first phase of this process would rely heavily on domain specific knowledge (ie: information about chess). It would require a pattern recognition facility and an organizational plan for storing a vast amount of chess knowledge in a manner conducive to rapid retrieval. When this first phase was successful in identifying appropriate goals and producing relevant modifications in the evaluation function, the full-width search which followed would select a move which was thematic with the appropriate goal. If the first phase were unable to identify a key feature, the evaluation function would employ the same general heuristics which it presently uses. For this reason, the pattern recognition and information retrieval modules can be gradually implemented without a lengthy period in which serious blunders are frequent occurrences. This is a major advantage that the conditional evaluation function has in comparison to a selective search strategy.

## Chess Structure

To implement a conditional evaluation function, it is necessary to develop a hierarchical descriptive structure for chess. At the top level, one can make the conventional distinctions between the opening, the middle game, and the end game. Within each of these three major divisions, there would be many specific subdivisions. Within each subdivision, there would be many specific variations.

The opening has three major themes: to develop a pawn structure which is favorable for you but unfavorable for your opponent; to increase the mobility of your minor pieces and limit the mobility of your opponent's minor pieces; and to castle as soon as possible and delay your opponent's opportunity to castle. These general goals provide a framework for evaluating specific variations. They do not provide a specific prescription for selecting a move because a sequence of moves which is thematic with these goals may have a tactical refutation. An apparently good move may not work because it loses material. For this reason, general principles are best applied at the terminal points of a look-ahead search rather than being used as a checklist for selecting the most thematic move as advocated by Church and Church in *Chess Skill in Man and Machine* (see references).

The tournament player who knows opening theory as well as many specific move variations will have a clear advantage over an opponent who knows the general principles but is not familiar with the specific variations. For this reason, tournament players and good chess programs rely on a library of memorized opening variations. The contestant who has carefully planned his opening variations can often gain an important advantage early in the game. To maximize the benefit of a well-prepared opening library, it is also necessary to continue the general theme of the opening once the predigested move sequences have been exhausted. At this stage it is necessary to have a conditional evaluation function. When the machine leaves the library and starts to use a look-ahead procedure to calculate its move, it should use an evaluation function that augments general opening principles with special goals which are thematic with that type of opening.

A portion of the work required to implement this proposal has already been started. Chess specialists have prepared highly detailed analyses of specific opening variations and have developed well-defined rules for categorizing different move sequences into specific subdivisions. For example, a game which starts (1) P-K4, P-K3 is labeled as the French defense. If the game continues (2) P-Q4, P-Q4; (3) N-QB3, B-N5, it is called the Nimzovich (or Winawer) variation of the French defense. If it continues (2) P-Q4, P-Q4; (3) N-QB3, N-KB3, the game is labeled as the classical variation. A continuation of (2) P-Q4, P-Q4; (3) N-QB3, PxP is called either the Rubinstein variation or the Burn variation depending upon subsequent moves. A different approach develops from (2) P-Q4, P-Q4; (3) N-Q2, which is labeled as the Tarrasch variation. And there are many more. The important point, however, is that each of these variations can be objectively identified, and that for each there are well-developed strategical ideas and specific immediate goals. These ideas can be stored in the opening library and can be retrieved when the machine leaves the library. In addition to general opening heuristics, the evaluation function would reflect the specific theoretical ideas which are appropriate to the particular opening at hand. In principle, this idea can be implemented without difficulty. In practice, however, a tremendous amount of chess knowledge is needed and hours and hours of effort are required. To our knowledge no serious attempt has yet been made to implement this strategy. The information on opening theory is needed only once during a game and thus could be stored on disk, since rapid access is not critical.

### Pattern Recognition and the Middle Game

From a conceptual point of view, the application of chess knowledge to the evaluation function in the middle game is much more challenging. In this case, pattern recognition becomes an important ingredient. In implementing a goal oriented move selection strategy, Church and Church limited their middle game strategy to either a Kingside attack, a Queenside attack, or concentration on a weak point (ie: a target). The Kingside or Queenside attack is triggered when the machine determines that it has superior forces on one side or the other. This determination can be based on who controls key squares. In calculating the power relationship of different pieces over given squares, it is important to note that less valuable pieces exert more control than valuable pieces. A pawn has greater control over territory than a Queen because it is harder to dislodge. If an attack on one side or the other is deemed appropriate, the evaluation function can be modified to give an extra bonus for moves which augment the attack on that side and for moves which increase the pressure on critical squares.

Pattern analysis is also important in detecting an appropriate target. There are several well-known chess relations which provide obvious targets for attack. One is the *backward pawn* which is prevented from advancing by a pawn or a minor piece. Another natural target is the minor piece which is pinned to the King or Queen. The third is the overworked piece, a key element in the defense against two or more different attacks. If the latter is removed in an exchange, the pieces it is defending will be open for attack. A fourth natural target is a square which would permit a Knight to fork two major pieces (ie: Rook, Queen, King) or a Bishop to skewer two major pieces. If the machine threatens to control that square and to locate an appropriate piece there, the opponent will be forced to devise a defense. Once one of these targets has been detected, the evaluation function can be modified to give a bonus for moves directed at the target. In addition, a plan might be devised to encourage the use of a decoy (a pawn or minor piece which is sacrificed to bring an important piece to a particular square) or to capture a piece which is serving an important defensive function.

### A Chess "Snapshot"

In the past, programmers have attempted to implement such plans by using a selective search (eg: Berliner, Zobrist and Carlson) or by using no search at all (eg: Church and Church). Zobrist and Carlson (see references) have developed an innovative technique in which "computer snapshots" are devised which summarize important piece relationships such as attacks, pins, skewers, forks, etc, which presently exist in the given position, or which could occur after one or two moves. Each snapshot is given a weight based on the relative values of the pieces involved and the location of the pieces in respect to the opposing King and the center of the board. The weighted snapshots are then used to select moves for inclusion in a Shannon type B tree search. This procedure provides considerable goal direction to the move selection process.

Although the Zobrist-Carlson snapshot procedure has much to offer (including a highly efficient bit map implementation strategy), it incorporates a common problem shared by all selective search techniques. Occasionally an important continuation is overlooked and this results in the selection of an inappropriate move which may be a gross blunder. By implementing the plans derived from the computer snapshots in the form of a conditional evaluation function, instead, the program can benefit from goal directedness without risking the oversights which are characteristic of selective searching. In this way, the machine can retain the benefits of the full-width search and at the same time engage in strategic planning.

There is a special class of positions for which this approach is especially appropriate. In his thesis at Carnegie-Mellon University Berliner described a special problem, the horizon effect, which plagues the conventional look-ahead approach (see *Chess Skill in Man and Machine,* pages 73 thru 77). One version of this problem involves a piece which is trapped and cannot be saved. Forward searching programs often engage in a bit of foolishness by making forcing but poor moves (such as attacking pieces with pawns or sacrificing pawns for no advantage) which delay the capture of the trapped piece and push its eventual loss beyond the horizon of the tree search. By doing this, the program erroneously concludes that the piece is safe, when in reality the planned move sequence weakens a reasonable position and is still insufficient to save the piece. In this type of situation, the trapped piece should be given up for lost and the program should do its best to take advantage of the tempo required by the opponent to capture the piece. A piece whose time has come is sometimes referred to as a desperado. The only option available is to make the opponent pay as dearly as possible for the capture. If the desperado can be traded for a pawn or a piece of lesser value, this is preferable to being given up for nothing.

This strategy can be implemented with a conditional evaluation function by simply assuming that the trapped piece has a material value of zero. This change would cause the search process to trade the piece for the highest valued candidate that can be found. This is obviously better than having the program engage in useless sacrifices of position and material in a hopeless attempt to resurrect a lost piece. The key element to this implementation is the ability to determine when a piece is truly lost and can be labeled as a desperado. This is a very difficult problem even for a very sophisticated pattern analysis facility.

### End Game Considerations

The most interesting application of the conditional evaluation function is in the end game. Because end game strategy is highly dependent on the specific characteristics of the position, a general purpose evaluation function is not very effective. It is necessary to understand what is required in a given position and then select moves which are clearly directed at an appropriate goal. Church and Church list three common goals in the end game: to mate the opponent's King, capture a weak pawn, or promote a pawn. In this case, pattern analysis is important. First the machine must be able to identify the position as one belonging to the end game. Then it has to determine whether a mate attempt is reasonable or whether a pawn can be captured or promoted. Church and Church (see *Chess Skill in Man and Machine*, pages 151 thru 154) describe a general strategy for identifying and capturing a weak pawn. Although their approach does not involve a forward tree search, the specific techniques which they describe can be adapted to the full-width search strategy. Let us consider several specific end game positions involving either a mate, a pawn capture, or a pawn promotion.

For a number of mating situations, a specific algorithm (step-by-step instructions) or a complete lookup table can be developed to produce mate in a minimum number of moves. Typical applications would be King and Queen versus King; King and Rook versus King; and King, Bishop, and Knight versus King. The mating algorithm for each case would include rules for assigning the potential piece relationships into a few general categories, and a prescription for an appropriate type of move for each category. This approach requires no search. A second approach involving a lookup table is even more explicit. An appropriate move is stored in a table for every possible piece configuration. To play the mate perfectly, the machine uses the position to determine an address in the table and then simply reads the correct move.

Both of these procedures are perfectly feasible and avoid many problems which can be encountered in the end game. The limitation of this approach is that there are a very large number of mating situations and a tremendous amount of work would be required to make a detailed analysis of each one. In addition, this strategy requires the storage of a great deal of information which would be used only infrequently.

A third approach, and one which is thematic with the idea of conditional evaluations, is to make a small modification in the evaluation function for each specific mating situation. The notion is that a shallow search combined with a few key ideas should suffice to produce a mate in a reasonable number of moves. With King and Queen or King and Rook versus King, it is sufficient for the program to "know" that the defending King must be forced to the edge. To do this, the program simply needs to add bonus points to the evaluation function when the defending King is near the edge. The size of the bonus should be a linear function of closeness to the edge. This modification of the evaluation function causes the minimax search to select a pathway in the look-ahead tree which forces the defending King to the edge.

With King, Bishop, and Knight against King, the job is slightly more complicated. In this case it is important to know that the defending King must be forced to one of the two corners having the same color as the Bishop's squares. The trick is to add a large bonus when the defending King is on the appropriate corner squares and a smaller credit when it is near these corners. This modification will cause the minimax procedure to find a sequence of moves which forces the defending King into one of the appropriate corners. The general theme is that the full-width search is a powerful device by itself and that the addition of a small amount of chess knowledge is sufficient to produce the desired outcome.

## Kings and Pawns in the End Game

Some of the most challenging positions in the end game involve only Kings and pawns. Many of these require an approach which is more sophisticated than those described previously. Consider, for example, the position diagrammed in figure 1. This is a modification of a position presented in Berliner's thesis which demonstrates one of the major weaknesses of a full-width forward search. White has a pawn on f6 which could advance and be promoted if the Black King were out of the way. *[Algebraic notation is used throughout this article to designate chessboard squares. The horizontal rows (ranks) are numbered from 1 to 8, starting at the bottom (White). The files are labeled a through h from left to right . . . . CM]* To win, White must do an end run with his King and bring it to the aid of the pawn. Since Black cannot attack White's pawns on c3 or g5 without leaving the passed pawn, he is helpless to stop White's maneuver. Although this analysis is obvious at a glance to an experienced player, a program that discovers truth by doing a full-width search is faced with a difficult problem. In order to determine that the King can force promotion of the pawn, White must complete a look-ahead search of approximately 35 plies. This is beyond the scope of even the most powerful computer. If the machine employs a general purpose algorithm which encourages the King to centralize its position during the end game, it will search for a pathway which eventually places it on its present square (f4) or one of the neighboring squares (e3 or f3). Because of this, the correct sequence of moves would never be discovered.

In order for a full-width search to make progress in this type of position, the evaluation function must produce goal direction. One way to do this is to provide a bonus for moves which reduce the distance between the White King and the passed pawn. A secondary goal is to reduce the distance between the White King and any Black pawns which are not defended by another pawn. A tertiary goal is to centralize the White King. The first step in developing a specific implementation of this plan is to identify the territory which is denied to the White King. For this purpose, we wish to determine which squares are controlled by the pawns. The White King cannot move to a square occupied by one of its own pawns, nor can it move to a square attacked by an opposing pawn. Figure 2 presents a map of the position with each of the forbidden squares darkened. The location of these "taboo" squares provides the defining boundaries for potential access routes to the desired goals. The second step in implementing this plan is to use a technique described by Church and Church. Starting at each goal object, work backward toward the attacking piece(s). In our case, we are interested in creating a reward gradient which encourages the White King to approach its own passed pawn and the target pawns. To do this, we consider one goal object at a time. All passed pawns are identified. In our example, only the White pawn at f6 qualifies. The two squares diagonally in front of it (e7 and g7) are each credited with 8 "points" each. All squares immediately adjacent to these squares (but not including squares inaccessible to the White King) are credited with 7 points. Next all squares adjacent to these squares (excluding inaccessible squares) are credited with 6 points. This process is continued until we run out of squares or until we have assigned all credits down to and including 1.

The next step in the process is to identify Black pawns which are not defended by other pawns (ie: targets). In this case, the pawns at e6 and g6 qualify. Credit these two squares and the adjacent ones with 5 points each, excluding darkened squares. Next, credit squares adjacent to these with 4 points. Continue this process until all available squares have been exhausted or until the value of 1 has been assigned. This process is executed independently for each target pawn. The last step involves credit for centralization. The four most central squares (d4, d5, e4, e5) are credited with 3 points. The squares which surround these squares are credited with 2 points. The squares which surround those squares are credited

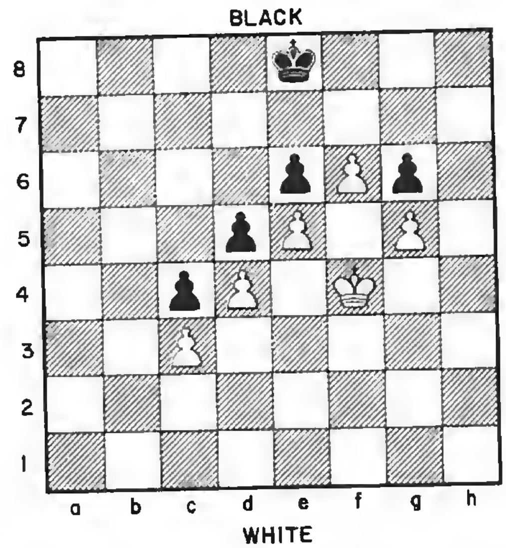


*Figure 1: Chess position which demonstrates a weakness of the* full-width forward search. *In this example, White has a pawn on square f6 which could advance and be promoted if the Black King were out of the way. To win, the White King must come to the aid of the pawn. Since Black cannot attack White's pawns on c3 or g5 without leaving the passed pawn, he is helpless to stop White's maneuver. Although this analysis is obvious to an experienced player, a program using a full-width search would have to search its decision tree to a depth of 35 plies (ie: 35 half moves; a ply is defined as a move by one side) in order to come to the same conclusion.*

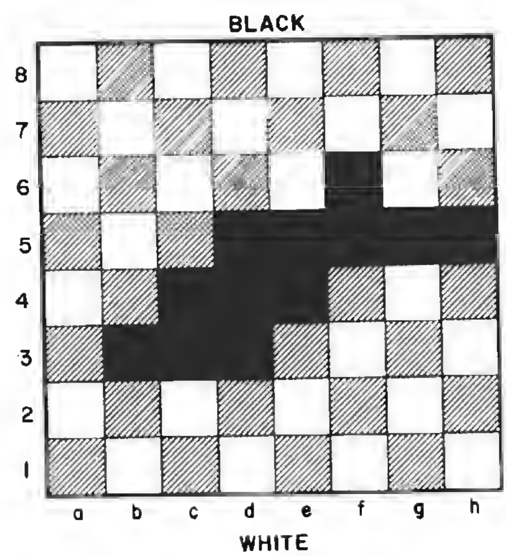


*Figure 2: Forbidden squares in the figure 1 position used to help White (the computer) evaluate the position more efficiently. The White King cannot move to a square occupied by one of its own pawns, nor can it move to a square attacked by an opposing pawn. All of these squares are darkened in the figure. This diagram is used in implementing the goal directed technique described by Church and Church (see figure 3).*

BLACK

| | a | b | c | d | e | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 8 | 6 | 9 | 12 | 14 | 15 | 15 | 15 | 14 |
| 7 | 6 | 10 | 13 | 16 | 18 | 18 | 18 | 15 |
| 6 | 6 | 10 | 14 | 17 | 18 | | 17 | 15 |
| 5 | 6 | 10 | 14 | | | | | |
| 4 | 6 | 10 | | | | 2 | 1 | |
| 3 | 6 | | | | 2 | 2 | 1 | |
| 2 | 4 | 5 | 3 | 2 | 1 | 1 | 1 | |
| 1 | 2 | 2 | 2 | 1 | | | | |

WHITE

*Figure 3: Bonus map for the White King in the position of figure 1, based on a technique described by Church and Church (see references). A goal is established for a particular attacking piece, in this case the White King, and an iterative numerical technique is used to implement it. The goal is to encourage the White King to approach its own passed pawn and the target pawns. (A target pawn is an enemy pawn not defended by other pawns.) Numerical figures of merit are assigned to strategic squares close to White's passed pawn and Black's undefended pawns. Points are also awarded or subtracted for positional characteristics such as centralization of squares, etc. A type of flow algorithm assigns lower and lower values to squares in direct proportion to their distances from the strategic squares, avoiding any forbidden squares. The resulting map of numbered squares enables the King to find the right pathway by constantly searching for ascending values of squares whenever possible.*

with 1 point. Points are then removed from any square which is inaccessible to the White King. When this process has been completed, the credits are totaled for each square to provide a bonus map for the White King. This map is presented in figure 3. By applying this bonus map to the terminal positions of the look-ahead search, the evaluation process will select a move sequence which causes the White King to gravitate in the proper direction. In fact, the correct sequence of moves will be selected even if White is restricted to a 5 ply search each time a move is selected. The bonus map, though simple in concept, has a tremendously beneficial effect.

There is an additional point which needs consideration. In our exposition, we have assumed that the pawns remained stationary. If a pawn were to move, the bonus map would have to be changed. This is not a major problem, however, since there are only a small number of positions that can result from pawn moves, and once the bonus map has been computed for a given configuration, it can be stored and used each time that configuration is encountered in the look-ahead tree. For this reason, the calculations which are required will not be particularly time consuming.

Another example of this strategy is based on the position presented in figure 4. This is a slight modification of figure 6.7 from the chapter of *Chess Skill in Man and Machine* by Church and Church. To apply our technique with respect to the bonus map for the White King it is necessary to determine which squares are not accessible to the White King by virtue of pawn control. As before, these include squares occupied by White pawns and squares attacked by Black pawns. The relevant squares are darkened in figure 5.

The next step is to locate passed pawns for White. There is only one and it is located at c6. The two squares diagonally in front of this pawn (b7 and d7) are credited with 8 points. Squares adjacent to these squares which are not among the darkened squares in figure 5 are credited with 7 points. Squares adjacent to these receive 6 points. This process is continued until there are no more available squares or until the credit value of 1 has been assigned. The next step is to determine whether any Black pawns are potential targets. As before, a target pawn is defined as one which is not defended by a friendly pawn. In the present example, there are three candidates: the pawns at a6, d6 and h7. For each pawn, the value of 5 is credited to the pawn's square and the adjacent squares. Then the value of 4 is credited to each adjacent square. This process of establishing a gradient of decreasing values from 5 down to 1 as distance increases from the target is continued until the last values have been assigned. This is done for each target pawn and in each case, squares darkened in figure 5 are always excluded from the process. The last assignment process is conducted for centralization, with center squares (d4, d5, e4 and e5) receiving 3 credits each and neighboring squares receiving 2 credits. The squares one move in from the edge are assigned the value of 1 and

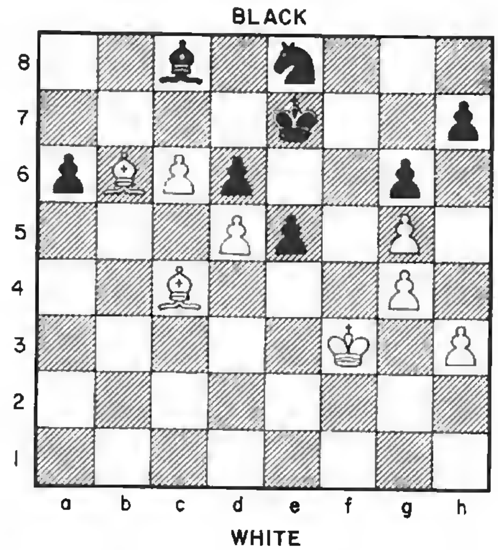


*Figure 4: Another end game position, analyzed by the method of Church and Church in figures 5 and 6.*

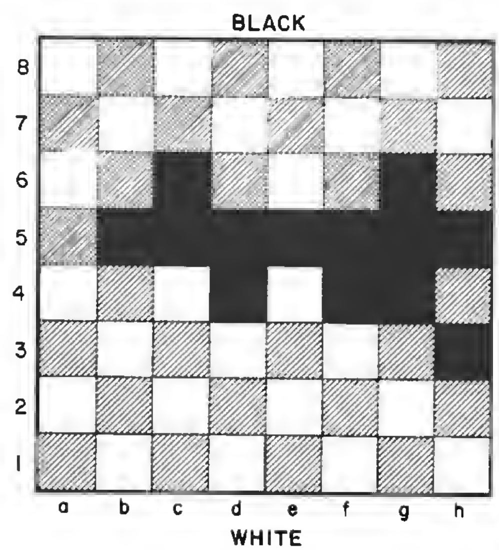


*Figure 5: Forbidden squares for the position in figure 4.*

then credits are removed from any square which has been darkened. The final step in developing a bonus map for the White King is to total the credits for each square.

The composite map is presented in figure 6. This set of bonus points will encourage the White King to move in the appropriate direction. Without this strategy an 11 ply search would be required for White to discover that the pawn at a6 can be captured. With the implementation of these attack gradients for the White King, however, the correct move can be selected with only a 3 ply search. As was the case in the previous example, the establishment of a

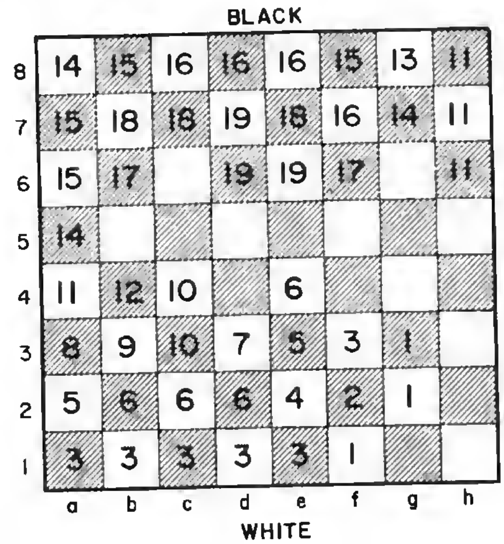


*Figure 6: Bonus map for the position of figure 4. Without this map, an 11 ply search would be required for the computer (White) to discover that the pawn at a6 can be captured. Using the map, only a 3 ply search is required.*

plan within the evaluation function produces a goal directed search without requiring an enormous look-ahead tree. This increase in efficiency is highly desirable.

Because the process is directed by the location of the pawns, changes in the map will occur infrequently and therefore only a relatively small number of bonus maps will be required for any one search. Once a map has been calculated for a particular pawn configuration, it can be stored and used later whenever it is needed. Although this strategy seems to work well in the examples we have presented, it is reasonable to ask whether this procedure will work in all end game situations. Unfortunately, the answer is no.

Consider the position presented in figure 7. This is a famous end game problem which appears as diagram 70 in Reuben Fine's classic chess book, *Basic Chess Endings* (see references). It was analyzed in 1975 by Monroe Newborn to determine if his special end game program, Peasant, could solve it. After several unsuccessful efforts, Newborn concluded that the problem would require about 25,000 hours of processor time before a solution could be found (see *Chess Skill in Man and Machine*, page 129). The problem is difficult, but not as impossible as Newborn suggests. Because Peasant does not have a transposition table, the program did not take advantage of the tremendous number of identical terminal positions which are encountered when an exhaustive search is made of this position. Because the pawns are locked, the only moves which are possible are King moves, and this greatly increases the potential number of transpositions.

The position was submitted to Northwestern's chess program Chess 4.5 running on the CYBER 176 system at Control Data headquarters in Minneapolis. David Cahlander discovered that Chess 4.5 could solve the problem after a 26 ply search! This required ten minutes of processor time on the powerful CYBER 176. Although it is interesting to know that the problem can be solved by a brute force search, this type of solution is not particularly elegant and it requires a level of hardware sophistication that is not likely to be available in the small system for a few years yet.

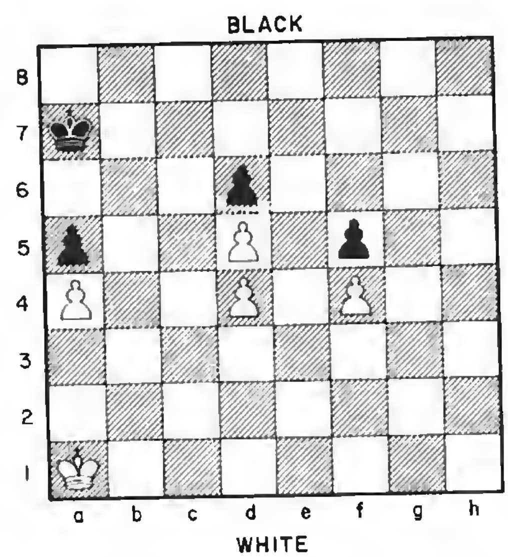


*Figure 7: A chess position which can be analyzed efficiently by means of the coordinate square concept proposed by Ken Church (see references). In this approach, the Black King must coordinate precisely with the White King in order to successfully defend its pawns. The technique is illustrated in table 1.*

## The Coordinate Squares Approach

What can be done to make this problem more manageable? Interestingly enough, there is a rather neat approach to problems of this type which has been examined in some detail by Ken Church in his undergraduate thesis at MIT. Working with Richard Greenblatt as his advisor, Church applied the chess concept of coordinate squares to this position. The basic notion is that the Black King must coordinate precisely with the moves of the White King in order to successfully defend its pawns. For any particular square which the White King occupies, there are only a limited number of squares which the Black King can occupy and still hold his act together.

In his thesis, Ken Church presents a fairly extensive analysis of King and pawn end games. For our present purpose, we will limit our analysis to King and pawn end games in which the pawns are locked and we will modify Church's approach to suit our conditional evaluation strategy. The major difference is that Church attempts to discover a complete solution to the problem using the coordinate squares idea. We propose, instead, to use the coordinate squares approach to provide the evaluation function with additional chess knowledge. With this modification, a full-width search of reasonable depth can find the correct move.

Using figure 7 as an example, the first step in this process is to determine which squares are denied to each of the Kings by the existing pawn configuration. By noting that each King cannot move to a square that is occupied by its own pawn or that is attacked by an opponent's pawn, one can easily determine that squares a4, b4, c5, d4, d5, e4, e5, f4 and g4 are denied to the White King. Likewise, squares a5, b5, c5, c6, d6, e5, e6, f6 and g6 are denied to the Black King. Neither side has a passed pawn, but there are multiple targets, since none of the pawns are defended by friendly pawns.

By applying the strategy described earlier, it is possible to calculate a composite attack map for the White King on the basis of the target pawns at a5, d6, and f5 and taking into account the centralization subgoal. The resulting map for Fine's position is presented in figure 8. The squares without a number are the squares which are denied to the White King because of the pawn structure. Given the position of the White King (a1), a shallow search using this attack map as part of the evaluation function would encourage the White King to approach the target pawn at a5 (eg: b2, c3, c4, b5, a5). If the Black King were more than five moves from a5, this sequence of moves would lead to success. Given that the Black King is at a7, however, this plan is doomed to failure. In fact, the first move in the sequence, b2, is fatal and transforms a winning position into a draw. There are two important conclusions that follow from this discovery. The first is that our simple goal-gradient approach does not always work. The second is that chess end games are much more difficult than a novice player might suppose.

Let us extend Ken Church's ideas and apply the concept of coordinate squares to this position. First, we wish to assign each of the squares to one of three categories: under the influence of the Black King, under the influence of the White King, or contested. To do this we compute the distance from each King to each square, given the constraints imposed by the existing pawn structure. This creates two distance maps, one for the White King and one for the Black King. For squares which are not accessible to one or both of the Kings, we assign a distance score based on the number of King moves required to reach that square by traveling across accessible squares. Next, each square which is closer in moves to the Black King than to the White King and is not denied to the Black King is assigned to Black. Each square which is closer to the White King than to the Black King and is not denied to

BLACK

| | a | b | c | d | e | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 8 | 7 | 9 | 10 | 10 | 9 | 8 | 6 | 5 |
| 7 | 8 | 11 | 13 | 13 | 12 | 10 | 8 | 6 |
| 6 | 9 | 12 | 14 | 14 | 14 | 12 | 9 | 6 |
| 5 | 9 | 12 | | | | 13 | 9 | 6 |
| 4 | | | 10 | | | | | 6 |
| 3 | 3 | 6 | 7 | 7 | 6 | 5 | 5 | 4 |
| 2 | 3 | 4 | 4 | 4 | 5 | 4 | 3 | 2 |
| 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 |

WHITE

*Figure 8: Bonus map for the position of figure 7, a composite attack map for White based on the target pawns at a5, d6 and f5, and taking into account the centralization subgoal.*

*Figure 9: The square control concept applied to the position of figure 7. Each of the squares is assigned to one of three categories: under the influence of the Black King, under the influence of the White King, or contested. To do this, the distance from each King to each square is computed, given the constraints imposed by the existing pawn structure. Each square closer in moves to the Black King and not denied to the Black King is assigned to Black, and vice-versa. The remaining squares are labelled as contested. Through a complex series of manipulations and the use of so-called frontier squares (see text), White is actively directed to attack Black's pawns using the strategy of trying to prevent Black from moving onto strategic coordinate squares which are vital to Black's defense.*

BLACK

| | a | b | c | d | e | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 8 | B | B | B | B | B | B | B | B |
| 7 | B | B | B | B | B | B | B | B |
| 6 | B | B | | | | B | B | B |
| 5 | | | | | | | | B |
| 4 | | | W | | | | | W |
| 3 | W | W | W | W | W | W | W | W |
| 2 | W | W | W | W | W | W | W | W |
| 1 | W | W | W | W | W | W | W | W |

WHITE

the White King is assigned to White. The remaining squares are assigned to the contested category. The results of this procedure are summarized in figure 9. The squares assigned to Black are indicated by the letter B and the squares assigned to White are indicated by a W. The blank squares belong in the contested category.

If the territory under the influence of either King is adjacent to an opponent's pawn, the contest is essentially settled since that pawn would be open for capture. Since this is not the case for the present position, we wish to define a special category of squares called *frontier squares*. A frontier square is any square under your influence that is adjacent to an accessible contested square or is adjacent to an accessible square under the influence of the opponent.

For the position diagramed in figure 7, the frontier squares for White are c4 and h4. The next step is to determine, for each of these frontier squares, the set of squares under Black's influence which, if the Black King were located on that square, would prevent the White King from moving from the frontier square to any of the contested squares or to any of Black's squares. For the frontier square at c4, the Black King would have to be at either a6 or b6 to prevent the White King from penetrating to b5. For the frontier square at h4, the Black King would have to be at g6 or h6 to prevent penetration by the White King. (Note that the Black King could not legally be at h5 if the White King were at h4.) These defense squares for Black can be determined by the machine by placing the White King on the frontier square and conducting a shallow tree search with White to move first and determining empirically which locations for the Black King successfully repel the invader.

The next step in this process is to determine the shortest distance between each pair of frontier squares. For the present position, there are only two frontier squares and thus one minimal distance. Five King moves are required to travel between the two frontier squares. If Black is to be successful in defending, the Black King must be able to move from a defense square for h4 to a defense square for c4 in the same number or in fewer moves than it takes the White King to travel between the two frontier squares.

For this reason, each square in Black's defense set for c4 must be five or fewer moves from one of the defense squares for h4. Also, each square in the defense set for h4 must be five or fewer moves from one of the defense squares for c4. This requirement places a further restriction on those squares which satisfy the necessary defense conditions. One will note that a6 is six moves from the nearest square in the defense set for h4. Also, h6 is six moves from the nearest square in the defense set for c4. Therefore, the true defense set for c4 contains only b6 (a6 will not suffice). The true defense set for h4 contains only g6 (h6 will not suffice). Thus, we have determined that when the White King is on c4 and has the move, there is one, and only one, coordinate square for the Black King (b6). If the White King is on h4 and has the move, there is one, and only one, coordinate square for the Black King (g6).

The next step is to generalize this analysis to squares in White's territory which are immediately adjacent to the frontier squares. In this case, squares b3, c3, d3, g3 and h3. The square at b3 is one King move from the frontier square at c4 and six moves from the frontier square at h4. If the White King is at b3, therefore, the Black King must be on a square which is simultaneously one move from b6 and six or fewer moves from g6. The squares which satisfy this condition (ie: the coordinate squares for b3) are a6, a7, b7, and c7. This same set of calculations can be made for the other adjacent squares. The coordinate squares for c3 are b7 and c7. For d3, there is only one coordinate square, namely c7. Since the White King can move directly from c3 to d3 and Black must move to c7, and only c7, to maintain his defense, it is not possible for him to be on c7 when the White King is on c3. If he were, he would not be able to move when White moved from c3 to d3 and still satisfy the defense requirements. For this reason, only square b7 is sufficient for Black when White is on c3. In addition, since b3 is adjacent to c3, the coordinate square for c3 is not available for b3. Thus the set for b3 is further restricted to a6, a7 and c7.

If we examine g3, we will discover that it is one move from the frontier square at h4 and four moves from the frontier square at c4. This implies that the Black King must be on a square which is one move from b6 and four or fewer moves from g6. There are only two squares which satisfy this requirement, namely, f6 and f7. Therefore we can conclude that no square other than f6 or f7 will serve as a coordinate for g3. When we examine h3, we will find that there are three potential coordinate squares: f6, f7 and g7. Since this set shares f6 and f7 with the defense squares for g3, further restrictions are implied. It is not possible for the same square to serve as a coordinate square for two adjacent squares since it is not possible for Black to pass when it is his turn to move. Therefore if f6 is assigned to h3, then f7 *must* be assigned to g3. If f7 is assigned to h3, then f6 *must* be assigned to g3.

The next step in this process is to determine the set of coordinate squares for each

| Square of the White King | Coordinate Squares for the Black King |
|---|---|
| b3 | a6, a7, c7 |
| c3 | b7 |
| c4 | b6 |
| d3 | c7 |
| e2 | d7, d8 |
| e3 | d7, d8 |
| f2 | e7, e8 |
| f3 | e7, e8 |
| g3 | f6, f7 |
| h3 | f6, f7, g7 |
| h4 | g6 |

*Table 1: Results of the coordinate square analysis for the position of figure 7. Shown are the potential squares for the Black King which defend against the White King's threats when it is White's turn to move.*

square on the minimum pathway(s) between the two frontier squares for which the coordinate squares have not yet been determined. The new squares are e2, e3, f2 and f3. By following the same analysis as before, we can determine that the coordinate squares for e2 and e3 are d7 and d8. The coordinate squares for f2 and f3 are e7 and e8. Because of the adjacency restrictions, the assignment of one of these values automatically restricts the other square to the remaining value.

The results of our coordinate square analysis are summarized in table 1. When it is Black's turn to move and White has moved to one of the squares listed in the table, Black must be able to move to a coordinate square. For this reason, the evaluation function for the machine can be modified to give a bonus of 20 points to White for any terminal position in the look-ahead tree where it is Black's turn to move and the Black King is more than one move from a necessary coordinate square. If it is White's turn to move, a 20 point bonus will be awarded to any terminal position in the look-ahead tree where Black is not located on a necessary coordinate square.

Let us consider how this in combination with the White King attack map (figure 8) will affect the outcome of the look-ahead search. The machine will try to find a pathway to squares c3 or d3 because their attack value of 7 is higher than any of the surrounding squares. Even better would be a pathway to c4, since its attack value of 10 is larger than 7. In each of these cases, the machine will also try to satisfy the condition that Black cannot be on a proper coordinate square when the White King reaches c3, d3, or c4 so that the additional 20 point bonus is also earned. In attempting to do this, it will find that if the White King moves from a1 to either a2 or b2 on his first move, the 20 point bonus will be lost forever. The reason is that either of these moves allows the Black King to coordinate and, because of the minimax strategy, the tree search will always assume replies for Black which maintain this coordination. If the White King's first move is to square b1, the Black King cannot coordinate and the 20 point bonus will still be available at some of the terminal positions in the tree. It is not surprising, therefore, to find Reuben Fine advising that K-N1 is the only move for White which preserves the win.

In order for the machine to find this move, assuming that both the attack map and the coordinate squares information are incorporated in the evaluation function, a search of nine plies is required. This is a tremendous improvement over the 26 ply search required by the unmodified program. In order to actually win a Black pawn, the White King must move to c3 or c4 with Black not in coordination and make a 13 ply look-ahead search. If the White King moves to d3 with Black not in coordination, an 11 ply search will suffice. In order to prevent a draw, White will avoid repeating identical positions and thus will eventually travel to c3. From this vantage point, the win of a pawn can be visualized with a 9 ply search. Therefore, the problem could be solved by the machine if it searched to a depth of nine plies for each move calculation. With a program such as Chess 4.5, a 9 ply search for this position can be conducted in less than two minutes on even a medium power computer.

The procedures which we have described are applicable to a wide range of end game positions. The coordinate squares analysis demonstrates that even highly complex end game positions are manageable when the full-width search employs a sufficiently knowledgeable evaluation function. Although the examples we have discussed encompass only a few types of chess positions, we hope that the reader will envision the power which is potentially available when the evaluation function is modified to incorporate relevant chess knowledge. The implementation of this approach on a broad scale should eventually produce chess programs which can be run on medium power machines and still compete on equal terms with strong human players.

## Quiescence

Another important area for the application of chess knowledge is the problem of *quiescence*. It is essential that the static evaluation function not be applied to a turbulent position. If the next move has the potential to produce a major perturbation of the situation, the evaluation which is rendered will not be accurate. For example, it makes little sense to apply a static evaluation function in the middle of a piece exchange or when one of the Kings is in check. In each case, the judgment which is rendered will not be reliable. For this reason Chess 4.5 presently goes beyond the predetermined search depth at "terminal" positions where a capture might be profitable for the side whose turn it is to move, where certain types of checking moves are possible, or where a pawn is on the seventh rank. This extended search facility is called the quiescence search, and its major objective is to produce reasonably static positions for which the evaluation function can provide accurate assessments.

A weakness of this present implementation is that the definition of a turbulent position is much too narrow. There are many situations in addition to capture threats, checks on the King, and pawn promotion threats which are clearly turbulent. Larry Harris has characterized some of these in chapter 7 of *Chess Skill in Man and Machine*. Harris includes in this category positions which involve a pawn lever, a back rank mate threat, or sacrifice potential. The interested reader can consult Harris' chapter for operational definitions of these patterns. It is essential to note that these and other important patterns are not easily detected. In each case, a fairly sophisticated pattern analysis capability is required. A reasonable goal for improving the present forward search chess programs would be the development of an efficient procedure for detecting potential sources of turbulence. The central objective would be to use this information as one of the decision criteria for terminating search at a node. If the position is not quiescence in respect to a potential perturbation which has been detected, the look-ahead process should be continued.

For example, during the opening when the machine leaves its library with information that the control of a particular square is an important objective, the decisions about search termination can consider whether the position is quiescent in respect to perturbations which might influence control of the key square. Another example of this idea involves the end game. If the preliminary analysis indicates that a particular pawn should be an attack target, the decision for search termination should consider whether each position is quiescent with respect to this goal. Positions at the predetermined depth level will be evaluated only if all potential attackers are more than two moves away from the target. When one or more attackers are close to the goal, the search process will be continued to determine if capture is feasible. This modification of the search process introduces a goal directed selective search at the terminal positions of the full-width tree. The addition of several extra plies of search at relevant nodes in the tree can mean the difference between finding and just missing an important continuation. This type of facility is difficult to implement and difficult to control properly, but the potential gains are such that the effort is worthwhile.

### Establishing Appropriate Goals

In order to implement this goal direction feature in the evaluation function and quiescence search, it is necessary to recognize that a goal which may be of paramount importance at the base node of the look-ahead tree may no longer be relevant at some of the terminal nodes. Intervening moves may accomplish the necessary goal or may alter the situation such that it is no longer possible. In these cases, the conditional evaluation function would be directed at an inappropriate goal. One way to deal with this problem would be to select goals which were both general and long range. In this case, they should continue to be relevant at the terminal nodes of the look-ahead tree. Unfortunately, this is a fairly severe limitation on the goal directed search and is therefore not desirable. A second approach would be to apply pattern analysis at each terminal node instead of at the base node only. In this case, the goals which were selected would always be relevant to the position. This procedure would be very time-consuming, since feature analysis is a complex process. The essential aspect of the problem is a time relevance trade-off in which a guarantee that relevant goals are being pursued requires a heavy investment in additional computing time. The third and most reasonable approach would be to designate which features of the position are crucial to each particular goal and to incrementally update our goals (and thus the evaluation function and the decision rules for the quiescence search) whenever these features change. This is a highly sophisticated approach which would be difficult to implement.

### Conclusion

Let us summarize our conclusions and relate them to the world of personal computing. We have attempted to argue that a full-width search strategy is feasible with a small computer, and that ultimately this approach will produce better chess than a selective search strategy. For this plan to be successful, it is necessary to employ software and hardware suited to the task. The software must incorporate recent improvements in tree searching strategy (ie: $\alpha$-$\beta$ pruning, the capture and killer heuristics, iterative searching, staged move generation, incremental updating, serial evaluation and transposition analysis) as well as other refinements such as conditional evaluations which provide goal direction to the search process.

On the hardware side, it is necessary to have a reasonably powerful system. Although there have been a number of recent efforts to program microprocessor systems to play chess, the games which have resulted have not been comparable to those played by established large system programs. Although it is quite an accomplishment to produce even rudimentary chess from a microprocessor system, the level of play to date is not very encouraging. An example of this type of game appeared in March 1978 BYTE, "Microchess 1.5 versus Dark Horse," page 166.

The type of chess program described in this article requires reasonably powerful hardware in order to provide an interesting game. Because of the many operations requiring bit map manipulation, a 16 bit processor is much more desirable than an 8 bit processor. It is more efficient to represent a set of 64 squares with four 16 bit words than with eight 8 bit words. With a need for computing power in mind, one might select a microprocessor system based on one of the new high-speed 16 bit processors such as the Zilog Z-8000 or the Intel 8086. In addition, this type of program will require quite a bit of memory. The program itself will require about 20 K bytes and the transposition table, if implemented, will need at least another 20 K bytes. If the programmer plans to add chess knowledge for conditional evaluations, a total of 64 K bytes is desirable. An opening library which is sufficient to keep a skilled opponent on his toes requires disk storage.

These considerations may dampen the enthusiasm of many would-be chess programmers. On the other hand, a realistic orientation at the start could save a great deal of grief along the way. When implemented on fairly sophisticated hardware, our demonstration chess program will usually provide a reasonable chess move after two or three minutes of computation. If more time is available (eg: selecting a move for a postal chess game by letting the machine "think" for several hours), a fairly respectable level of play can be anticipated. With future hardware improvements, this type of program may soon become reasonably competitive at tournament time limits, even on a personal computing system.■

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# An APL Interpreter in Pascal

**Alan Kaniss**

**Vincent DiChristofaro**

**John Santini**

For our APL interpreter we used Michael Wimble's flowcharts (see "An APL Interpreter for Microcomputers," BYTE, Aug, Sept and Oct 1977) as generalized guidelines rather than coding directly from them. We used most of his ideas on function implementation, table storage, input scanning, and statement parsing. There were a few minor errors in logic, but for the most part the flowcharts were clear and easy to work with. We expanded the interpreter to include functions that Wimble made reference to but did not flowchart — inner product, outer product, catenate, and index-of. We made the interpreter extremely portable by making the character set machine (as well as keyboard) independent. We accomplished this by having the program read in the installation's character set from a file at the start-up of the program.

### Values

We store all values as real numbers. We decided to do this based on the fact that although APL's data structures are weak (eg, reals and integers can be stored in the same array), Pascal's data structures are very strongly typed. Numbers are checked to be whole numbers (nonfractional) for certain operations such as index generation (monadic iota) and reshaping (dyadic rho). Numbers are checked to be Boolean for such operations as logical negation (tilde), ANDs, and ORs.

### Tables

Rather than using Wimble's method of storing tables in arrays (variable table, function table, token table), we took advantage of one of Pascal's data structures, the *linked list*. This offers two big advantages to the design of the interpreter:

- Array sizes do not have to be declared anywhere in the program. There is no way of telling which tables will grow very large and which ones will stay small; this is dependent on the calculations being performed with the interpreter and will vary from one terminal session to another. With linked lists, storage allocation is dynamic and can be used for each table as needed (storage is taken from a common pool of storage reserved for linked lists).
- It is a simple procedure to deallocate storage (using the standard procedure "dispose" in Pascal) so that it can be re-used by the program as needed. This helps to keep the size of the running program to a minimum.

### Character Sets

In keeping with the goal by easy transportability, the character set is installation (as well as keyboard) independent. This is accomplished by storing the character set on a file (created at installation time) and reading it into storage each time the interpreter is activated. Due to the development in a CDC environment some special considerations had to be made:

- The normal CDC character set consists of 64 characters — letters, digits, and special characters. These characters are represented by 6 bit bytes (octal display codes 00 thru 77) stored 10 to a computer word (60 bits).
- The APL interpreter requires 89 distinct characters excluding over-strikes (over-strikes are considered APL characters, but are not implemented in this version of APL). CDC's ASCII mode fulfills this requirement in that in ASCII mode, upper and lowercase letters are differentiated (in "normal" mode, they are not), thus yielding the extra 26 characters needed.
- In ASCII mode, characters are

represented in one of two ways — a 6 bit display code (uppercase A: octal 01, uppercase Z: octal 32, etc.), b) a 6 bit prefix (octal 74 to 76) and a 6 bit root (lowercase a: octal 7601, lowercase z: octal 7632, etc.).

- CDC's version of Pascal (obtained from University of Minnesota with local modifications made at NADC) does not recognize the special ASCII mode (i.e., octal 7601, the lowercase a, would be picked up as two distinct characters — the circumflex (^) and capital A).
- To compensate for this, the program does two things:

A test is made for the special prefix when characters are read in (the "ORDs" of these prefixes are 60 and 62 respectively).

Rather than the characters being stored, their "ORDs" are. If a character has a prefix, it is stored as (100 times the "ORD" of the prefix plus the "ORD" of the character root) — thus lowercase a, (octal 7601 display code) would be stored as 100×ORD (^) + ORD (A). Characters without prefixes will be stored by their ORDs.

- Characters will be packed five to a word. Characters with prefixes will have a value greater than 6000, thus flagging them for special input/output (I/O) consideration.

Due to the fact that DCD's interactive system responds to the user in uppercase letters only, (and in APL, the uppercase are special symbols, [↑,↓,⍴,~,⌈,⌊,∘, ⎕, etc], the lowercase are capital letters A...Z), the messages to be returned to the user (diagnostics, etc.) are also typed in lowercase into the character set file at installation time.

These local considerations and adjustments will be removed or will be transparent (in input routines, two sections of code will be removed; in output routines, the code will be transparent) for another system.

This implementation of APL will use *all of the correct APL symbols* (← for assign, ⍴ for reshape, ∘ for null, etc.) with the exception of log-to-a-base [O overstruck with *] — it will be O (large circle) only.

**Procedures and Functions**

INITIALIZE CHARACTER SET — Reads installation character set from a file, stores *"orders"* of characters in character set array (APLCHARSET) which is indexed by the name of the characters.

READINERROR MESSAGES — Reads user-feedback and error messages in from a file and stores them in a two dimensional array (ERRORMSGS).

FILLUP TABLES — Initializes tables of monadic, dyadic, and reduction operators and special characters with the orders of characters from the character set.

PRINTAPLSTATEMENT — Echoes an input statement back to the user.

SERROR — Scanner error-handling routine. Invokes echo of statement causing the error and prints a pointer to the item causing the error.

GETAPLSTATEMENT — Reads in and stores (in APLSTATEMENT) an input line from the terminal. Checks input line for being null (carriage return only) and being too long (greater than MAXINPUTLINE).

SKIPSPACES — Self-explanatory.

ITSADIGIT — (Boolean function) — Determines whether a character passed to it is a digit (0..9).

ITSALETTER — (Boolean function) — Determines whether a character passed to it is a letter (A..Z).

CHARTONUM — (integer function) — Returns the integer representation of a number in character representation.

NAMESMATCH — (Boolean function) — Determines whether the two names passed to it are identical.

TABLELOOKUP — Determines whether the character passed to it is contained in the table passed to it (MOPTAB, DOPTAB, REDTAB, CHARTAB, SPECTAB). If contained, the index (array position) of the character is returned; 0 otherwise (TABLEINDEX).

IDENTIFIER — Determines if the next token of the APL statement is an identifier (variable name). If so, the identifier is returned (NAME). The length of the name is checked for length error (greater than MAXVARNAMELENGTH).

MAKENUMBER — Determines if the next token of the APL statement is a number. If so, the number is returned (REALNUMBER). The number is checked for validity (digit must follow a minus sign; digit must follow a decimal point).

MONADICREFERENCE — (Boolean function) — Determines whether an operator passed to it is monadic in the context of line (operator cannot be preceded by a FORMAL ARGU-

Table 1: Six legitimate function headers.

| Number of Arguments | 0 (NILADIC) | 1 (MONADIC) | 2 (DYADIC) |
|---|---|---|---|
| No explicit result | NAME | NAME B | A NAME B |
| explicit result | Z←NAME | Z←NAME B | Z←A NAME B |

MENT, EORMAL RESULT, GLOBAL VARIABLE, CONSTANT, PERIOD, LEFT PAREN, or LEFT BRACKET to be considered monadic in context).

DYADICOPCHECK — Checks to see if next character in input line is a dyadic operator, special character, comment delimeter (rest of statement is ignored), or invalid character. If valid, the operator/special character is stored in TOKENTABLE.

CHECKOTHERTABLES — Checks to see if next charcter in input line is a valid reduction operator or a valid monadic operator. If so, it is stored in TOKENTABLE.

TRYTOGETANUMBER — If next token in input line is a number (scalar or vector), it is assembled and stored in VALTAB (value table). It is also stored in TOKENTABLE.

NAMEINVARTABLE — (Boolean function) — Checks to see if the identifier (name) passed to it is in VARTAB (variable table). If so, the address (pointer) to the name is returned.

ADDNAMETOVARTABLE —, Adds the name (identifier) passed to it to the variable table (VARTAB).

FUNCTIONALREADYDEEINED — (Boolean function) — Checks to see if the function name passed to it is in the function table (FUNCTAB). If so, the pointer to its address in FUNCTAB is returned.

MAKETOKENLINK — Sets up a new link of storage in TOKENTABLE and ties it to the rest of the table.

PROCESSFUNCTION HEADER — Scans function header to check for characteristics of function and the validity of the header. There are six legitimate types of function headers as shown in table 1.

The procedure checks the validity of the result (if present), arguments (if present), the function, extraneous characters following function header, the function being previously defined. If the header is valid, it is stored in the function table (EUNCTAB).

DESTROYSTATEMENT — Returns (disposes) links of TOKENTABLE after the statement is scanned and parsed (if in immediate mode). This releases unneeded storage for further use. Also, returns links of subroutine call information from the parser.

SCANNER — (main program) — Drives above routines until /* (slash asterisk) appears as the first two characters on an input line.

**Parser Routines**

The parsing and execution of a string of tokens is accomplished utilizing the following routines:

ERROR
PARSER
RELEASE
EXPRESSION
RETURNTOCALLINGSUBR
SPECSYMBOL
CALLSUBR
FUNCALL
NUMWRITE
OUTPUTVAL
INPUTVAL
GETARRAYPOSITION
LINKRESULTS
STACKPOINTERS
SIMPLEVARIABLE
INDEX
VARIABLE
PRIMARY
VECTOR
ASSIGNMENT
MOP
DOP
FUNCTCALL

ERROR — Given control upon detection of improper syntax within either the SCANNER or PARSER. An error code is printed accompanied by an appropriate diagnostic message. (See table 2 for error messages.)

PARSER — Controls all parsing; calls RELEASE, EXPRESSION, RETURNTO-CALLINGSUBR, OUTPUTVAL to print last resultant (OPERTABPTR'). Whenever an assignment has not been detected in current statement, detects function completion and returns control to calling token via RETURNTOCALLINGSUBR's action upon current subroutine table pointer (SUBRTABPTS'); SPECSYMBOL detects branching directive "→";

prior to exiting parser RELEASE clears unneeded memroy allocations to the resultant table (OPERTAB).

RELEASE — Calls upon PRIMARY, FUNCALL, EXPRESSION (recursive), ASSIGNMENT, MOP, MONADIC, DOP and DYADIC to interpret a valid expression. The parsing of all expressions and their components proceeds from the right most token to the left. PRIMARY is first called to process the right most token which is required to be in primary component; FUNCALL then detects and executes a monadic or dyadic function with a recursive call to EXPRESSION, else; an assignment, if found, is processed by ASSIGNMENT else; MOP detects a monadic operator and PRIMARY is called to distinguish the preceding primary else; the previously found primary returns the call from EXPRESSION with a valid indication.

RETURNTOCALLINGSUBR — Called from PARSER; returns control from the current function to the calling function or, if none, to the current subroutine table pointer (destroys old pointers; utilizes NAMEINVARTABLE to check result name).

SPECSYMBOL — Called from various parser modules, detects various special symbols (:/→/←/°/./(/)/[/]/;/□) yielding a true if the passed symbol is found in the current token.

CALLSUBR — Called from PRIMARY or FUNCTCALL to provide necessary subroutine table (SUBRTAB') pointers, pass function parameters, and execute branch to called function's first token. (Utilizes NAMEINVARTAB to check argument names.)

FUNCALL — Called from EXPRESSION,

*Table 2: Error messages displayed by APL interpreter.*

| | | | |
|---|---|---|---|
| 00002 | DIGIT MUST FOLLOW A DECIMAL POINT | 00051 | ARGUMENT IS A VECTOR OF LENGTH ONE |
| 00003 | EXTRANEOUS CHARACTERS FOLLOW FUNCTION HEADER | 00052 | ARGUMENTS NOT COMPATIBLE FOR INNER PRODUCT |
| 00004 | INVALID CHARACTER ENCOUNTERED | 00053 | ARGUMENT(S) WITH RANK GREATER THAN ONE |
| 00005 | FUNCTION ALREADY DEFINED | 00054 | ATTEMPTED INVERSE OF ZERO |
| 00006 | ILLEGAL NAME TO RIGHT OF EXPLICIT RESULT | 00055 | ARGUMENTS INCOMPATIBLE FOR DYADIC OPERATION |
| 00007 | INVALID FUNCTION/ARGUMENT NAME | 00056 | LEFT ARGUMENT NOT A VECTOR |
| 00008 | RESULT OF ASSIGNMENT NOT VALID VARIABLE | 00057 | NOT USED |
| 00009 | INVALID FUNCTION RIGHT ARGUMENT NAME | 00058 | NOT USED |
| 00010 | INVALID EXPRESSION | 00059 | NOT USED |
| 00011 | SYMBOL NOT FOUND | 00060 | GREATER THAN THREE DIMENSIONS |
| 00012 | STATEMENT NUMBER TO BRANCH TO NOT INTEGER | 00061 | NIL |
| 00013 | DYADIC OPERATOR NOT PRECEDED BY PRIMARY | 00062 | RE-ENTER LAST LINE |
| 00014 | INVALID EXPRESSION WITHIN PARENTHESES | 00063 | INPUT |
| 00015 | MISMATCHED PARENTHESES | 00064 | NOT USED |
| 00016 | NOT USED | 00065 | NOT USED |
| 00017 | LEFT ARGUMENT OF DYADIC FUNCTION NOT A PRIMARY | 00066 | NOT USED |
| 0001B | NOT USED | 00067 | NOT USED |
| 00019 | VALUE NOT BOOLEAN | 0006B | NOT USED |
| 00020 | ATTEMPTED DIVISION BY ZERO | 00069 | NOT USED |
| 00021 | ARGUMENT NOT A SCALAR | 00070 | IDENTIFIER TOO LONG |
| 00022 | ARGUMENT IS NEGATIVE | 00071 | INPUT LINE TOO LONG |
| 00023 | ARGUMENT IS NOT AN INTEGER | 00072 | INVALID REDUCTION OPERATOR |
| 00024 | ARGUMENT IS A SCALAR OR EMPTY VECTOR | 00073 | DYADIC REDUCTION REFERENCE |
| 00025 | NOT USED | 00074 | MONADIC REFERENCE TO DYADIC OPERATOR |
| 00026 | INVALID OUTER PRODUCT EXPRESSION | 00075 | FUNCTION DEFINED WITH NO STATEMENTS |
| 00027 | INVALID INNER PRODUCT EXPRESSION | 00076 | NOT USED |
| 00028 | NOT USED | 00077 | NOT USED |
| 00029 | LEFT ARGUMENT IS NOT A VECTOR | 00078 | NOT USED |
| 00030 | NOT USED | 00079 | NOT USED |
| 00031 | NOT USED | 00080 | NOT USED |
| 00032 | ERROR IN FUNCTION ARGUMENT | 00081 | NOT USED |
| 00033 | ERROR IN FUNCTION ARGUMENT | 00082 | NOT USED |
| 00034 | INVALID INDEX EXPRESSION | 00083 | NOT USED |
| 00035 | NON-SCALAR INDICES | 00084 | NOT USED |
| 00036 | ASSIGNED EXPRESSION NOT A SCALAR | 00085 | NOT USED |
| 00037 | NON-INTEGER INDICES | 00086 | NOT USED |
| 00038 | INDEX OUT OF RANGE | 00087 | NOT USED |
| 00039 | INVALID INDEX EXPRESSION | 00088 | NOT USED |
| 00040 | NOT USED | 00089 | NOT USED |
| 00041 | NOT USED | 00090 | NOT USED |
| 00042 | NOT USED | 00091 | NOT USED |
| 00043 | NOT USED | 00092 | NOT USED |
| 00044 | NOT USED | 00093 | NOT USED |
| 00045 | NOT USED | 00094 | NOT USED |
| 00046 | NOT USED | 00095 | NOT USED |
| 00047 | NOT USED | 00096 | NOT USED |
| 00048 | NOT USED | 00097 | NOT USED |
| 00049 | NOT USED | 00098 | NOT USED |
| 00050 | NUMBER AND BASE OF DIFFERENT SIGN | 00099 | VARIABLE NOT ASSIGNED A VALUE |

calls FUNCTCALL, PRIMARY, and CALLSUBR; if FUNCTCALL finds a function name, PRIMARY is called to get a primary component if function is dyadic; CALLSUBR is used to establish function pointers in SUBRTAB'. Having transferred control to the called function a valid function indication is returned to EXPRESSION.

NUMWRITE — Prints a signed numeric value, yielding the APLFILE define negative symbol.

OUTPUTVAL — Prints the vector indicated by the last stacked resultant (OPERTABPTR'); greater than three dimensions are not printed, nil vectors are not printed; calls NUMWRITE to ensure correct printing of sign. Called by PARSER and VARIABLE.

INPUTVAL — Called from VARIABLE; inputs vectors of one dimension or SCALARS via keyboard. Input is requested with the prompt "input," a carriage return, and a line feed.

GETARRAYPOSITION — Called from LINKRESULTS and STACKPOINTERS; produces a pointer to an array value given the indices of the value and a pointer to the array.

LINKRESULTS — Called from VARIABLE; places results (OPERTAB') into its assigned position, utilizes GETARRAYPOINTER if result is to be positioned within an indexed array.

STACKPOINTERS — Called from VARIABLE; places a result on the stack (OPERTAB'), utilizes GETARRAYPOINTER if result comes from an indexed array.

SIMPLEVARIABLE — Called from VARIABLE; detects a variable's name and type and assembles a pointer to the variable's values; returns a valid indication if variable found.

INDEX — Called from VARIABLE; determines indices utilizing EXPRESSION and stacks the indices in the resultant table (OPERTAB'); SPECSYMBOL insures that the indices are delimited by semicolons.

VARIABLE — Called from PRIMARY and ASSIGNMENT; calls SPECSYMBOL, INDEX, INPUTVAL, OUTPUTVAL, SIMPLEVARIABLE, LINKRESULTS, STACKPOINTERS in order to parse a valid variable, which is comprised of: a simple variable, a quad indicating I/O or an indexed variable.

PRIMARY — Called from EXPRESSION and FUNCALL; calls VECTOR, VARIABLE, SPECSYMBOL, EXPRESSION, FUNCTCALL, and CALLSUBR; The primary may be a vector, a variable, an expression enclosed in parens, or a niladic function call; if any are found a valid indication is returned to the calling procedure.

VECTOR — Called from PRIMARY; yields a valid indication if SPECSYMBOL detects a left arrow (←) and VARIABLE finds a valid variable after the arrow.

ASSIGNMENT — Called from EXPRESSION; yields a valid indication if SPECSYMBOL detects a left arrow (←) and VARIABLE finds a valid variable after the arrow.

MOP — Called EXPRESSION; determines if the current token points to a reduction operator; if found, a valid indication is returned to EXPRESSION.

DOP — Called by EXPRESSION; determines if the next grouping of tokens indicate a dyadic operator, an inner product or an outer product; if one of these are found, a valid indication is returned to EXPRESSION.

FUNCTCALL — Called by PRIMARY and FUNCALL; calls FUNCTIONALREADYDEFINED to determine if current token is a function name, if true a new subroutine table (SUBTAB') is created and a valid indication is returned to the calling procedure.

**Implemented Operators and Functions**

DYADCOMP — Routine that performs mathematical and logical operations for reduction and dyadic computations

INDEXGENERATOR — Routine that performs the index generator function (also referred to as the monadic iota operator). Produces a vector of the first ARG integers.

RAVEL — Routine that performs the ravel function (also referred to as monadic comma operator). The result is a vector containing all elements of ARG in odometer order.

SHAPEOF — Routine that performs the shape of or size function (also referred to as the monadic rho operator). The result is a vector containing the dimensions of ARG.

REDUCTION — Routine that performs the interpretation of the reduction monadic argument and calls DYADCOMP to perform the indicated mathematical or logical operation

MONADIC — Routine that performs the interpretation of valid monadic operators or calls the necessary routines for reduction or mixed monadic operations.

CATENATE — Routine that performs the concatenate function of joining two arguments (also referred to as dyadic comma operator).

INDEXOF — Routine that performs the index-function which returns for each element of vector RIGHTARG the least index I in the vector LEFTARG for which RIGHTARG [I] equals the element. If no value in LEFTARG is equal, the result element is 1 plus THE SIZE OF LEFTARG (also referred to as dyadic iota operator).

RESHAPE — Routine that performs the reshape function which forms a result having the dimension specified by LEFTARG and having elements taken from RIGHTARG in odometer order (also referred to as dyadic rho operator).

INNERPRODUCT — Routine that performs the inner product function which applied a scalar dyadic function (associated with RIGHTARG) between each vector along the last coordinate of LEFTARG, and each vector along the first coordinate of RIGHTARG, then performs a reduction using the scalar dyadic function (associated with LEFTARG) to that result.

OUTERPRODUCT — Routine that performs the outer product function which applies a scalar dyadic function using all elements of LEFTARG and all elements of RIGHTARG where the rank of the result is the number of coordinates of LEFTARG plus the number of coordinates of RIGHTARG and the dimensions of the result are size of LEFTARG, size of RIGHTARG.

DYADIC — Routine that performs the interpretation of valid dyadic operators and calls DYADCOMP to perform the operations for simple dyadic operators or calls the necessary routines to perform inner and outer products, index-of, reshape, or concatenate.

REVERSELINKLIST — Routine that performs the reversing of the order of the elements in the value table (VALUES).

The entire interpreter, written in Pascal for the CDC 6600 is given in Appendix C, page 291. Since Pascal is a portable language, it should be possible to run this program on other Pascal systems. ■

# A Pascal Print Utility

**by Carl Helmers**

A personal computer system is only useful when it is programmed to personal tasks, whether by purchasing canned software or by using one's ingenuity to write original software. Since I am the type of person who tends to like to program as a recreation as much as for getting the final job done, I prefer to write my own applications. One of the first such applications for my UCSD Pascal oriented machine was a file printing utility, begun with its earliest versions within a month of delivery of the computer.

In my occupation, I do a lot of writing. Whether the subject is an editorial for BYTE magazine, a memo for circulation within our company, or a letter to an author, I tend to write the text using the excellent large file (L2) editor of the UCSD Pascal system. But being able to edit texts does not complete what I need to get done with the computer. I also have to be able to print out the files in a formatted manner, so that annoying creases in the fanfold paper do not come in the middle of lines and so that I keep track of page counts. The program described here, called PRINT, is what I have contrived. It represents several months of evolution of its functions toward what I actually do.

The PRINT program is written with a menu list orientation for all main functions and their selection. In the notes which follow, we cover the main functional aspects of the print program, but not the details of the Pascal code of the program. Within the program (see listing 1), verbal comments are made at the beginning of most procedures to document purpose and point out any machine dependencies or subtleties of the code (yes, such can exist even in Pascal). When going through the menu lists, references to procedures in the program are made by name enclosed in quotation marks.

The main functional menu of the program is shown in figure 1 as it would appear on computer. This menu contains the highest level functions of the program. For aesthetic purposes, the list of functions has two parts. The upper list of functions are single letter commands which change options and standard data for the program. The lower list of functions are executable actions the program may take. The menu is printed out by the procedure print_menu, found on page 20 of listing 1.

The actual main routine of the PRINT program consists of a WHILE loop. This loop starts out by performing print menu. Then it reads a single character from the keyboard. This character is checked to see if it is an ASCII <ESC> character (decimal equivalent "27"). If it is not an escape character, then a CASE statement is used to decode which active key was pressed.

If a "D" is pressed, then the program executes a procedure called diablo which sets up the printer spacing constants for my Diablo printer. In using this program with another system, a customized version of this setup may be required if the printer is not a Diablo HYTYPE II. This diablo procedure provides facilities for either 10 or 12 pitch horizontal spacing, and either single or double spacing vertically on the paper. The setup here applies to all the print functions.

The "#" option is used to preset a page number different from the one currently listed. On entering the program for the first time, a starting page count of 1 is guaranteed by initialization to 0. Typing "#" followed by a carriage return will cause the page number to be cleared to 0 again. The procedure pagenumber, which sets the page number, is found on page 19 of listing 1. It contains its own menu of three options: clearing (<return>), initializing (!), or keeping the previous value (<ESC>).

Printing always assumes we will have a file specified. The "N" option is used to specify a file name for the program to use. When the program is first activated, a default value of the system work file SYSTEM.WRK.TEXT is initialized. Then, when actually using the program, this is usually changed. When "N" is pressed, the routine namefile is executed, which asks for the new file name. The program always assumes a ".TEXT" file name extension. Thus when it was set up to print its own listing, after pressing "N", I simply entered the word "PRINT," resulting in the name "PRINT.TEXT" as seen in the menu of figure 1 and in listing 1.

Now since I am involved in a publishing occupation, one of the options I put into the program is that of specifying copyrights. For my own version of the program, I use either no copyright (rarely), BYTE Publications Inc. for business applications of the printer, or (most often) a personal tag of Carl T Helmers Jr. The menu list of figure 1 was made using my personal version of the program to produce listing 1. It thus shows my own personal option as the copyright option. (In the actual listing and in the version to create the samples of figures 2 and 4, I recompiled the program using generic forms of strings such as "< < < your name > > >".) This copyright option is invoked by use of the command character "C" in response to the main menu. The procedure getcopyspec performs these actions.

The option "Q" in the main menu is one which controls whether or not the print program should search for the keyword "procedure" in lines which happen in the last fourth of the page. Each time the "Q" command is given, the option toggles between "YES" and "NO." The "YES" form of the option is used to implement a very crude form of Pascal pretty printing. A heuristic rule is used, that if a procedure begins in the last quarter of a page, the printing program will go to the next page and start the procedure at the top of that page. This option is implemented by execution of the procedure proccheck.

The final options-oriented choice in the main menu list is "W," used to specify the date field for printouts. In the best of all possible worlds this would not be needed at all, since the operating system's data routines would be accessed to get the current system date. But at this writing I have not figured out how to do that with UCSD Pascal, so I put in an explicit date definition routine and date field. The routine get_the_date is used to define this field and is found on page 5 of listing 1.

The remaining choices of the main menu are executable actions. The most often used such action is the first choice, "P," which invokes the procedure called any_file_print. This routine performs printing with a standard header that includes the file name, copyright specification, date field, running page count, and the current page header. This is the original print routine which has been running essentially unchanged for about six months at this writing.

In operation the any_file_print routine (as well as the two letter printing routines) treats the first line read from the file as a beginning page header string. This string is, for example, the comments string printed above the dashed line on every page of listing 1. After the initial header definition which is a default action of the program, explicit new header strings can be set up during the printing operation by a two line sequence within the file: the first line con-

```
Carl's Printing Program... 7/18/79

Pick an option from the following list...

        D --> printer spacing = normal text
        # --> set starting page number =     0
        N --> file name = PRINT.TEXT
        C --> copyright = Carl T Helmers, Jr.
        Q --> toggle PROCEDURE search option = YES
        W --> date = July 20 1979

        P --> print routine
        L --> print as personal letter
        B --> print as business letter
        T --> enter typewriter routine
        R --> prepare return addresses on envelopes

Type <esc> to leave the program
```

*Figure 1: This is a printed image of the display of the main menu for the print program, as compiled from the author's custom version. The options have all been set up to refer to the file PRINT.TEXT which contains listing 1, as printed on July 20 1979.*

```
LetterTST.TEXT        (c) 1979 <<< your name >>>     July 20 1979    Page  1
Letter Test Text...
--------------------------------------------------------------------------------------

Second Line of Salutation
Third Line of Salutation
* dummy end of salutation line
Dear Recipient

   This is a letter which signifies absolutely nothing
to you, but tells us whether the letter writing routines work.
It starts out with a first page, then following the end of
the first page, skips to the next page...

   We are about to skip to the next page using the special
code of "#" in the second column of the input text...
```

a

```
                          <<< your name here >>>
                         <<< your street here >>>
                          <<< your town here >>>
                       <<< your state, zip here >>>

                               July 20 1979


To:
Letter Test Text...
Second Line of Salutation
Third Line of Salutation




Dear Recipient

   This is a letter which signifies absolutely nothing
to you, but tells us whether the letter writing routines work.
It starts out with a first page, then following the end of
the first page, skips to the next page...

   We are about to skip to the next page using the special
code of "#" in the second column of the input text...
```

b

```
<<< your name >>> to Letter Test Text...   July 20 1979    Page  2
--------------------------------------------------------------------------------------

    There now, if all worked properly, we are now on the
second page of the letter, illustrating the form used for headings
on successive pages...

That's all we have to test...

                    Yours truly,

                        Somebody...
```

c

*Figure 2: When printing a letter form of a file, the first few lines are assumed to contain the address of the correspondent. Here are three pages taken from listings of a dummy letter file made by the compiled form of the program shown in listing 1. At (a) we see a printout of the first few lines of the file made with the "P" format; line 1 of the file becomes the heading line, and the rest is an image of the lines of the file, in particular showing the line with a single "*" character in column 1 which terminates the correspondent address if it is less than 5 lines long. At (b) we see the same file, but this time printed in the personal letter format, showing how the personally oriented strings of a return address are included, as well as appropriate spacings down the listing.*

*And finally, at (c) we see a continuation page in the letter format, where an abbreviated header format is used rather than the first page form. The first line of the correspondent address appears in the header of each continuation page, as well as a page number.*

```
Typing routine...
   <return>     = print the current line input
   <back space> = delete one character
   <ctrl> "I"   = skip to new page
   <ctrl> "J"   = delete line
   <ctrl> "G"   = confirm line buffer
   <esc> to leave typewriter

-------------------------------------------------

This is a test of the typewriter...
This is a test of the typewriter...
```

*Figure 3: The "T" option of the main menu invokes this typing routine. The display is shown as copied to the printer using a feature of my computer system called "print screen." The menu of possible options is refreshed whenever a carriage return causes a line to be printed on the printer.*

tains the arbitrarily chosen character "$" in the second character position of the line; the second line contains the new value of the header string to be used on all subsequent headings. The reason for checking the second column is to allow the first column to be used for the opening comment brace of a Pascal comment, so that the first line of the new heading sequence will be "{$}" in a Pascal program.

A similar technique of embedding command codes in the text is used to force page headings for reasons related to the logic of the text other than filling up a page or beginning a new procedure. This explicit page eject feature is accessed by embedding a "#" character in column 2 of a line. Again, in a Pascal program, a single line with "{#}" acts as a comment and does not affect the compilation of a program.

Both the heading redefinition and the page eject codes also work when using either the personal letter or business letter printing routines. These routines are invoked by the "L" and "B" command choices of the main menu, respectively. In each case, similar actions and formats are used. The example provided in figure 2b shows the letter format applied to a test file.

In preparing a letter, we assume that the file begins with up to 5 lines of correspondent address. If less than 5 lines are used, the last line of the address is followed by a line containing an asterisk (*) character in its first character position. In figure 2a, we see a printout of the first page of the letter test file, interpreted with the "P" option, so that the asterisk which terminates a 3 line correspondent address can be seen.

In printing a letter file, this assumed correspondent address is used in the heading for the first page, following the printing of the word "To:". Also, on the first page, a formally centered version of the appropriate return address will be printed. Again, in the example of figure 2b, as printed by the compiled form of listing 1, generic strings identify where a reader might substitute personal information in using this program. On second and succeeding pages of a letter (see figure 2c), an abbreviated page break is used rather than a repetition of the complete return address.

All the printing procedures, including any_file_print, personal_letter, and busi_letter are found on page 16 of listing 1. When you look there, you will find that they reference a procedure called fileprint, which begins on page 9 of listing 1 and ends on page 15. The differences in printing the various ways are largely those of handling the different forms of page headers, so a common procedure with a choice of header printing options is employed. The procedure headerprint (pages 10 to 13 of listing 1) within the procedure fileprint contains three detail header printing routines for the various kinds of files.

Much of the styling and detail of a letter can be changed at will by readers who implement a version of this program. These are my own personal choices of how to format distinctive letters of one or more pages, and may not be aesthetically pleasing to others. Knowing the number of choices available and the ease of making changes with a UCSD Pascal system's editor, I fully expect many users of this program to make such changes.

As an afterthought, I put in the final two executable choices of this program. The "T" option is used to invoke a typewriter simulation procedure, typing, as found on pages 17 to 19 of listing 1. This routine displays a menu list of special characters on the main terminal screen, and accepts characters from the screen one by one until a carriage return is received which causes the line to be printed. Figure 3 shows the typing menu as printed from the display, along with a sample line.

The "R" choice is used when preparing personal correspondence in order to place my home address on an envelope. When using blank envelopes, this is done by removing the paper from the printer and putting in envelopes one at a time. For monthly bills where a pre-addressed envelope comes from the source of the bill, I simply put each individual envelope in the printer as I write the checks, leaving the paper in and not bothering with attempting to make the return address fit the spaces usually provided.■

```
        <<< your name here >>>
       <<< your street here >>>
        <<< your town here >>>
     <<< your state, zip here >>>
```

*Figure 4: A sample of the simple printout of return address invoked by the "R" option of the main menu.*

*Table 1: A list of all procedures found in listing 1. This listing can be used as an index when studying the program for possible modifications. It was prepared by hand from listing 1.*

| Procedure | Listing Page | Refers to |
|---|---|---|
| setdiablospacing | 2 | — |
| diablo | 3 | setdieblospacing |
| inttos | 4 | — |
| println | 4 | — |
| center_the_string | 5 | — |
| get_the_date | 5 | — |
| getcopyspec | 5 | — |
| fix_copyright_tag | 6 | — |
| set_up_printer | 6 | println |
| open_file_now | 6 | — |
| really_initialize | 7 | setdiablospacing |
| my_address_lines | 9 | — |
| fileprint | 9 | — |
| grab_address_lines | 9 | — |
| initialize | 10 | open_file_now, fix_copyright_tag, set_up_printer, grab_address_lines, |
| headerprint | 10 | |
| normal_header | 10 | setdiablospacing, println, inttos |
| header_personal_letter | 11 | setdialospacing, println, my_eddress_print, center_the_string, inttos |
| header_business_letter | 12 | setdiablospacing, println, center_the_string |
| headerprint [BEGIN...END] | 13 | normal_headr, header_personal_letter, header_business_letter |
| checkprocedure | 14 | println |
| pagecheck | 14 | checkprocedure, headerprint |
| pagebumper | 14 | pagecheck, println, pagebumper |
| fileprint [BEGIN...END] | 15 | initialize, pagebumper, pegecheck, println |
| namefile | 15 | — |
| personal_letter | 16 | fileprint |
| busi_letter | 16 | fileprint |
| any_file_print | 16 | fileprint |
| console_input | 16 | — |
| typing | 17 | |
| promptings | 17 | — |
| typing [BEGIN...END] | 17 | set_up_printer, promtpings, con, console_input, println, |
| pagenumber | 19 | — |
| procheck | 19 | — |
| print_return_address | 19 | |
| setup_envelope | 19 | — |
| print_return_address [BEGIN...END] | 19 | setup_envelope, my_address_print |
| print_menu | 20 | — |
| print [BEGIN...END] | 20 | really_initialize, print_menu, diablo, getcopyspec, any_file_print, procheck, namefile, personal_letter, busi_letter, typing, pagenumber, print_return_address, get_the_date |

*Listing 1: The PRINT program. This is a complete Pascal program listing for the print program. It was printed by a compiled version customized for the author's personal use. The text printed here is a generic form in which strings like "<<< your name >>>" have been used to indicate places where the program should be changed for the reader's personal use. Note the header information which is repeated at he beginning of each page of listing.*

```
PRINT.TEXT        (c) 1979 Carl T Helmers, Jr.     July 22 1979     Page  1
{7/19/79: UCSD Pascal oriented print utility program}
------------------------------------------------------------------------------

(*$R+*)
PROGRAM print ;
{------------------------------------------------------------------------}
{            P E R S O N A L   P R I N T   U T I L I T Y               }
{                                                                        }
{                author: Carl T. Helmers, Jr.                            }
{                        Editorial Director                              }
{                        BYTE Publications Inc.                          }
{                                                                        }
{                version:  July 19 1979                                  }
{                systems asssumption:  UCSD Pascal Version 1.5           }
{                    running on Northwest Microcomputer Systems          }
{                    model 85/P with Diablo HYTYPE II printer            }
{------------------------------------------------------------------------}

{ What follow are G L O B A L declarations applicable to the whole program  }
{    In this program, as a general rule most linkages between procedures for }
{    data have been done using these global variables, ignoring the use of   }
{    formal parameters at (perhaps) some risk in understanding on the part of}
{    the reader...                                                           }

TYPE
   string_of_128 = STRING[128];
VAR
   copyright : (my_own,businesz,none);
      cstring : string_of_128;
   file_heading,s,hyphens : string_of_128;
   textfile : FILE OF CHAR;
   pstring,astring,firstline,filename : string_of_128;
   string_nothing : STRING[1];
   apage : INTEGER;
   horiz,verti,c5,c8 :INTEGER;
   pagecount,records : INTEGER;
   line_count,lines_per_page : INTEGER;
   alldone : BOOLEAN;

   which_print_heading : (miscellaneous,a_personal_letter,a_business_letter);
   first_heading_printed : BOOLEAN;
   todays_date : STRING[32];

   correspondent_address : ARRAY[0..4] OF string_of_128;

   we_print_a_program : BOOLEAN;
      c_we_print : STRING[3];
      criterion : INTEGER;

   arraychar: PACKED ARRAY[0..1] OF CHAR;
   anychar : CHAR;
```

```
PROCEDURE setdiablospacing(VAR horizontal,vertical : integer);
   { This is a very machine dependent interface program which sets up the
     spacing constants for the Diablo Hytype-II receive-only printer attached
     through a parallel port of the Northwest Microcomputer Systems 85/P
     computer upon which this program was developed.  It assumes that the
     address locations decimal 63520 and 63519 contain the spacing constants
     for horizontal and vertical motion of the print carriage respectively.
   }

   CONST
      vertaddress = 3519;
      horizaddress = 3520;
      bias=30000;
   TYPE
      ptr = ^CHAR;
      memaccess = (pointer,number);
      memory = {variant record used to suppress type checking of addresses}
         RECORD
            CASE memaccess OF
               pointer : (apointer : ptr);
               number  : (anumber  : INTEGER)
         END;
   VAR
         i : INTEGER;
         anybyte : memory;

   BEGIN

      {first set up an address as a number }
      anybyte.anumber := vertaddress+(2*bias);
      {then use the pointer variant of that number to change the byte}
      anybyte.apointer^ := chr(vertical);

      {first set up an address as a number }
      anybyte.anumber := horizaddress+(2*bias);
      {then use the pointer variant of that number to change the byte}
      anybyte.apointer^ := chr(horizontal);

   END {setdiablospacing};
```

```
PROCEDURE diablo;
  { This is a less machine dependent procedure which allows one to set up
    four different variants on the spacing of the printed outputs. All the
    combinations of single or double vertical spacing, 10 or 12 pitch
    horizontal spacing are provided.  "Normal" is single space, 12 pitch
    printing, which is used with a 10 pitch Daisy wheel as, for example, in
    this listing...

    If another printer is used, the semantics of the menu provided in the
    WRITE statements below would have to be rewritten.
  }
  VAR
    character : CHAR;
  BEGIN {setting up mickey-mouse }
    PAGE(OUTPUT);
    WRITELN('Diablo HYTYPE-II Setup For 85/P & UCSD Pascal');
    WRITELN(' ');
    WRITELN('Pick one of the following options...');
    WRITELN('   S --> normal text');
    WRITELN('   D --> double space');
    WRITELN('   X --> typewriter text');
    WRITELN('   Y --> typewriter double space text');
    WRITELN(' ');
    WRITELN('?');
    READ(KEYBOARD,character);
    WRITELN(character);

    {default diablo spacing is single}
    horiz:=5;
    verti:=8;
    pstring := 'normal text';
    lines_per_page := 58;

    CASE character OF
      'D','d' :
        BEGIN
          verti:=16;
          pstring := 'double spaced normal text';
          lines_per_page := 28
        END;
      'X','x' :
        BEGIN
          horiz:=6;
          verti:=8;
          pstring := 'typewriter text';
          lines_per_page := 58
        END;
      'Y','y' :
        BEGIN
          horiz:=6;
          verti:=16;
          pstring := 'double spaced typewriter text';
          lines_per_page := 28
        END
    END {CASE};

    setdiablospacing (horiz,verti);
    criterion := (3 * lines_per_page) DIV 4
```

```
   END {diablo};


PROCEDURE inttos(VAR i : INTEGER);
   {convert an integer into a string value in global "s" for use by "println"}
   {this procedure may not be absolutely necessary, but was incorporated at  }
   {an early stage in the author's understanding of Pascal as a language.    }
   VAR
      frap : STRING[1];
      txt : string_of_128;
      j : INTEGER;
   BEGIN
      j := i;
      frap := ' ';
      txt := '';
      REPEAT
         frap[1] := CHR(ORD('0')+(j MOD 10));
         txt := CONCAT(frap,txt);
         j := j DIV 10
      UNTIL j = 0;
      s := CONCAT(s,txt);
   END {inttos};


PROCEDURE println {s-->diablo};
   { This procedure is required to allow simultaneous operation of the main
      console device for interactive messages of the program, and the printer
      device (UCSD Pascal Unit 6).  The actual output of this program from some
      file goes to Unit 6, buffered by the global string variable "s".

      The operation of this procedure is functionally identical to the built in
      intrinsic "WRITELN" of the UCSD Pascal implementation.
   }
   VAR
      i : INTEGER;
      chp : PACKED ARRAY[0..127] OF CHAR;
   BEGIN
      FOR i := 1 TO LENGTH(s) DO chp[i-1] := s[i];
      UNITWRITE(6,chp,LENGTH(s),,1);
      chp[0] := CHR(13);
      UNITWRITE(6,chp[0],1,,1)
   END {println };
```

```
PROCEDURE center_the_string;
   { This procedure simply centers the standard global output string "s"
      in an 80 character wide field...
   }
   VAR
      i : INTEGER;
   BEGIN
      IF LENGTH(s) > 79 THEN s := 'String Conversion Error';
      FOR i := 1 TO (80 - LENGTH(s)) DIV 2 DO s := CONCAT(' ',s)
   END;


PROCEDURE get_the_date;
   { This procedure is used to input the current date for printing with
      the file being transferred...
   }
   BEGIN
      PAGE(OUTPUT);
      WRITELN('Enter today''s date or <return> for null date');
      READLN(astring);
      IF LENGTH(astring)<32 THEN todays_date := astring
   END {get_the_date};


PROCEDURE getcopyspec {determine copyright message};
   { This procedure is used to modify the default copyright specification,
      which may be "<<< your name >>>", "<<< your company name >>>" or a null
      specification.  Users should modify the two built in strings of this
      listing to reflect their own name and business affiliations.
   }
   BEGIN
      PAGE(OUTPUT);
      WRITELN('Enter copyright choice: B or N (<ret> for personal)');
      READ(KEYBOARD,anychar);
      copyright := my_own;
      IF ((anychar='B') OR (anychar='b')) THEN copyright := businesz;
      IF ((anychar='N') OR (anychar='n')) THEN copyright := none;
      CASE copyright OF
         my_own    : cstring := '<<< your name >>>';
         businesz   : cstring := '<<< your company name >>>';
         none   : cstring := ''
      END {CASE};
      WRITELN('')
   END;
```

```
PROCEDURE fix_copyright_tag;
   { This procedure defines the string named "file_heading" which is used
      for display purposes and reflects the current contents of the
      copyright option chosen...
   }
   BEGIN
      file_heading := CONCAT(filename,'         ');
      IF NOT(copyright=none) THEN
         file_heading := CONCAT(file_heading,'(c) 1979 ')
      ELSE
         file_heading := CONCAT(file_heading,'          ');
      IF copyright=my_own THEN
         file_heading:=CONCAT(file_heading,'<<< your name >>>')
      ELSE
         IF copyright=businesz THEN
            file_heading:=CONCAT(file_heading,
               '<<< your business name >>>');
      file_heading := CONCAT(file_heading,'      ')
   END {fix_copyright_tag};


PROCEDURE set_up_printer;
   { Ask for and receive an acknowledgement of paper position prior to
      the start of a printing operation.
   }
   BEGIN
      {clear the print buffers}
      s := '';
      println;
      println;
      println;

      {normal interactive query}
      WRITELN('Reset printer to bottom of page then ',
         'type any character');
      READ(KEYBOARD,anychar)
   END {set_up_printer};


PROCEDURE open_file_now;
   { This procedure is used to open the text file which is to be printed
      by the program.  The compiler control toggles "(*$I-*)" and "(*$I+*)"
      are used to suppress automatic error checking during the RESET operation
      so that if an error occurs the program can recover gracefully...
   }
   VAR
      errornumber : INTEGER;
   BEGIN
      records := 0;
      firstline := '';
      {----------------------- BEGIN UNPROTECTED CODE ----------------------}
                                       (*$I-*)
      RESET(textfile,filename);
      errornumber := IORESULT;
                                       (*$I+*)
      {----------------------- RESUME PROTECTED CODE ----------------------}
      IF errornumber = 0 THEN {file was found in good order }
         BEGIN
            READLN(textfile,firstline);
```

```
            UNITREAD(1{~},arraychar[0],1,,1)
          END

       ELSE {file was non-existent or invalid in some way }
          BEGIN
            WRITELN('File "',filename,'" invalid: result=',errornumber:3);
            WRITELN('Press <sp> to continue');
            READ(KEYBOARD,anychar)
          END

    END {open_file_now};


PROCEDURE really_initialize;
   { As suggested by its name this is the procedure which really initializes
      the whole program's operation.  It is performed once following the start
      of execution, as opposed to other initialization procedures for specific
      routines within the program which may be executed more than once...
   }
   VAR
      i : INTEGER;
   BEGIN
      filename := 'SYSTEM.WRK.TEXT';
      cstring := '<<< your name >>>';
      copyright := my_own;
      todays_date := '?';
      string_nothing := ' ';

      we_print_a_program := TRUE;
         c_we_print := 'YES';

      alldone := FALSE;

      {printer management constants are set up to defaults}
      c5 := 5;
      c8 := 8;
      line_count := 99;
      lines_per_page := 58;
      criterion := 44;
      horiz := 5;
      verti := 8;
      setdiablospacing(horiz,verti);
      pstring := 'normal text';
      pagecount := 0;

      records := 0;
      astring := '';
      firstline := '';
      hyphens := '';
      FOR i := 1 TO 90 DO hyphens := CONCAT(hyphens,'-')
    END {really_initialize};
```

```
PROCEDURE my_address_print;
  { This procedure used by header routines of fileprint, return address
     printer...
  }

  BEGIN
     s := '<<< your name here >>>';
     center_the_string;
     println;                         {1}
     s := '<<< your street here >>>';
     center_the_string;
     println;                         {2}
     s := '<<< your town here >>>';
     center_the_string;
     println;                         {3}
     s := '<<< your state, zip here >>>';
     center_the_string;
     println;                         {4}
     s := '';
     println                          {5}
  END {my_address_print};
```

```
PROCEDURE fileprint;

  { This is the master file printing routine, used for "miscellaneous"
     files, as well as personal letters and business letters... The global
     set variable "which_print_heading" controls one of three possible
     headings will be printed on each page.  The global BOOLEAN variable
     "we_print_a_program" controls whether or not the last fourth of a page
     being printed will have a test for the beginning of a new PROCEDURE
     used to automatically generate a skip to the next page.
  }


  PROCEDURE grab_address_lines;
     { When printing either a personal or a company letter, the working
        assumption made is that the text file with the letter begins with
        up to five lines of address information.  This set of lines is read
        at the beginning of a letter printing operation, with the occurrence
        of an asterisk ("*") in the first position of a line acting as a
        premature termination of the address read operation.  The first line
        of the address information will be repeated in any continuation pages
        of a letter printout.
     }
     VAR
        done : BOOLEAN;
        i : INTEGER;

     {read up to five lines of correspondent address from beginning
     of file.  Terminate address scan with a "*" character in a line.}
     BEGIN {grab_address_lines}
        IF (
             (which_print_heading = a_personal_letter)
                         OR
             (which_print_heading = a_business_letter)
           )
        THEN
           BEGIN
              correspondent_address[0] := firstline;
              FOR i := 1 TO 4 DO correspondent_address[i] := '';
              done := FALSE;
              i := 1;
              REPEAT
                 BEGIN
                    READLN(textfile,astring);
                    astring := CONCAT(astring,'  ') {guard against nulls};
                    IF ((i<=4) AND (astring[1] <> '*')) THEN
                       correspondent_address[i] := astring
                    ELSE
                       done := TRUE;
                    i := i + 1
                 END
              UNTIL done
           END;
      END {grab_address_lines};
```

```
PROCEDURE initialize {for "fileprint"};
   { This is the procedure which sets up initial conditions when a
      file is to be printed...
   }
   BEGIN
      open_file_now;
      fix_copyright_tag;
      set_up_printer;
      grab_address_lines;
      first_heading := TRUE;
      line_count := 99
   END {initialize for "fileprint"};


PROCEDURE headerprint;
   { This is the procedure which prints a header which breaks up the
      text into multiple pages...  It is invoked whenever necessary, and
      checks the type of printing operation as determined by the global
      variable "which_print_heading"...  All the headers are printed with
      a "normal" spacing option for the printer.
   }

   PROCEDURE normal_header;
      { This is the header used for most printing operations, including
         the printing of program files...  The printout of this program
         was made using this kind of header...
      }
      VAR
         i : INTEGER;
      BEGIN
         setdiablospacing(horiz,c8);
         s := '';
         IF ((pagecount > 0) AND (line_count<>100)) THEN
            FOR i := 1 TO 2 DO println {s-->diablo};
         pagecount := pagecount +1;
         IF verti = 16 THEN println {s-->diablo};
         println {s-->diablo};
         s := CONCAT(file_heading,todays_date,'     Page  ');
         inttos(pagecount);
         println {s-->diablo};
         s := firstline;
         println {s-->diablo};
         s := hyphens;
         println {s-->diablo};
         s := '';
         println {s-->diablo};
         setdiablospacing(horiz,verti);
         line_count := 0
      END {normal_header};
```

```
PROCEDURE header_personal_letter;
   { This is the header routine used for personal letters, where on the
     first time through, a full return address, date and correspondent
     address are provided.  On second and succeeding headings, only an
     abbreviated header is used containing the first line of the corre-
     spondent address, date and page number...
   }
   VAR
      i : INTEGER;
   BEGIN {header_personal_letter}
      setdiablospacing(horiz,c8);
      s := '';
      IF ((pagecount > 0) AND (line_count<>100)) THEN
         FOR i := 1 TO 2 DO println {s-->diablo};
      pagecount := pagecount +1;
      IF verti = 16 THEN println {s-->diablo};
      println {s-->diablo};
      IF first_heading THEN
         BEGIN
            {space down an amount equal to the continuation heading }
            s := '';
            println;
            println;
            println;
            println;
            setdiablospacing(horiz,verti);
                                              {line count is}
            my_address_print;                      {1-5}
            s := todays_date;
            center_the_string;
            println;                               {6}
            s := '';
            println;                               {7}
            println;                               {8}
            println;                               {9}
            s := 'To:';
            println;                               {10}
            FOR i := 0 TO 4 DO
               BEGIN
                  s := correspondent_address[i];
                  println                          {11-15}
               END;
            s := '';
            println;                               {16}
            println;                               {17}
            println;                               {18}
            line_count := 18 {lines printed so far}
         END
      ELSE
         BEGIN
            s := CONCAT('<<< your name >>> to ',correspondent_address[0],'   ',
               todays_date,'    Page  ');
            inttos(pagecount);
            println {s-->diablo};
            s := '';
            println {s-->diablo};
            s := hyphens;
            println {s-->diablo};
            s := '';
```

```
            println {s-->diablo};
            setdiablospacing(horiz,verti);
            line_count := 0
          END;
        first_heading := FALSE
      END {header_personal_letter};


    PROCEDURE header_business_letter;
      { This is the header routine used for business letters, where on the
          first time through, a full return address, date and correspondent
          address are provided.  On second and succeeding headings, only an
          abbreviated header is used containing the first line of the corre-
          spondent address, date and page number...
      }
      VAR
        i : INTEGER;
      BEGIN {header_business_letter}
        setdiablospacing(horiz,c8);
        s := '';
        IF ((pagecount > 0) AND (line_count<>100)) THEN
          FOR i := 1 TO 2 DO println {s-->diablo};
        pagecount := pagecount +1;
        IF verti = 16 THEN println {s-->diablo};
        println {s-->diablo};
        IF first_heading THEN
          BEGIN
            {space down an amount equal to the continuation heading }
            s := '';
            println;
            println;
            println;
            println;
            setdiablospacing(horiz,verti);
            {begin the first time heading}
            s := '<<< your business name >>>';
            center_the_string;           {line count is}
            println;                        {1}
            s := '<<< your business address >>>';
            center_the_string;
            println;                        {2}
            s := '<<< your business town, state, zip >>>';
            center_the_string;
            println;                        {3}
            s := '';
            println;                        {4}
            s := '<<< your name >>>';
            center_the_string;
            println;                        {5}
            s := '<<< your title >>>';
            center_the_string;
            println;                        {6}
            s := '';
            println;                        {7}
            s := todays_date;
            center_the_string;
            println;                        {8}
            s := '';
            println;                        {9}
```

```
              println;                                   {10}
              println;                                   {11}
              s := 'To:';
              println;                                   {12}
              FOR i := 0 TO 4 DO
                 BEGIN
                    s := correspondent_address[i];
                    println                              {13-17}
                 END;
              s := '';
              println;                                   {18}
              println;                                   {19}
              println;                                   {20}
              line_count := 20 {lines printed so far}
            END
         ELSE
            BEGIN
              s := CONCAT('<<< your name >>> to ',correspondent_address[0],
                 '    ',todays_date,'    Page  ');
              inttos(pagecount);
              println {s-->diablo};
              s := '';
              println {s-->diablo};
              s := hyphens;
              println {s-->diablo};
              s := '';
              println {s-->diablo};
              setdiablospacing(horiz,verti);
              line_count := 0
            END;
         first_heading := FALSE

      END {header_business_letter};


   BEGIN {headerprint};
      IF which_print_heading = miscellaneous
         THEN normal_header
      ELSE
         IF which_print_heading = a_personal_letter
            THEN header_personal_letter
         ELSE
            header_business_letter
   END {headerprint};
```

```
  PROCEDURE checkprocedure;
     { This procedure is used to determine whether the current input line
        contains the keyword "PROCEDURE" in order to perform a rudimentary
        type of "prettyprinting": a new procedure will not begin in the
        listing of a "normal" file if it starts more than "criterion"
        down the sheet of paper.
     }
     BEGIN
        IF POS('PROCEDURE',astring) > 0 THEN
           BEGIN
              s := '';
              REPEAT
                 BEGIN
                    println;
                    line_count := line_count + 1
                 END
              UNTIL line_count > lines_per_page
           END
     END {checkprocedure};


  PROCEDURE pagecheck {for "fileprint"};
     { This is the procedure used before every normal "println" call during
        the main portion of a file printing operation, in order to test
        whether a skip to the next page is reauired. It invokes the
        "checkprocedure" routine if the Pascal PROGRAM printing option is
        turned on.
     }
     VAR i : INTEGER;
     BEGIN
        line_count := line_count + 1;
        IF
            we_print_a_program
                    AND
          (line_count > criterion)
        THEN checkprocedure;
        IF line_count > lines_per_page THEN headerprint
     END {pagecheck for "fileprint"};


  PROCEDURE pagebumper {for "fileprint"};
     { This procedure implements a rudimentary form of word processing:
        if a "miscellaneous" file format is used, then the standard heading
        field "firstline" can be redefined by an input record with the key
        character "$" in column 2. (This allows it to be wrapped in comments
        braces in a Pascal program.)  For all formats, if the key character
        "#" is found in column 2 of a line, the printing will skip to the
        next page and start a new heading...

        NOTE THIS  P R O C E O U R E   USES  R E C U R S I O N !!!!
     }
     VAR
        i : INTEGER;
     BEGIN
        IF LENGTH(astring)<2 THEN astring := CONCAT(astring,'  ');
        IF astring[2] = '#' THEN
           BEGIN
              s := '';
              WHILE line_count > 0 DO
```

```
                  BEGIN
                     pagecheck;
                     println {s-->diablo}
                  END;
                READLN(textfile,astring);
                pagebumper {RECURSIVE CALL}
             END;
          IF astring[2] = '$' THEN
             BEGIN
                READLN(textfile,firstline);
                READLN(textfile,astring);
                pagebumper {RECURSIVE CALL}
             END
       END {pagebumper for "fileprint"};


    BEGIN {the "fileprint" PROCEDURE at last}
       initialize;
       WHILE NOT EOF(textfile) DO
          BEGIN
             READLN(textfile,astring);
             records := records + 1;
             pagebumper;
             pagecheck;
             s := astring;
             println {s-->diablo}
          END;
       s := '';
       line_count := line_count - 5 {adjustment to make it come out even};
       REPEAT
          BEGIN
             println;
             line_count := line_count + 1
          END
       UNTIL line_count > lines_per_page;
       CLOSE(textfile,LOCK)
    END {fileprint};


 PROCEDURE namefile;
    { This procedure sets the file name to be printed.  It is always assumed
       that a ".TEXT" extension will be used...
    }
    BEGIN
       PAGE(OUTPUT);
       WRITELN('Enter a new file name to be printed');
       READLN(filename);
       filename := CONCAT(filename,'.TEXT')
    END {namefile};
```

```
PROCEDURE personal_letter;
   BEGIN
      which_print_heading := a_personal_letter;
      fileprint
   END {personal_letter};


PROCEDURE busi_letter;
   BEGIN
      which_print_heading := a_business_letter;
      fileprint
   END {busi_letter};


PROCEDURE any_file_print;
   BEGIN
      which_print_heading := miscellaneous;
      fileprint
   END;


PROCEDURE console_input;
   { This procedure is used to read a single keystroke fromt the console
      keyboard unit.  It is required because the UCSD Pascal READ(KEYBOARD,
      anychar) intrinsic purges all the normal ASCII control characters...
   }
   VAR
      inch :  PACKED ARRAY[0..0] OF CHAR;
   BEGIN
      UNITREAD(2,inch[0],1,,1);
      WHILE UNITBUSY(2) DO;
      anychar := inch[0]
   END {console_input};
```

```
PROCEDURE typing;
   { This is a self contained procedure to make the terminal keyboard behave
     as a "memory" typewriter.  The contents of the input buffer are printed
     upon receipt of a "<RETURN>" code or upon exceeding an input length of
     96 characters.   The display is used to show the possible special
     function keys as well as the current input line contents...
   }
   VAR
      ichar : INTEGER;
      itemp : INTEGER;
      line_increment : INTEGER;


   PROCEDURE promptings;
      BEGIN {promptings};
         PAGE(OUTPUT);
         WRITELN('Typing routine...');
         WRITELN('   <return>     = print the current line input');
         WRITELN('   <back space> = delete one character');
         WRITELN('   <ctrl> "I"   = skip to new page');
         WRITELN('   <ctrl> "J"   = delete line');
         WRITELN('   <ctrl> "G"   = confirm line buffer');
         WRITELN('   <esc> to leave typewriter');
         WRITELN('');
         WRITELN(hyphens);
         WRITELN('')
      END;


   BEGIN
      set_up_printer;
      PAGE(OUTPUT);
      line_count := 0;
      IF verti = 16 THEN
         line_increment := 2
      ELSE
         line_increment := 1;
      anychar := ' ';
      s := '';
      promptings;
      UNITCLEAR(2);
      WHILE anychar <> CHR(27) DO
         BEGIN {other than escape <ESC>}

            console_input;

            WRITE(anychar);
            ichar := ORD(anychar);
            IF ichar >= ORD(' ') THEN
               BEGIN {normal ASCII}
                  string_nothing[1]  := anychar;
                  s := CONCAT(s,string_nothing);
                  IF LENGTH(s) >=  96 THEN ichar := 0 {signal end of line}
               END {normal ASCII};
            IF ichar < ORD(' ') THEN

               CASE ichar OF
```

```
            0 : {line overflow}
               BEGIN
                  line_count := line_count + line_increment;
                  IF line_count > 66 THEN line_count := 1;
                  println;
                  string_nothing[1] := anychar;
                  s := string_nothing
               END;

            10 : {line delete}
               BEGIN
                  s := '';
                  WRITELN('<<< l i n e   d e l e t e d >>>')
               END;

            7 : {bell}
               BEGIN
                  WRITELN('');
                  WRITELN(s)
               END;

            8 : {back space}
               BEGIN
                  IF LENGTH(s) > 1 THEN
                     BEGIN
                        itemp := LENGTH(s) - 1;
                        s := COPY(s,1,itemp)
                     END
                  ELSE
                     s := ''
               END;

            9 : {forms feed}
               BEGIN
                  line_count := line_count + line_increment;
                  IF line_count > 66 THEN line_count := 1;
                  println;
                  s := '';
                  promptings;
                  WHILE line_count < 66 DO
                     BEGIN
                        line_count := line_count + line_increment;
                        println
                     END
               END;

            13 : {print the line}
               BEGIN
                  line_count := line_count + 1;
                  IF verti > 8 THEN line_count := line_count + 1;
                  IF line_count > 66 THEN line_count := 1;
                  println;
                  s := '';
                  promptings
               END

         END {CASE}

      END {other than escape <ESC>};
```

```
    PAGE(OUTPUT)
  END {typing};


PROCEDURE pagenumber;
  BEGIN
    PAGE(OUTPUT);
    WRITELN('Enter starting page number from the following list');
    WRITELN('      <CR>  --> default start from 1');
    WRITELN('      "!"   --> entry of a new starting value');
    WRITELN('      <ESC> --> continue from ',pagecount:4);
    console_input;
    WRITELN(anychar);
    IF ORD(anychar) = 13 THEN
      pagecount := 0 {default to 1}
    ELSE
      BEGIN
        IF anychar = '!' THEN
          BEGIN
            WRITELN('');
            WRITELN('         Enter new page number:');
            READLN(pagecount);
            pagecount := pagecount - 1
          END
      END
  END {pagenumber};


PROCEDURE proccheck;
  BEGIN
    we_print_a_program := NOT we_print_a_program;
    IF we_print_a_program THEN
      c_we_print := 'YES'
    ELSE
      c_we_print := 'NO'
  END;


PROCEDURE print_return_address;
  {Procedure to print return addresses on letter size envelopes}
  VAR
    done : BOOLEAN;

  PROCEDURE setup_envelope;
    BEGIN {setup_envelope};
      WRITELN('Place envelope in printer, then press any character');
      READ(KEYBOARD,anychar);
    END {setup_envelope};


  BEGIN {print_return_address}
    done := FALSE;
    REPEAT
      setup_envelope;
      my_address_print;
      WRITELN('More? <esc> to quit');
      READ(KEYBOARD,anychar);
      IF ORD(anychar) = 27 THEN done:=TRUE
    UNTIL done
```

```
   END {print_return_address};
PROCEDURE print_menu;
   { This is the main function menu for the print utility program
   }
   BEGIN
      PAGE(OUTPUT);
      WRITELN('Carl''s Printing Program... 7/18/79');
      WRITELN('');
      WRITELN('');
      WRITELN('Pick an option from the following list...');
      WRITELN('');
      WRITELN('      D --> printer spacing = ',pstring);
      WRITELN('      # --> set starting page number = ',pagecount:4);
      WRITELN('      N --> file name = ',filename);
      WRITELN('      C --> copyright = ',cstring);
      WRITELN('      Q --> toggle PROCEDURE search option = ',c_we_print);
      WRITELN('      W --> date = ',todays_date);
      WRITELN('');
      WRITELN('      P --> print routine');
      WRITELN('      L --> print as personal letter');
      WRITELN('      B --> print as business letter');
      WRITELN('      T --> enter typewriter routine');
      WRITELN('      R --> prepare return addresses on envelopes');
      WRITELN('');
      WRITELN('Type <esc> to leave the program')
   END {print_menu};


BEGIN {print program main PROCEDURE}
   really_initialize;
   WHILE alldone <> TRUE  DO
      BEGIN
         print_menu;
         READ(KEYBOARD,anychar);
         IF anychar <> CHR(27) THEN
            CASE anychar OF
               'D','d' :diablo;
               'C','c' :getcopyspec;
               'P','p' :any_file_print;
               'Q','q' :proccheck;
               'N','n' :namefile;
               'L','l' :personal_letter;
               'B','b' :busi_letter;
               'T','t' :typing;
               'R','r' :print_return_address;
               'W','w' :get_the_date;
               '#','3' :pagenumber
            END {CASE}
         ELSE
            alldone := TRUE
      END
END.
(*$D+*)
(*$L+*)
```

# An Automatic Metric Conversion Program

**David A Mundie**

Calculators and personal computers have already liberated us from trigonometric and logarithmic tables. It is time they do the same with respect to metric conversion tables. I recently wrote the SUPERMETRIC program shown in listing 1 for just that purpose. (Listing 2 shows a sample run of the program.)

Although my design goals seemed quite modest and straightforward, achieving them turned out to require an astonishing amount of number crunching and devious programming, as the length of the listing testifies. My first requirement was that the program distinguish rigorously between customary units, primary metric units, and secondary metric units. By "primary" metric units I mean the System International (SI) base units such as metre, kilogram, kelvin, and so on, as well as the derived units such as watt, newton, m/s, pascal, and volt. By "secondary" metric units I mean units like °C and km/h which are accepted but not part of SI, along with the formulas for derived units with special names, eg, kg m/s as the formulas for the newton.

This design goal was met by storing the various units and their conversion factors in a table whose structure may most conveniently be understood by examining the "data statements" which generate it in the subroutine INITIALIZE. Each entry in the table contains three items: two units and a conversion factor. The units on the right are all primary units. In the top part of the table (above MAXCUST) the left-hand units are customary, while in the bottom section they are secondary metric units.

The program automatically converts customary and secondary units to primary units. Primary units may be converted to customary by using the "C" command, while the "S" command converts them to secondary units. As it stands now, the program will only convert a given primary unit to the first customary unit it finds in the table. However, it would be a simple matter to add a new command that would allow the user to specify the target unit, "gallon" instead of "fl. ounce," for example. The table is quite easily expanded through the use of additional "data statements."

A second design goal was to have the program automatically add prefixes to metric units as needed, and to adjust inputs with prefixes that are too large or too small. For example, I wanted 5700 kJ to be converted automatically to 5.7 MJ. To this end, the subroutine DEPREFIX removes prefixes from the units input by the user, so that the data is stored internally in unprefixed primary units. The subroutine PREFIX then prints the correctly prefixed measurement. The prefixes themselves are contained in the strings NORMP and SPECP. NORMP contains the normal set of prefixes, each 1000 times larger than the next, as shown in table 1, whereas SPECP stores the special set of prefixes used for volumes and areas, as shown in table 2. Thus 15000 m is converted to 15 km, whereas 15000 $m^2$ is converted to 1.5 $hm^2$.

A third design goal was to have the program deal with the problem of precision in a reasonable manner. Nothing is more absurd than to convert 3 square yards to 2.5083821 $m^2$, although anti-

| Power | Prefix | Abbreviation |
|---|---|---|
| $10^{18}$ | exe | E |
| $10^{15}$ | peta | P |
| $10^{12}$ | tera | T |
| $10^{9}$ | giga | G |
| $10^{6}$ | mega | M |
| $10^{3}$ | kilo | k |
| $10^{-3}$ | milli | m |
| $10^{-6}$ | micro | μ |
| $10^{-9}$ | nano | n |
| $10^{-12}$ | pico | p |
| $10^{-15}$ | femto | f |
| $10^{-18}$ | atto | a |

*Table 1: Prefixes used by SUPERMETRIC for measurements other than volumes and areas.*

| Power | Prefix | Abbreviation |
|---|---|---|
| $10^{3}$ | kilo | k |
| $10^{2}$ | hecto | h |
| $10^{1}$ | deka | da |
| $10^{-1}$ | deci | d |
| $10^{-2}$ | centi | c |
| $10^{-3}$ | milli | m |

*Table 2: Prefixes used by SUPERMETRIC for volumes and areas.*

| Correct SI Form | SUPERMETRIC Approximation |
|---|---|
| μ | u |
| da | D |
| · | * (multiplication) |
| o | $ (degree) |
| m² etc. | m2 |
| Ω | @ (ohm) |

*Table 3: Differences between SUPERMETRIC and correct System International (SI) symbols.*

metric journalists often feign to believe this is correct practice. My approach was to have the program give a converted measurement whose implied error is between 10% and 100% that of the input. This insures that the converted measurement will be at least as precise as the input, but never more than one significant digit more precise. To achieve this goal, the subroutine VALUE reads the measurement which the user enters and calculates the number of significant digits it contains (P). This number is then used to control the number of significant digits in the output. For example, the program automatically converts 3 square yards (implied error ± 0.5 square yard or ± 0.42 $m^2$) to 2.5 $m^2$ (implied error ± 0.05 $m^2$). As a convenience to the user, the program will accept numbers with a trailing decimal point and treat all the digits to the left of the decimal point as significant. Thus, although "1000" is treated as having one significant digit, "1000." is treated as having four.

My final design goal was to adhere as closely as possible to standard SI notation within the bounds of the ASCII character set. The points where this goal was not met are shown in table 3. I regret all of these, but had no choice except in the case of the "da" prefix. Since the other deviations were unavoidable, the extra coding needed to handle a 2-character prefix did not seem worthwhile.■

*The author wishes to thank Joe Berman and Steve Wellons, of the University of Virginia's Microprocessor Laboratory, for their assistance in the preparation of the listings for this article. The listings were done on equipment purchased under NASA contract #NAS1-14862.*

*Listing 1: The automatic metric conversion program written in UCSD Pascal.*

```
PROGRAM supermetrics;
(*$S+*)
CONST
  normp='afpnum kMGTPE';     {normal prefixes}
  specp='mcd Dhk';           {special prefixes for areas and volumes}
  maxentries = 100;
TYPE
  entry = RECORD
            left, right: STRING;
            factor: REAL;
          END;
  index = 0..maxentries;

VAR
  table      :array[index] of entry;
  curtop     :index;      {current top of table}
  current    :index;      {points to current entry}
  maxcust    :index;      {top of customary section of table}
  top        :index;      {permanent top of table}
  leftside   :BOOLEAN;
  finished   :BOOLEAN;
  oldm,oldf  :REAL;
  line       :STRING;     {one line of user input}
  u          :STRING;     {the unit}
  m          :REAL;       {the measurement}
  p          :INTEGER;    {the precision}

{********** mathematical utilities *****************************}

FUNCTION floor(r:REAL): INTEGER;
BEGIN floor:=trunc(r-ord((r<0)and(r<>trunc(r))))
END;

FUNCTION nl(r:REAL):REAL; {Avoids bug in ln function}
BEGIN IF r<1 THEN nl:=-ln(r) ELSE nl:=ln(r)
END;

FUNCTION power(i,j:INTEGER):REAL;
BEGIN power:=exp(nl(i)*j)
END;

FUNCTION log(r:REAL):REAL;
BEGIN log:=nl(abs(r))/nl(10)
END;

FUNCTION lop(r:REAL; p:INTEGER):REAL;
{ Reduce a real to p significant digits }
VAR f:REAL;
BEGIN f:=power(10,floor(log(r))-p+1);
 IF r/f<maxint THEN lop:=f*round(r/f) ELSE lop:=r
END;

FUNCTION norm(r:REAL):REAL;
BEGIN norm:=r/power(10,floor(log(r)))
END;


{********** Convert a string to a real number **********}

FUNCTION value(VAR s:STRING; VAR p:INTEGER):REAL;
CONST
  limit=1.67772E6;        { (2**23)/5) }
  z    =48;               { ord(0) }
VAR
  a,y            :REAL;
  e,i,j,p2       :INTEGER;
  neg,negexp,gtl:BOOLEAN;
  digits         :SET OF CHAR;
BEGIN
  i:=1;p:=0;p2:=0; gtl:=false; digits:=['0'..'9'];
  s:=concat(s,'%'); {safety character}
  a:=0; e:=0; neg:=s[i]='-'; WHILE s[i]=' ' DO i:=i+1;
  IF (s[i]='+')or neg THEN i:=i+1;
  WHILE s[i] in digits DO
    BEGIN
      IF s[i]='0' THEN p2:=p2+1
      ELSE BEGIN p:=p+p2+1; p2:=0; gtl:=true END;
      IF a<limit THEN a:=10*a+ord(s[i])-z ELSE e:=e+1; i:=i+1
    END;
  IF s[i]='.' THEN
    BEGIN p:=p+p2; i:=i+1;
      IF not(s[i] in digits) THEN
        BEGIN insert('0',s,i); i:=i+1
        END
    END;
  p2:=0;
```

```
 WHILE s[i]='0' DO
   BEGIN p2:=p2+1; IF a<limit THEN
     BEGIN a:=10*a+ord(s[i])-z; e:=e-1
     END; i:=i+1
   END;
 IF gt1 THEN p:=p+p2;
 WHILE s[i] in digits DO
   BEGIN p:=p+1;
     IF a<limit THEN
     BEGIN a:=10*a+ord(s[i])-z; e:=e-1
     END; i:=i+1
   END;
 IF s[i] in ['e','E'] THEN
   BEGIN i:=i+1; j:=0; negexp:=(s[i]='-');
     IF(s[i]='+') or negexp THEN i:=i+1;
     WHILE s[i] in digits DO
       BEGIN IF j<limit THEN j:=10*j+ord(s[i])-z; i:=i+1
       END;
     IF negexp THEN e:=e-j ELSE e:=e+j
   END;
 y:=a; IF neg THEN y:=-y;
 IF e<0 THEN value:=y/power(10,-e)
 ELSE IF e<>0 THEN value:=y*power(10,e)
 ELSE value:=y;
 WHILE s[i]=' ' DO i:=i+1; s:=copy(s,i,length(s)-i);
END; {value}

{********** Write a real in appropriate format and return a blank **}

FUNCTION f(r:REAL): CHAR;
CONST
  width  = 22;
VAR
  intpart,decimals,floating:INTEGER;
BEGIN
  intpart:=floor(log(r));
  decimals:=p-intpart-1;
  r:=lop(r,p);
  IF r>10000 or r<0.0001 THEN  {floating point}
    write(r:width)
  ELSE
    IF decimals<=0 THEN  {integer}
      write(round(r): width)
    ELSE  {fixed point}
     write(r:width:decimals);
  f:=' '
END;

{********** Special handling for temperatures ****************}

PROCEDURE temperature(VAR m:REAL; b:BOOLEAN; fact:INTEGER);
VAR
  d:INTEGER;
BEGIN
  d:=p-floor(log(m))-1;
  m:=m+fact*273.15+fact*186.52*ord(b);
  p:=d+floor(log(m))+1
END;

{********** Find u in the table of units **********************}

FUNCTION inlist:BOOLEAN;
VAR t:STRING;

FUNCTION match(s:string):BOOLEAN;
BEGIN match:=(u=s)or(t=s)
END;

BEGIN
  leftside:=true; current:=1;
  t:=u; IF length(t)>1 THEN delete(t,1,1);
  WHILE (not(match(table[current].left))) and(current<=curtop) DO
    current:=current+1;
  IF current<=curtop THEN
    inlist:=true
  ELSE
    BEGIN current:=curtop; leftside:=false;
      WHILE (not(match(table[current].right))) and(current>0)DO
        current:=current-1;
      inlist:=current>0
    END;
END;

{********** Add correct metric prefix **********************}

PROCEDURE prefix(m: REAL; u:STRING);

PROCEDURE pref(p:STRING; fac,term:INTEGER);
VAR
```

```
  i,range: INTEGER;
BEGIN
  range:=floor(log(m)/fac);
  IF abs(range)>term THEN
    range:=term*(1-2*ord(range<-term));
  m:=m/power(10,fac*range);
  IF range<>0 THEN
    BEGIN
      p:=copy(p,range+term+1,1);
      u:=concat(p,u);
      writeln(f(m),u)
    END
END;

BEGIN {prefix}
  IF pos('2',u) =2 THEN pref(specp,2,3)
  ELSE IF pos('3',u)=2 THEN pref(specp,3,3)
  ELSE pref(normp,3,6)
END;

{********** Convert to primary units **********************}

PROCEDURE primary;
VAR
  oldp:INTEGER;
BEGIN
  WITH table[current] DO
    BEGIN
      IF u='mpg' THEN m:=1/m;
      IF length(u)=2 THEN
        IF(u[1]='$')and(u[2] in ['F','C']) THEN
          temperature(m,u[2]='F',1);
      oldm:=m;
      oldf:=factor;
      oldp:=p;
      p:=p+ord(norm(m)*norm(factor)>=10);
      u:=right;
      m:=m*factor;
      writeln(f(m),u);
      prefix(m,u);
      p:=oldp;
      leftside:=false
    END;
END;

{********** Check metric prefix and adjust if necessary ***********}

PROCEDURE normalize(VAR m:REAL; VAR u:STRING);
VAR
  s:STRING;

PROCEDURE depref(p:STRING; fac,term:INTEGER);
VAR
  range,k  :INTEGER;
  needspref:BOOLEAN;
BEGIN
  needspref:=floor(log(m)/fac)<>0;
    IF pos(s,u)=2 THEN
      BEGIN
        range:=term+1;
        FOR k:=1 TO length(p) DO
          IF u[1]=p[k] THEN
            range:=k-term-1;
        IF range+term+1 in [1..term*2+1] THEN
          BEGIN
            m:=m*power(10,fac*range);
            delete(u,1,1);
            writeln(f(m),u)
          END
        ELSE
          writeln('illegal prefix ignored')
      END;
    IF needspref
      THEN
        prefix(m,u)
END;

BEGIN {normalize}
  IF leftside THEN
    s:=table[current].left
  ELSE s:=table[current].right;
  IF pos('2',s)=2 THEN
    depref(specp,2,3)
  ELSE
    IF pos('3',s)=2 THEN
      depref(specp,3,3)
    ELSE depref(normp,3,6)
END;

{********** Convert to customary or secondary units ***********}
```

```
PROCEDURE custandsec(m:REAL);
VAR
  oldp:INTEGER;
BEGIN
  WITH table[current] DO
    BEGIN
     oldp:=p;
     p:=p+ord(norm(oldm)*norm(oldf/factor)>=10);
     m:=m/factor;
     IF (u='m3/m') and (current<=maxcust) THEN m:=1/m;
     IF u='K' THEN temperature(m,left[2]='F',-1);
     writeln(f(m),left);
     IF current>maxcust THEN prefix(m,left);
     p:=oldp
    END
END;

{********** Set up the table ********************************}

PROCEDURE initialize;
PROCEDURE data(l,r:STRING; f:REAL);
BEGIN
  curtop:=curtop+1;
  WITH table[curtop] DO
    BEGIN
      left:=l;
      right:=r;
      factor:=f;
    END;
END;

BEGIN {initialize}
  curtop:=0;
  data('$F','K',5.5556E-1);     data('mpg','m3/m',2.352E-6);
  data('horsepower','W',7.355E2);
  data('inch of mercury','Pa',3.37685E3);
  data('mph','m/s',4.4704E-1);  data('yard','m',9.144E-1);
  data('yard2','m2',8.361274E-1);
  data('acre','m2',4047);       data('barrel','m3',0.159);
  data('kCal','J',4.1868E3);    data('BTU','J',1055);
  data('Curie','Bq',3.7E10);
  maxcust:=curtop;
  data('L','m3',1.0E-3);        data('N/m2','Pa',1);
  data('L/100km','m3/m',1.0E-8);  data('m/h','m/s',2.777E-4);
  data('kW-h','J',3.6E6);
  data('$C','K',1);
  data('N*m','J',1);
  top:=curtop
END;

{********** Main subprograms ************************************}

PROCEDURE commands;
VAR
  i:INTEGER;
BEGIN
  CASE line[1] OF
 'f': finished:=true;
 's': IF inlist and (current>maxcust) and not(leftside) THEN
        custandsec(m);
 'c': BEGIN
        curtop:=maxcust;
        IF inlist THEN
          custandsec(m);
        curtop:=top
      END;
  'l': FOR i:=1 TO curtop DO
         WITH table[i] DO
           writeln(left,' ',right,' ',factor)
   END;
   writeln
END;

PROCEDURE process;
BEGIN
  m:=value(line,p); u:=line; oldf:=1;
  IF not inlist THEN
    writeln('unit not available')
  ELSE
    BEGIN
      IF (current>maxcust) or (not leftside) THEN
        normalize(m,u);
      IF leftside THEN
        primary
   END;
 writeln
END;

BEGIN {supermetrics}
  finished:=false;
```

```
    initialize;
    writeln('SUPERMETRIC CONVERSION PROGRAM');
    writeln;
    REPEAT
      write('Measure and unit >>');
      readln(line);
      IF line[1] in ['0'..'9','+','-']
        THEN
          process
        ELSE
          commands
    UNTIL finished
  END.
```

*Listing 2: A sample run of the program shown in listing 1.*

```
Measure and unit>>5700 kJ
            5.70000E6 J
                  5.7 MJ

Measure and unit>>secondary
            5.70000E6 N*m
                  5.7 MN*m

Measure and unit>>15000 m
                   15 km

Measure and unit>>15000 m2
                  1.5 hm2

Measure and unit>>customary
                 3.71 acre

Measure and unit>>3 yard2
                  2.5 m2

Measure and unit>>3.0000 yard2
              2.50838 m2

Measure and unit>>5 barrel
                  0.8 m3
                  800 dm3

Measure and unit>>secondary
                  800 L

Measure and unit>>38 mpg
            6.20000E-8 m3/m
                   62 mm3/m

Measure and unit>>secondary
                  6.2 L/100 km

Measure and unit>>50 horsepower
            3.70000E3 W
                   37 kW

Measure and unit>>300 BTU
            3.00000E5 J
                  300 kJ

Measure and unit>>secondary
            3.00000E5 N*m
                  300 kN*m

Measure and unit>>55 mph
                 24.6 m/s

Measure and unit>>secondary
            8.90000E4 m/h
                   89 km/h

Measure and unit>>37 kW-h
            1.33000E8 J
                  133 MJ

Measure and unit>>1200 kCal
            5.00000E6 J
                  5.0 MJ

Measure and unit>>29.5 inch of mercury
            9.96000E4 Pa
                 99.6 kPa

Measure and unit>>secondary
            9.96000E4 N/m2
                 99.6 kN/m2

Measure and unit>>68 $F
                293.2 K

Measure and unit>>secondary
                 20.0 $C

Measure and unit>>12 $C
                  285 K

Measure and unit>>customary
                   54 $F

Measure and unit>>0.005 Curie
            1.85000E8 Bq
                  185 MBq

Measure and unit>>finished
```

# A Computer-Assisted Dieting Program

**David A Mundie**

Each spring as I set out to lose my winter fat, I reach for the program shown in listing 1 to decide on a sensible combination of diet and exercise. (A sample run of this program is shown in listing 2.) The program estimates how long a given weight loss will take, based on the person's activity level and food energy intake. Knowing that the unpleasant process will not last forever is a great encouragement.

The program is based on an article by Vincent Antonetti in the American Journal of Clinical Nutrition. In this article, Antonetti shows that the time to go from an original weight $W_o$ to a final weight $W_f$ is given by

$$\theta = \gamma \int_{W_o}^{W_f} \frac{dW}{(1-\alpha)I - (K_a W + K_b W^n)}$$

where $\gamma$ is the energy value of one unit of weight gained or lost, $\alpha$ is the specific dynamic action of food, I is the daily food energy intake, n is a constant for estimating the surface area of the body, and $K_a$ and $K_b$ are activity and basal coefficients for the given person, expressed in terms of energy per unit weight per day. This formula is easily solved using the numerical technique known as Simpson's rule.

It is ironic that Antonetti, writing in 1973, felt his formula itself was virtually useless, since people did not have computers in their homes to perform the necessary computations. Nothing speaks more eloquently of how fast the revolution in personal computers has taken place.

To avoid the use of a computer, Antonetti published a massive collection of tables giving selected values of the above formula for various combinations

*Listing 1: The computer-assisted dieting program written in UCSD Pascal.*

```
PROGRAM diet;
CONST
  gamma=32000;            { 1 kg of body weight = 32000 kJ }
  p=10;                   { number of iterations }
  alpna=0.1;              { specific dynamic action of food }
  n=0.425;                { constant for estimating surface area of body }
  male= 1;
VAR
  theta,                  { days for given weight change }
  wo,                     { original weight }
  wf,                     { final weight }
  intake,                 { food intake, kJ/d }
  kb,                     { basal coefficient, kJ/(kg*d) }
  ka,                     { activity coefficient, kJ/(kg*d) }
  b,                      { basal metabolic rate, kJ/(m2*h) }
  height,                 { in metres }
  age: REAL;
  sex: INTEGER;
  answer:STRING;

FUNCTION find(s:STRING):REAL;
VAR r:REAL;
BEGIN
  write(s,'>>'); readln(r); find:=r
END;

FUNCTION sum:REAL;
VAR
  s:REAL;
  j:INTEGER;

FUNCTION f(j:INTEGER):REAL;

FUNCTION w(j:INTEGER):REAL;
BEGIN
  w:=wo-(j/p)*(wo-wf)
END;

BEGIN {f}
  f:=1/((1-alpha)*intake-(ka*w(j)+kb*exp(n*ln(w(j)))))
END;

BEGIN {sum}
  s:=f(0)+f(p);
  FOR j:=1 TO p-1 DO
    IF odd(j)
      THEN
        s:=s+4*f(j)
      ELSE
        s:=s+2*f(j);
  sum:=s
END;
```

*Listing 1, continued:*

```
BEGIN {diet}
  writeln;
  writeln('Welcome to the diet!');
  age:=find('Age');
  sex:=round(find('Sex (Male=1)'));
  height:=find('Height in metres');
  IF sex=male
    THEN
      b:=173.8-0.5195*age
    ELSE
      b:=156.36-0.3636*age;
  kb:=4.8*b*exp(0.725*ln(height));
  REPEAT
    writeln;
    writeln('Sample Activity Coefficients:');
    writeln('Sedentary 34, light 40, moderate 53, vigorous 74, severe 113');
    writeln;
    ka:=find('Activity coefficient');
    wo:=find('Initial weight, kg');
    wf:=find('Final weight, kg');
    intake:=find('Daily food intake, kJ');
    theta:=(gamma*(wf-wo)/(3*p))*sum;
    writeln;
    writeln('Time for this weight change is ',round(theta),' days.');
    write('Another?');
    readln(answer)
 UNTIL not(answer[1] in ['y','Y'])
END.
```

*Listing 2: A sample run of the program shown in listing 1.*

```
Welcome to the diet!
Age>>32
Sex (Male=1)>>1
Height in metres>>1.75

Sample Activity Coefficients:
Sedentary 34, light 40, moderate 53, vigorous 74, severe 113

Activity coefficient>>74
Initial weight, kg>>77
Final weight, kg>>70
Daily food intake, kJ>>5000

Time for this weight change is 28 days.
Another?y


Sample Activity Coefficients:
Sedentary 34, light 40, moderate 53, vigorous 74, severe 113

Activity coefficient>>53
Initial weight, kg>>77
Final weight, kg>>70
Daily food intake, kJ>>5000

Time for this weight change is 35 days.
Another?n
```

| **Description** | **Activity Coefficient kJ/(kg·d)** |
|---|---|
| Inactive: very little standing or walking. | 34 |
| Seated most of day: four hours of standing and walking. | 40 |
| Stands as often as is seated. | 53 |
| Standing and walking most of the day. | 74 |
| Very hard physical work. | 113 |

*Table 1. Typical values of the Physical Activity Coefficient.*

of the variables, but my program gives much more accurate answers than any table can. I have converted all measurements to System International (SI) metric units. In particular, food energy is not expressed in kilocalories, but in joules, the only unit of energy in SI. For purposes of conversion and comparison, one "nutritional" calorie (ie 1000 calories) equals about 4.186 kilojoules.

Using the program is quite straightforward, except that the user is required to enter his activity coefficient. This may be estimated from the figures in table 1. The effect of additional exercise may be taken into account using any of the many available tables which give the food energy equivalents for given exercises. For example, if I weigh 60 kg and do 240 kj (57 kilocalories) of running per day, I will raise my activity coefficient by 4.■

*The author wishes to thank Steve Wellons and Joe Berman of the University of Virginia's Microprocessor Laboratory for their help in making the listings of this program, which were done on equipment purchased under NASA contract #NAS1-14862.*

**REFERENCES**

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# Appendices

# Appendix A:

## Pascal Run Time Routines (in 8080 Assembly Language) and P-Code to 8080 Assembly Language Translator (in North Star BASIC)

# Listing 1: Pascal Run Time Routines (in 8080 Assembly Language)

*The run time routines perform the mathematical operations needed by the translated code. They are a collection of subroutines written in assembly language that can be called by a program to perfrom various arithmetic and logical operations. The operations implemented include: a stack, 16 bit addition and subtraction, multiplication and division. The relational operations test for: less than, less than or equal, greater than, greater than or equal conditions. A 16 bit shift routine is also included. The input and output routines are also defined.*

```
SYMBOL TABLE
ADD16:1C02   BASE :1A15   BB   :1DF2   BS1  :1A16   CAL  :1AAE
CAL1 :1AA3   CALA :1ADE   D2   :1C8F   D3   :1C96   D4   :1CA5
D4A  :1CAA   DIV16:1C77   DM1  :1C68   DVCK :1C5C   EP1  :1A55
EP1A :1A56   EP2  :1A7D   EP3  :1AB3   EQH  :1D07   EQUAL:1CD5
ER1  :1B54   ER2  :1B3D   EXIT :2028   FALSE:1D02   GETC :1AE2
GETN :1B1B   HEX  :1DCD   HX   :1DDA   IHX  :1DA6   INHEX:1D9E
INP  :2010   INT  :1A27   L9   :1DE1   LESS :1CF0   LIT  :1A20
LOD  :1A52   LOD1 :1A49   LODA :1ACB   LODX :1A5F   LODX1:1A60
LP   :1C31   LZ   :1B06   MER1 :1B5D   MER2 :1B6B   MUL8 :1C2F
NE   :1D12   NEGB :1BE0   NEGH :1BD3   NUM  :1B1E   OUTP :200D
OVFL :1BEA   P00  :1BA6   P01  :1C23   P02  :1C0F   P03  :1C15
P04  :1C3C   P05  :1C51   P06  :1CBE   P07  :1CC7   P08  :1CD3
P09  :1CE9   P10  :1D16   P11  :1CED   P12  :1D1D   P13  :1D24
P14  :1D2A   P15  :1D35   P16  :1D40   P17  :1D49   P18  :1D5A
P19  :1D72   P20  :1D7C   P21  :1D86   PNT  :1BF5   POP  :1BBC
POP1 :1BCC   PRINT:1BF3   PUSH :1BC6   SIGN :1B78   SKIP :1C37
SL1  :1D52   SM1  :1A38   SM2  :1A3E   SR1  :1D64   STK2 :1DF4
STKOV:1A2E   STO  :1A7A   STO1 :1A71   STOA :1AD6   STOX :1A86
STOX1:1A87   SU2  :1C03   SUB1 :1BFF   SUB16:1C18   SYS0 :1AE9
SYS1 :1AF2   SYS2 :1AF9   SYS3 :1B79   SYS4 :1D91   SYS5 :1DC4
SYS8 :1DE7   TRUE :1CE6   WR   :1B9C   Y2   :1AFA   Y2R  :1B43
Y3   :1B8C   Y4   :1D92   Y4E  :1DB9   Y8   :1DE8   YE1  :1B57
```

```
                        ; PASCAL RUN-TIME ROUTINES
                        ; HY.1  1/30/78   BY  H. YUEN
                        ; VERSION 2.0  2/28/78
                        ; VERSION 2.1  4/7/78
                        INP    EQU   #2010      ; CHAR INPUT ROUTINE IN DOS
                        OUTP   EQU   #200D      ; CHAR OUTPUT ROUTINE IN DOS
                        EXIT   EQU   #2028      ; RETURN TO DOS
                        ;
                        ; ON ENTRY: HL -  STACK START ADDR
                        ;           DE -  COMP. OF END ADDR
                        ;
1A00                          ORG   #1A00
1A00  23                      INX   H           ; INITIALIZATION
1A01  22 F2 1D                SHLD  BB          ; BASE
1A04  2B                      DCX   H
1A05  2B                      DCX   H
1A06  EB                      XCHG              ; DE USED AS STACK PTR.
1A07  22 F4 1D                SHLD  STK2
1A0A  21 05 00                LXI   H,#0005
```

```
1A0D  19               DAD  D          ; (T+3)
1A0E  01 28 20         LXI  B,EXIT     ; EXIT ADDR
1A11  70               MOV  M,B
1A12  23               INX  H
1A13  71               MOV  M,C
1A14  C9               RET
                 ;==========
1A15  D5         BASE  PUSH D
1A16  5E         BS1   MOV  E,M
1A17  2B               DCX  H
1A18  56               MOV  D,M
1A19  EB               XCHG
1A1A  3D               DCR  A
1A1B  C2 16 1A         JNZ  BS1
1A1E  D1               POP  D
1A1F  C9               RET
1A20  EB         LIT   XCHG            ; LOAD LITERAL CONSTANT
1A21  23               INX  H
1A22  70               MOV  M,B
1A23  23               INX  H
1A24  71               MOV  M,C
1A25  EB               XCHG
1A26  C9               RET
1A27  19         INT   DAD  D          ; INCREMENT STACK PTR
1A28  EB               XCHG
1A29  2A F4 1D         LHLD STK2
1A2C  19               DAD  D
1A2D  D0               RNC
1A2E  21 38 1A   STKOV LXI  H,SM1
1A31  CD F3 1B         CALL PRINT
1A34  E1               POP  H          ; POP RETURN ADDR
1A35  C3 28 20         JMP  EXIT
1A38  20         SM1   DB   ' STACK'
1A3E  20         SM2   DB   ' OVERFLOW',0D,0A
                 ;
1A49  2A F2 1D   LOD1  LHLD BB
1A4C  CD 15 1A         CALL BASE
1A4F  C3 55 1A         JMP  EP1
1A52  2A F2 1D   LOD   LHLD BB         ; LOAD VARIABLE
1A55  13         EP1   INX  D
1A56  09         EP1A  DAD  B
1A57  2B               DCX  H
1A58  7E               MOV  A,M
1A59  12               STAX D
1A5A  23               INX  H
1A5B  7E               MOV  A,M
1A5C  13               INX  D
1A5D  12               STAX D
1A5E  C9               RET
1A5F  AF         LODX  XRA  A
1A60  2A F2 1D   LODX1 LHLD BB         ; LOAD VAR INDEXED
1A63  B7               ORA  A
1A64  C4 15 1A         CNZ  BASE
1A67  09               DAD  B
1A68  EB               XCHG
1A69  4E               MOV  C,M
1A6A  2B               DCX  H
1A6B  46               MOV  B,M
1A6C  EB               XCHG
1A6D  09               DAD  B          ; ADD INDEX
1A6E  C3 56 1A         JMP  EP1A
                 ;...
1A71  2A F2 1D   STO1  LHLD BB
1A74  CD 15 1A         CALL BASE
1A77  C3 7D 1A         JMP  EP2
1A7A  2A F2 1D   STO   LHLD BB         ; STORE VARIABLE
1A7D  09         EP2   DAD  B
1A7E  1A               LDAX D
1A7F  77               MOV  M,A
1A80  2B               DCX  H
1A81  1B               DCX  D
1A82  1A               LDAX D
```

```
1A83  77          MOV  M,A
1A84  1B          DCX  D
1A85  C9          RET
1A86  AF    STOX  XRA  A
1A87  EB    STOX1 XCHG             ; STORE VAR INDEXED
1A88  5E          MOV  E,M
1A89  2B          DCX  H
1A8A  56          MOV  D,M
1A8B  2B          DCX  H
1A8C  D5          PUSH D           ; SAVE VALUE TO BE STORED
1A8D  5E          MOV  E,M
1A8E  2B          DCX  H
1A8F  56          MOV  D,M
1A90  2B          DCX  H
1A91  EB          XCHG             ; INDEX IS NOW IN HL
1A92  29          DAD  H
1A93  09          DAD  B
1A94  44          MOV  B,H
1A95  4D          MOV  C,L
1A96  2A F2 1D    LHLD BB
1A99  B7          ORA  A
1A9A  C4 15 1A    CNZ  BASE
1A9D  09          DAD  B
1A9E  C1          POP  B           ; RETRIEVE VALUE
1A9F  71          MOV  M,C
1AA0  2B          DCX  H
1AA1  70          MOV  M,B
1AA2  C9          RET
            ;...
1AA3  2A F2 1D CAL1 LHLD BB
1AA6  44          MOV  B,H         ; SAVE BB IN B,C
1AA7  4D          MOV  C,L
1AA8  CD 15 1A    CALL BASE
1AAB  C3 B3 1A    JMP  EP3
1AAE  2A F2 1D CAL  LHLD BB        ; PROC OR FUNC CALL
1AB1  44          MOV  B,H
1AB2  4D          MOV  C,L
1AB3  D5    EP3   PUSH D
1AB4  EB          XCHG             ; BASE(L) IN D,E
1AB5  23          INX  H
1AB6  72          MOV  M,D
1AB7  23          INX  H
1AB8  73          MOV  M,E
1AB9  22 F2 1D    SHLD BB          ; BB=T+1
1ABC  D1          POP  D           ; RESTORE T
1ABD  23          INX  H
1ABE  70          MOV  M,B
1ABF  23          INX  H
1AC0  71          MOV  M,C         ; S(T+2)=BB
1AC1  C1          POP  B           ; GET RETURN ADDR
1AC2  C5          PUSH B
1AC3  03          INX  B
1AC4  03          INX  B
1AC5  03          INX  B           ; RET ADDR +3
1AC6  23          INX  H
1AC7  70          MOV  M,B
1AC8  23          INX  H
1AC9  71          MOV  M,C
1ACA  C9          RET
            ;...
1ACB  EB    LODA  XCHG             ; LOAD VAR WITH ABS ADDR
1ACC  5E          MOV  E,M
1ACD  2B          DCX  H
1ACE  56          MOV  D,M
1ACF  36 00       MVI  M,00
1AD1  1A          LDAX D
1AD2  23          INX  H
1AD3  77          MOV  M,A
1AD4  EB          XCHG
1AD5  C9          RET
            ;...
1AD6  1A    STOA  LDAX D           ; STORE VAR WITH ABS ADDR
```

```
1AD7  1B                DCX  D
1AD8  1B                DCX  D
1AD9  CD CC 1B          CALL POP1
1ADC  77                MOV  M,A
1ADD  C9                RET
                  ;...
1ADE  CD CC 1B    CALA  CALL POP1      ; CALL ABS ADDR SUBROUTINE
1AE1  E9                PCHL
                  ;...
1AE2  CD 10 20    GETC  CALL INP       ; GET A CHAR
1AE5  47                MOV  B,A
1AE6  C3 0D 20          JMP  OUTP      ; ECHO THE CHAR
                  ;...
1AE9  13          SYS0  INX  D         ;   [ INCHR ]
1AEA  AF                XRA  A
1AEB  12                STAX D
1AEC  13                INX  D
1AED  CD E2 1A          CALL GETC
1AF0  12                STAX D
1AF1  C9                RET
                  ;...
1AF2  1A          SYS1  LDAX D         ;   [ OUTCHR ]
1AF3  1B                DCX  D
1AF4  1B                DCX  D
1AF5  47                MOV  B,A
1AF6  C3 0D 20          JMP  OUTP
                  ;...
1AF9  D5          SYS2  PUSH D         ;   [ INNUM ]
1AFA  06 3F       Y2    MVI  B,'?'
1AFC  CD 0D 20          CALL OUTP
1AFF  50                MOV  D,B       ; SET INIT FLAG
1B00  AF                XRA  A
1B01  32 78 1B          STA  SIGN
1B04  67                MOV  H,A
1B05  6F                MOV  L,A
1B06  CD E2 1A    LZ    CALL GETC
1B09  FE 20             CPI  20
1B0B  CA 06 1B          JZ   LZ        ; SKIP LEADING BLANKS
1B0E  FE 2B             CPI  '+'
1B10  CA 1B 1B          JZ   GETN
1B13  FE 2D             CPI  '-'
1B15  C2 1E 1B          JNZ  NUM
1B18  32 78 1B          STA  SIGN
1B1B  CD E2 1A    GETN  CALL GETC
1B1E  D6 30       NUM   SUI  30
1B20  FA 43 1B          JM   Y2R
1B23  FE 0A             CPI  0A
1B25  F2 43 1B          JP   Y2R
1B28  5F                MOV  E,A
1B29  AF                XRA  A
1B2A  57                MOV  D,A       ; RESET FLAG
1B2B  29                DAD  H         ; 2*HL
1B2C  44                MOV  B,H
1B2D  4D                MOV  C,L
1B2E  29                DAD  H
1B2F  8F                ADC  A
1B30  29                DAD  H
1B31  8F                ADC  A
1B32  09                DAD  B         ; 2*HL+8*HL
1B33  8F                ADC  A
1B34  19                DAD  D
1B35  8F                ADC  A
1B36  C2 3D 1B          JNZ  ER2
1B39  B4                ORA  H
1B3A  F2 1B 1B          JP   GETN
1B3D  21 6B 1B    ER2   LXI  H,MER2
1B40  C3 57 1B          JMP  YE1
1B43  AF          Y2R   XRA  A
1B44  82                ADD  D         ; CHECK FLAG
1B45  C2 54 1B          JNZ  ER1
1B48  3A 78 1B          LDA  SIGN
1B4B  B7                ORA  A
```

```
1B4C  C4 D3 1B        CNZ  NEGH      ; NEGATE THE NUM IF SIGN IS '
-'
1B4F  D1              POP  D
1B50  13              INX  D
1B51  C3 C6 1B        JMP  PUSH
1B54  21 5D 1B  ER1   LXI  H,MER1
1B57  CD F3 1B  YE1   CALL PRINT
1B5A  C3 FA 1A        JMP  Y2
1B5D  20        MER1  DB   ' INPUT ERROR',0D,0A
1B6B  20        MER2  DB   ' SIZE ERROR',0D,0A
1B78  00        SIGN  DB   00
                ;...
1B79  CD CC 1B  SYS3  CALL POP1      ;  [ OUTNUM ]
1B7C  D5              PUSH D         ; SAVE NEW STK PTR
1B7D  AF              XRA  A
1B7E  3D              DCR  A
1B7F  F5              PUSH SW        ; PUT -1 & FLAG
1B80  A4              ANA  H         ; TEST SIGN
1B81  F2 8C 1B        JP   Y3
1B84  06 2D           MVI  B,'-'
1B86  CD 0D 20        CALL OUTP
1B89  CD D3 1B        CALL NEGH      ; NEGATE THE NUMBER
1B8C  01 0A 00  Y3    LXI  B,#000A
1B8F  CD 77 1C        CALL DIV16     ; DIVIDE BY 10
1B92  3E 30           MVI  A,30
1B94  83              ADD  E         ; CONVERT TO ASCII
1B95  F5              PUSH SW        ; SAVE ON STACK (REVERSE ORDER)
1B96  7C              MOV  A,H
1B97  B5              ORA  L
1B98  C2 8C 1B        JNZ  Y3
1B9B  F1              POP  SW
1B9C  47        WR    MOV  B,A
1B9D  CD 0D 20        CALL OUTP      ; OUTPUT EACH DIGIT
1BA0  F1              POP  SW
1BA1  F2 9C 1B        JP   WR
1BA4  D1              POP  D
1BA5  C9              RET
                ;...
1BA6  2A F2 1D  P00   LHLD BB        ;  [ PROC RETURN]
1BA9  23              INX  H
1BAA  56              MOV  D,M
1BAB  23              INX  H
1BAC  5E              MOV  E,M
1BAD  EB              XCHG
1BAE  22 F2 1D        SHLD BB        ; BB=S(T+2)
1BB1  EB              XCHG
1BB2  23              INX  H
1BB3  56              MOV  D,M
1BB4  23              INX  H
1BB5  5E              MOV  E,M       ; P=S(T+3) IN DE
1BB6  01 FA FF        LXI  B,#FFFA   ; 2'S COMP OF -6
1BB9  09              DAD  B         ; T=BB-1
1BBA  EB              XCHG
1BBB  E9              PCHL
                ;...
1BBC  EB        POP   XCHG
1BBD  4F              MOV  C,M
1BBE  2B              DCX  H
1BBF  46              MOV  B,M       ; S(T) -> B,C
1BC0  2B              DCX  H
1BC1  5E              MOV  E,M
1BC2  2B              DCX  H
1BC3  56              MOV  D,M
1BC4  EB              XCHG
1BC5  C9              RET            ; S(T-1) -> H,L
                ;...
1BC6  EB        PUSH  XCHG
1BC7  72              MOV  M,D
1BC8  23              INX  H
1BC9  73              MOV  M,E       ; H,L -> S(T)
1BCA  EB              XCHG
```

```
1BCB  C9                    RET
                     ;...
1BCC  EB             POP1   XCHG
1BCD  5E                    MOV  E,M
1BCE  2B                    DCX  H
1BCF  56                    MOV  D,M      ; S(T) -> H,L
1BD0  2B                    DCX  H
1BD1  EB                    XCHG
1BD2  C9                    RET
                     ;...
1BD3  AF             NEGH   XRA  A        ; NEGATE HL
1BD4  95                    SUB  L
1BD5  6F                    MOV  L,A
1BD6  9C                    SBB  H
1BD7  95                    SUB  L
1BD8  67                    MOV  H,A
1BD9  D6 80                 SUI  80
1BDB  B5                    ORA  L
1BDC  C0                    RNZ
1BDD  C3 EA 1B              JMP  OVFL
                     ;...
1BE0  AF             NEGB   XRA  A        ; NEGATE B,C
1BE1  91                    SUB  C
1BE2  4F                    MOV  C,A
1BE3  98                    SBB  B
1BE4  91                    SUB  C
1BE5  47                    MOV  B,A
1BE6  D6 80                 SUI  80
1BE8  B1                    ORA  C
1BE9  C0                    RNZ
1BEA  21 3E 1A       OVFL   LXI  H,SM2
1BED  CD F3 1B              CALL PRINT
1BF0  C3 C6 1B              JMP  PUSH
                     ;
1BF3  0E 0A          PRINT  MVI  C,0A     ; PRINT MESSAGE
1BF5  46             PNT    MOV  B,M
1BF6  23                    INX  H
1BF7  CD 0D 20              CALL OUTP
1BFA  B9                    CMP  C
1BFB  C2 F5 1B              JNZ  PNT
1BFE  C9                    RET
                     ;...
1BFF  CD E0 1B       SUB1   CALL NEGB
1C02  78             ADD16  MOV  A,B      ;  [16 BIT SIGNED ADD]
1C03  AC             SU2    XRA  H
1C04  09                    DAD  B
1C05  4F                    MOV  C,A
1C06  1F                    RAR
1C07  A9                    XRA  C        ; XOR SIGN OF CARRY
1C08  AC                    XRA  H        ; SIGN OF RESULT
1C09  F2 C6 1B              JP   PUSH
1C0C  C3 EA 1B              JMP  OVFL
                     ;...
1C0F  CD BC 1B       P02    CALL POP      ;   [ ADD ]
1C12  C3 02 1C              JMP  ADD16
                     ;...
1C15  CD BC 1B       P03    CALL POP
1C18  78             SUB16  MOV  A,B      ;  [16 BIT SIGNED SUBTRACT]
1C19  D6 80                 SUI  80
1C1B  B1                    ORA  C
1C1C  C2 FF 1B              JNZ  SUB1
1C1F  79                    MOV  A,C
1C20  C3 03 1C              JMP  SU2
                     ;...
1C23  EB             P01    XCHG          ;   [ NEGATE ]
1C24  AF                    XRA  A
1C25  96                    SUB  M
1C26  77                    MOV  M,A
1C27  4F                    MOV  C,A
1C28  2B                    DCX  H
1C29  9E                    SBB  M
1C2A  91                    SUB  C
```

```
1C2B  77                  MOV  M,A
1C2C  23                  INX  H
1C2D  EB                  XCHG
1C2E  C9                  RET
                    ;...
1C2F  16 08         MUL8  MVI  D,08       ; 8-BIT MULTIPLY
1C31  29            LP    DAD  H
1C32  07                  RLC
1C33  D2 37 1C            JNC  SKIP
1C36  09                  DAD  B
1C37  15            SKIP  DCR  D
1C38  C2 31 1C            JNZ  LP
1C3B  C9                  RET
                    ;...
1C3C  CD BC 1B      P04   CALL POP        ;   [ MULTIPLY]
1C3F  D5                  PUSH D
1C40  7C                  MOV  A,H        ; HIGH BYTE
1C41  5D                  MOV  E,L
1C42  21 00 00            LXI  H,#0000
1C45  B7                  ORA  A
1C46  C4 2F 1C            CNZ  MUL8
1C49  7B                  MOV  A,E        ; LOW BYTE
1C4A  CD 2F 1C            CALL MUL8
1C4D  D1                  POP  D
1C4E  C3 C6 1B            JMP  PUSH
                    ;...
1C51  CD BC 1B      P05   CALL POP        ;   [ DIVIDE ]
1C54  D5                  PUSH D
1C55  CD 77 1C            CALL DIV16
1C58  D1                  POP  D
1C59  C3 C6 1B            JMP  PUSH
                    ;...
1C5C  21 68 1C      DVCK  LXI  H,DM1
1C5F  CD F3 1B            CALL PRINT
1C62  21 00 00            LXI  H,#0000
1C65  54                  MOV  D,H
1C66  5D                  MOV  E,L
1C67  C9                  RET
1C68  20            DM1   DB   ' DIVIDE CHECK',0D,0A
1C77  78            DIV16 MOV  A,B
1C78  B1                  ORA  C
1C79  CA 5C 1C            JZ   DVCK
1C7C  AF                  XRA  A
1C7D  80                  ADD  B
1C7E  F5                  PUSH SW         ; SAVE SIGN OF DIVISOR
1C7F  F4 E0 1B            CP   NEGB
1C82  AF                  XRA  A
1C83  84                  ADD  H
1C84  F5                  PUSH SW         ; SAVE SIGN OF DIVIDEND
1C85  FC D3 1B            CM   NEGH
1C88  EB                  XCHG            ; DIVIDEND IN DE
1C89  21 00 00            LXI  H,#0000
1C8C  3E 10               MVI  A,10
1C8E  29            D2    DAD  H          ; SHIFT HL
1C8F  EB                  XCHG
1C90  29                  DAD  H          ; SHIFT DE
1C91  EB                  XCHG
1C92  D2 96 1C            JNC  D3
1C95  23                  INX  H          ; ADD CARRY FROM DE
1C96  E5            D3    PUSH H          ; SAVE HL
1C97  09                  DAD  B
1C98  D2 A5 1C            JNC  D4
1C9B  1C                  INR  E          ; PUT 1 IN LOW ORDER BIT OF DE
1C9C  33                  INX  SP         ; THROW AWAY OLD HL
1C9D  33                  INX  SP
1C9E  3D                  DCR  A
1C9F  C2 8E 1C            JNZ  D2
1CA2  C3 AA 1C            JMP  D4A
1CA5  E1            D4    POP  H          ; GET OLD HL
1CA6  3D                  DCR  A
1CA7  C2 8E 1C            JNZ  D2
```

```
1CAA  EB          D4A   XCHG          ; SWITCH QUOT. & REM.
1CAB  C1                POP  B        ; SIGN OF DIVIDEND
1CAC  F1                POP  SW       ;  "   DIVISOR
1CAD  A8                XRA  B
1CAE  FC D3 1B          CM   NEGH
1CB1  7A                MOV  A,D
1CB2  B3                ORA  E        ; REMAINDER=0 ?
1CB3  C8                RZ
1CB4  AF                XRA  A
1CB5  80                ADD  B        ; DIVIDEND + ?
1CB6  F0                RP
1CB7  AF                XRA  A
1CB8  93                SUB  E        ; NEGATE THE REMAINDER
1CB9  5F                MOV  E,A
1CBA  9A                SBB  D
1CBB  93                SUB  E
1CBC  57                MOV  D,A
1CBD  C9                RET
                  ;...
1CBE  1A          P06   LDAX D        ; TEST FOR ODD
1CBF  E6 01             ANI  01
1CC1  12                STAX D
1CC2  AF                XRA  A        ; SET HI BYTE TO 0
1CC3  1B                DCX  D
1CC4  12                STAX D
1CC5  13                INX  D
1CC6  C9                RET
                  ;...
1CC7  CD BC 1B    P07   CALL POP      ;   [ MOD ]
1CCA  D5                PUSH D
1CCB  CD 77 1C          CALL DIV16
1CCE  EB                XCHG          ; PUT REMAINDER IN HL
1CCF  D1                POP  D
1CD0  C3 C6 1B          JMP  PUSH
                  ;...
1CD3  3E 01       P08   MVI  A,01     ; TEST FOR =
                  ;...
1CD5  F5          EQUAL PUSH SW       ; SAVF FLAG
1CD6  CD BC 1B          CALL POP
1CD9  AF                XRA  A
1CDA  12                STAX D        ; PUT 0 IN HI BYTE
1CDB  13                INX  D
1CDC  7D                MOV  A,L
1CDD  B9                CMP  C
1CDE  C2 02 1D          JNZ  FALSE
1CE1  7C                MOV  A,H
1CE2  B8                CMP  B
1CE3  C2 02 1D          JNZ  FALSE
1CE6  F1          TRUE  POP  SW
1CE7  12                STAX D
1CE8  C9                RET
                  ;...
1CE9  AF          P09   XRA  A        ; TEST FOR <>
1CEA  C3 D5 1C          JMP  EQUAL
                  ;...
1CED  06 00       P11   MVI  B,00     ; TEST FOR >=
1CEF  48                MOV  C,B      ; (OPPOSITE OF P10)
1CF0  C5          LESS  PUSH B        ; SAVE FLAG
1CF1  CD BC 1B          CALL POP
1CF4  AF                XRA  A
1CF5  12                STAX D        ; PUT 0 IN HI BYTE
1CF6  13                INX  D
1CF7  7C                MOV  A,H
1CF8  B8                CMP  B
1CF9  CA 07 1D          JZ   EQH
1CFC  1F                RAR           ; GET CARRY IN MSB
1CFD  AC                XRA  H
1CFE  A8                XRA  B
1CFF  FA E6 1C          JM   TRUE
1D02  F1          FALSE POP  SW
1D03  EE 01             XRI  01       ; COMPLEMENT FLAG
1D05  12                STAX D
```

```
1D06  C9                RET
1D07  7D          EQH   MOV  A,L
1D08  B9                CMP  C
1D09  DA E6 1C          JC   TRUE
1D0C  C1                POP  B           ; RETRIEVE FLAG
1D0D  78                MOV  A,B
1D0E  C2 12 1D          JNZ  NE          ; L <> C
1D11  A9                XRA  C           ; HL=BC
1D12  EE 01       NE    XRI  01
1D14  12                STAX D
1D15  C9                RET
                  ;...
1D16  06 01       P10   MVI  B,01        ; TEST FOR <
1D18  0E 00             MVI  C,00
1D1A  C3 F0 1C          JMP  LESS
                  ;...
1D1D  06 00       P12   MVI  B,00        ; TEST FOR >
1D1F  0E 01             MVI  C,01        ; (OPPOSITE OF P13)
1D21  C3 F0 1C          JMP  LESS
                  ;...
1D24  06 01       P13   MVI  B,01        ; TEST FOR <=
1D26  48                MOV  C,B
1D27  C3 F0 1C          JMP  LESS
                  ;...
1D2A  CD BC 1B    P14   CALL POP         ;   [ OR ]
1D2D  7C                MOV  A,H
1D2E  B0                ORA  B
1D2F  12                STAX D
1D30  7D                MOV  A,L
1D31  B1                ORA  C
1D32  13                INX  D
1D33  12                STAX D
1D34  C9                RET
                  ;...
1D35  CD BC 1B    P15   CALL POP         ;   [ AND ]
1D38  7C                MOV  A,H
1D39  A0                ANA  B
1D3A  12                STAX D
1D3B  7D                MOV  A,L
1D3C  A1                ANA  C
1D3D  13                INX  D
1D3E  12                STAX D
1D3F  C9                RET
                  ;...
1D40  1A          P16   LDAX D           ;   [ COMPLEMENT ]
1D41  2F                CMA
1D42  12                STAX D
1D43  1B                DCX  D
1D44  1A                LDAX D
1D45  2F                CMA
1D46  12                STAX D
1D47  13                INX  D
1D48  C9                RET
                  ;...
1D49  CD BC 1B    P17   CALL POP         ;   [ SHL ]
1D4C  AF                XRA  A
1D4D  81                ADD  C
1D4E  C8                RZ
1D4F  FA 64 1D          JM   SR1
1D52  29          SL1   DAD  H           ; SHIFT LEFT
1D53  3D                DCR  A
1D54  C2 52 1D          JNZ  SL1
1D57  C3 C6 1B          JMP  PUSH
                  ;...
1D5A  CD BC 1B    P18   CALL POP         ;   [ SHR ]
1D5D  AF                XRA  A
1D5E  91                SUB  C
1D5F  C8                RZ
1D60  F2 52 1D          JP   SL1
1D63  4F                MOV  C,A
1D64  AF          SR1   XRA  A
1D65  B4                ORA  H           ; CLEAR CARRY
```

```
1D66  1F                RAR          ; SHIFT RIGHT
1D67  67                MOV  H,A
1D68  7D                MOV  A,L
1D69  1F                RAR
1D6A  6F                MOV  L,A
1D6B  0C                INR  C
1D6C  C2 64 1D          JNZ  SR1
1D6F  C3 C6 1B          JMP  PUSH
                  ;...
1D72  1A          P19   LDAX D       ;   [INC]
1D73  C6 01             ADI  01
1D75  12                STAX D
1D76  D0                RNC
1D77  62                MOV  H,D
1D78  6B                MOV  L,E
1D79  2B                DCX  H
1D7A  34                INR  M       ; INCREMENT HI BYTE BY 1
1D7B  C9                RET
                  ;...
1D7C  1A          P20   LDAX D       ;   [DEC]
1D7D  D6 01             SUI  01
1D7F  12                STAX D
1D80  D0                RNC
1D81  62                MOV  H,D
1D82  6B                MOV  L,E
1D83  2B                DCX  H
1D84  35                DCR  M       ; DECREMENT HI BYTE BY 1
1D85  C9                RET
                  ;...
1D86  62          P21   MOV  H,D     ;   [COPY]
1D87  6B                MOV  L,E
1D88  13                INX  D
1D89  2B                DCX  H
1D8A  7E                MOV  A,M
1D8B  12                STAX D
1D8C  13                INX  D
1D8D  23                INX  H
1D8E  7E                MOV  A,M
1D8F  12                STAX D
1D90  C9                RET
                  ;...
1D91  13          SYS4  INX  D       ;   [INHEX]
1D92  CD 9E 1D    Y4    CALL INHE
1D95  81                ADD  C
1D96  12                STAX D
1D97  CD 9E 1D          CALL INHEX
1D9A  81                ADD  C
1D9B  13                INX  D
1D9C  12                STAX D
1D9D  C9                RET
1D9E  CD A6 1D    INHEX CALL IHX     ; INPUT 2 HEX DIGITS
1DA1  07                RLC
1DA2  07                RLC
1DA3  07                RLC
1DA4  07                RLC
1DA5  4F                MOV  C,A     ; SAVE HI ORDER HEX DIGIT (SHIFTED)
1DA6  CD E2 1A    IHX   CALL GETC
1DA9  D6 30             SUI  30
1DAB  FA B9 1D          JM   Y4E
1DAE  FE 0A             CPI  0A
1DB0  F8                RM
1DB1  D6 07             SUI  07
1DB3  FA B9 1D          JM   Y4E
1DB6  FE 10             CPI  10
1DB8  F8                RM
1DB9  21 5D 1B    Y4E   LXI  H,MER1
1DBC  CD F3 1B          CALL PRINT
1DBF  E1                POP  H
1DC0  E1                POP  H
1DC1  C3 92 1D          JMP  Y4
```

```
1DC4  1A          SYS5  LDAX D          ;   [ OUTHEX ]
1DC5  6F                MOV  L,A        ; SAVE LOW ORDER BYTE
1DC6  1B                DCX  D
1DC7  1A                LDAX D
1DC8  1B                DCX  D
1DC9  CD CD 1D          CALL HEX
1DCC  7D                MOV  A,L
1DCD  4F          HEX   MOV  C,A
1DCE  E6 F0             ANI  F0         ; HI ORDER HEX DIGIT
1DD0  0F                RRC
1DD1  0F                RRC
1DD2  0F                RRC
1DD3  0F                RRC
1DD4  CD DA 1D          CALL HX
1DD7  79                MOV  A,C
1DD8  E6 0F             ANI  0F         ; LO ORDER HEX DIGIT
1DDA  FE 0A       HX    CPI  0A
1DDC  FA E1 1D          JM   L9
1DDF  C6 07             ADI  07
1DE1  C6 30       L9    ADI  30         ; CONVERT TO ASCII
1DE3  47                MOV  B,A
1DE4  C3 0D 20          JMP  OUTP
                  ;...
1DE7  E1          SYS8  POP  H          ;   [ OUTSTR ]
1DE8  46          Y8    MOV  B,M
1DE9  CD 0D 20          CALL OUTP
1DEC  23                INX  H
1DED  0D                DCR  C          ; CHAR COUNT
1DEE  C2 E8 1D          JNZ  Y8
1DF1  E9                PCHL            ; JUMP TO LOC FOLLOWING STRING
                  ;...
1DF2  00 00       BB    DW              ; BASE ADDR
1DF4  00 00       STK2  DW              ; COMPLEMENT OF STACK END ADDR

                        END
```

# Listing 2: P-Code to 8080 Assembly Language Translator

*The p-code to 8080 translator is written in North Star BASIC. The p-codes are usually translated into subroutine calls to the appropriate run time routine. In this way, a pseudo-macroassembler is used. The translator also performs a crude form of 8080 code optimization which is discussed in table 4 of part 3.*

```
LIST

5REM..LAST MOD 5/21/78
10REM..P-CODE TO 8080 TRANSLATOR
20REM  HY.1 2/5/78  BY  H. YUEN
25REM  HY.2 3/23/78
30 DIM A$(4),B$(4),H0$(16),B0$(4)
40 S1=500:S2=400
50 DIM T$(S1):REM..TABLE OF REFERENCES
60 DIM D$(S2):REM..8080 ADDR OF P-CODE LABELS
65 DIM E(S2):REM..TABLE OF FORWARD REF
68 DIM W$(36),Z$(88):O2=21
70 DIM Y1(15),Y2(15),Y$(60)
75 DIM Z1(30),Z2(30)
78 H0$="0123456789ABCDEF"
80REM..       LIT LOD LD1 LDX LX1 LDA STO ST1
82 Y$(1,32)="1A201A521A491A5F1A601ACB1A7A1A71"
84REM..       STX SX1 STA CAL CL1 CLA INT
86Y$(33,60)="1A861A871AD61AAE1AA31ADE1A27"
90REM..P00,P01,..P21
94 Z$(1,32)= "1BA61C231C0F1C151C3C1C511CBE1CC7"
96 Z$(33,64)="1CD31CE91D161CED1D1D1D241D2A1D35"
98 Z$(65,88)="1D401D491D5A1D721D7C1D86"
99REM..SYS0,..SYS8
100 W$(1,24)="1AE91AF21AF91B791D911DC4"
102 W$(33,36)="1DE7"
103REM============
105REM SETUP ADDR OF ENTRY PT IN RUN-TIME ROUTINE
106REM============
110 M=0:FOR K=1 TO 60 STEP 4
112 M=M+1:Y2(M)=FND(Y$(K,K+1),2)+X
113 Y1(M)=FND(Y$(K+2,K+3),2)+X:NEXT
114 M=0:FOR K=1 TO 88 STEP 4
115 Z2(M)=FND(Z$(K,K+1),2)+X
116 Z1(M)=FND(Z$(K+2,K+3),2)+X
117 M=M+1:NEXT
118 M=O2+1:FOR K=1 TO 36 STEP 4
119 Z2(M)=FND(W$(K,K+1),2)+X
120 Z1(M)=FND(W$(K+2,K+3),2)+X
122 M=M+1:NEXT:GOTO 300
123REM============
125REM..CONVERT HEX TO DECIMAL
130 DEF FND(H1$,L)
135 N=0:FOR I=1 TO L
140 J=ASC(H1$(I,I))-48
145 IF J>9 THEN J=J-7
150 N=N*16+J:NEXT:RETURN N
160 FNEND
165REM..CONVERT INTEGER TO HEX
```

```
170 DEF FNH$(L)
175 R=INT(L/16)+1:S=L-R*16+17
180 RETURN H0$(R,R)+H0$(S,S)
185 FNEND
190REM..CODE GENERATOR
200 DEF FNG(O,M,N)
210 FILL P,O:FILL P+1,M
220 FILL P+2,N:RETURN P+3
230 FNEND
240REM..CODE GENERATOR 2
250 DEF FNO(O,M)
260 FILL P,O:FILL P+1,Y1(M)
270 FILL P+2,Y2(M):RETURN P+3
280 FNEND
285REM===========
290REM
300 PRINT"*** P-CODE TO 8080 TRANSLATION ****"
302 INPUT"ADDR (HEX) OF PAS.LIB:",B0$
304 IF B0$="" THEN B0$="1A00"
306 X=FND(B0$,4)-FND("1A00",4)
310 INPUT"ADDR (HEX) OF P-CODE:",A$
315 IF A$="" THEN A$="9800"
320 X=FND(A$,4):X0=X
330 INPUT"ADDR (HEX) OF OUTPUT 8080 PGM:",B$
335 IF B$="" THEN B$="9000":P0=FND(B$,4)
340 INPUT"STACK START ADDR (HEX):",B$
345 IF B$<>"" THEN 360
350 PRINT"DEFAULT STACK ADDRESSES USED"
355 A$="9FFF":GOTO 365
360 INPUT"STACK END ADDR (HEX):",A$
365 K=65536-FND(A$,4)
370 J=INT(K/256):I=K-J*256
375 P=P0+3:P=FNG(17,I,J)
380 P=FNG(205,FND(B0$(3,4),2),FND(B0$(1,2),2))
385 B0$=B$
388REM==========
390REM..1ST PASS..PICK UP LABELS
400 W=1:REM..TABLE PTR
420 J=EXAM(X):IF J=255 THEN 470
430 X=X+4:IF J<4 THEN 420
435 IF J=5 OR J>7 THEN 420
440 T$(W,W+1)=CHR$(EXAM(X-1))+CHR$(EXAM(X-2))
450 W=W+2:GOTO 420
470 PRINT(W-1)/2," REFERENCES":W=W-2
472REM===
475REM..PRE-COMPRESS TABLE
477REM COMPARE ITEM WITH LAST 3 ENTRIES, DELETE IF =
480 IF W<160 THEN 500
482 J=5:FOR I=7 TO W STEP 2
484 FOR K=J-4 TO J STEP 2
486 IF T$(I,I+1)=T$(K,K+1) THEN EXIT 490
488 NEXT:J=J+2:T$(J,J+1)=T$(I,I+1)
490 NEXT:W=J
492REM===
495REM..BUBBLE SORT
500 FOR I=1 TO W-2 STEP 2:A$="0"
510 FOR J=W-2 TO I STEP -2
520 IF T$(J,J+1)<=T$(J+2,J+3) THEN 550
530 B$=T$(J,J+I):T$(J,J+1)=T$(J+2,J+3)
540 T$(J+2,J+3)=B$:A$="1"
550 NEXT:IF A$="0" THEN EXIT 600
560 NEXT
565REM===
570REM..REPACK TABLE
600 J=1:FOR I=3 TO W STEP 2
610 IF T$(I,I+1)=T$(J,J+1) THEN 630
620 J=J+2:T$(J,J+1)=T$(I,I+1)
630 NEXT:W0=J
640 T$(J+2,J+3)=CHR$(255)+CHR$(255)
660 FOR I=1 TO J STEP 2
670 D$(I,I+1)="  ":NEXT
680 PRINT(J+1)/2," ACTUAL LABELS"
```

```
685REM==========
690REM..2ND PASS..TRANSLATE
700 X=X0-4:K=-1:G=0
702 K1=0:L1=0
705 U=ASC(T$(2,2)):W=1:M=15
710 X=X+4:K=K+1:R0=0
711 J=INT(P/256):I=P-J*256
712 M=M+1:IF M<=14 THEN 715
714 PRINT:PRINT%4I,K,"  ",FNH$(J),:M=0
715 PRINTFNH$(I)," ",
716 F=EXAM(X)
720 C1=EXAM(X+2):C2=EXAM(X+3)
725 IF K<U THEN 765
740 D$(W,W+1)=CHR$(I)+CHR$(J)
750 W=W+2:R0=1:REM R0=1 MEANS INSTR. REFERENCED
760 U=ASC(T$(W,W))*256+ASC(T$(W+1,W+1))
765 V=0:IF F<=8 THEN 780
770 V=1:F=F-16:REM..INDEX ADDR
775 IF F>8 THEN 1700
778REM.........LIT.OPR.LOD.STO..CAL..INT..JMP..JPC..CSP.
780 ON F+1 GOTO 800,850,900,1100,1200,1500,1250,1550,1600
790REM===
800 IF C1+C2=0 THEN 830:REM..LIT
810 P=FNG(1,C1,C2)
820 P=FNQ(205,1):GOTO 710
830 P=FNG(175,19,18)
840 P=FNG(19,18,0)-1:GOTO 710
845REM===
850 J=205:IF C1>3 THEN 890:REM..OPR
855 IF C1=0 THEN 885
860 IF EXAM(X-4)<>0 THEN 890:REM LAST INSTR. =LIT ?
862 IF C1>1 THEN 870:REM LAST CODE = NEGATE ?
864 J=P-5:FILL J,256-EXAM(J)
866 FILL J+1,255-EXAM(J+1):GOTO 710
870 IF EXAM(X-1)>0 THEN 890
872 L=EXAM(X-2):IF L>3 THEN 890
874 P=P-6:N=17+C1:REM CONVERT ADD TO INC, SUB TO DEC
876 FOR I=1 TO L
878 P=FNG(J,Z1(N),Z2(N))
880 NEXT:GOTO 710
885 J=195:REM JMP
890 P=FNG(J,Z1(C1),Z2(C1)):GOTO 710
895REM===
900 F=2:REM..LOD
902 IF R0 OR V THEN 925
904 IF K>K1+1 OR L<>L1 THEN 925
906 IF C1<>EXAM(X-2) OR C2<>EXAM(X-1) THEN 925
910 K1=K:IF EXAM(X-4)=2 THEN 920:REM LAST CODE = LOD ?
915 P=FNG(19,19,0)-1:GOTO 710
920 P=FNG(205,Z1(21),Z2(21)):GOTO 710
925 J=4:L=EXAM(X+1):IF L=255 THEN 1040
930 GOSUB 1450:REM..GET 2A
940 P=FNG(1,C1,C2)
950 J=2:IF V THEN 960
955 J=0:K1=K:L1=L:REM..NON-INDEXED LOD OR STO
960 IF L=0 THEN 1040
1030 J=J+1:P=FNG(62,L,0)-1
1040 P=FNQ(205,F+J):GOTO 710
1090REM===
1100 F=7:GOTO 925:REM..STO
1190REM===
1200 L=EXAM(X+1):IF L>0 THEN 1225:REM..CAL
1210 P=FNQ(205,12)
1220 GOTO 1260
1225 IF L<255 THEN 1230
1227 P=FNQ(205,14):GOTO 710
1230 P=FNG(62,L,0)-1
1240 P=FNQ(205,13):GOTO 1260
1245REM===
1250 IF C1+C2*256=K+1 THEN 710:REM..JMP
1260 GOSUB 1300
1270 P=FNG(195,I,J):GOTO 710
```

```
1280REM=====
1290REM...TABLE LOOKUP, RETURNS ADDR IN I,J
1300 A$=CHR$(C2)+CHR$(C1)
1310 I=1:J=W0:REM..BINARY SEARCH
1320 N=INT((I+J)/4)*2+1
1330 IF A$=T$(N,N+1) THEN 1360
1340 IF A$>T$(N,N+1) THEN I=N+2 ELSE J=N-2
1350 IF I<=J THEN 1320
1360 IF D$(N,N+1)<>"  " THEN 1400
1370 G=G+1:E(G)=P+1:REM..FORWARD REF
1390 J=INT(N/256):I=N-J*256:RETURN
1400 I=ASC(D$(N,N)):J=ASC(D$(N+1,N+1)):RETURN
1440REM=====
1450 C1=C1+C1:C2=C2+C2:REM..2A
1460 IF C1<256 THEN 1480
1470 C1=C1-256:C2=C2+1
1480 IF C2>256 THEN C2=C2-256:RETURN
1490REM===
1500 IF C1+C2=0 THEN 710:REM..INT
1505 GOSUB 1450:N=C1+C2*256
1510 IF N>4 AND N<65530 THEN 1530
1515 J=19:IF N<=4 THEN 1520:N=65536-N:J=27
1520 FOR I=1 TO N/2:P=FNG(J,J,0)-1
1525 NEXT:GOTO 710
1530 P=FNG(33,C1,C2)
1535 P=FNQ(205,15):GOTO 710
1540REM===
1550 IF C1+C2*256=K+1 THEN 710:REM..JPC
1555 P=FNG(26,27,27)
1560 FILL P,31:P=P+1:REM..RAR
1570 GOSUB 1300:N=210
1575 IF EXAM(X+1)>0 THEN N=218
1580 P=FNG(N,I,J):GOTO 710
1590REM===
1600 I=C1+C2+1:REM..CSP
1605 IF C1=8 THEN 1620
1610 P=FNG(205,Z1(I),Z2(I)):GOTO 710
1620 J=EXAM(X-2):REM GET LENGTH OF STRING
1625 P=P-J*6-6:X1=X-J*4-2:REM BACK UP
1630 P=FNG(14,J,0)-1
1632 P=FNG(205,Z1(I),Z2(I))
1635 FOR I=1 TO J
1640 FILL P,EXAM(X1)
1645 P=P+1:X1=X1+4
1650 NEXT:GOTO 710
1700 PRINT:PRINT"  ",G," FORWARD REFERENCES"
1710 P1=P
1770REM===========
1775REM..3RD PASS..FIXUP FOR. REF.
1780 FOR N=1 TO G
1790 P=E(N)
1800 J=EXAM(P)+EXAM(P+1)*256
1810 FILL P,ASC(D$(J,J))
1820 FILL P+1,ASC(D$(J+1,J+1))
1830 NEXT
1840REM..SETUP STACK ADDR
1850 IF B0$="" THEN P=P1 ELSE P=FND(B0$,4)
1860 J=INT(P/256):I=P-J*256
1870 P=P0:P=FNG(33,I,J)
1940 PRINT"P-CODE..",K," INSTRUCTIONS"
1950 PRINT"8080..",P1-P0," BYTES"
1960 PRINT"P-CODE:8080 =",(P1-P0)/(K*4)
1970 PRINT"* END TRANSLATION *"
1980 PRINTCHR$(129):REM..TURNOFF PRINTER
2000 END
READY
```

# Appendix B:

## "Tiny" Pascal 8080 Assembly Language

# Listing 1: A Sample Compilation in "Tiny" Pascal

```
{PROGRAM DECODE}
CONST STOP=%FF; EXIT=%6946;
VAR STADR, INDX, NUM: INTEGER;
PROC CRLF;
 BEGIN WRITE (13) END;
PROC FMT (VAL, LEN);
 VAR I, J: INTEGER;
 BEGIN {FMT}
 J := VAL;
 FOR I := 2 + (J=0) TO LEN DO
  IF J=0 THEN WRITE (32) ELSE J := J DIV 10;
 IF J>9 THEN WRITE ('&');
 WRITE (VAL#)
END {FMT};
BEGIN {MAIN}
 WRITE (12, 'START DECODING AT '); READ (STADR%); CRLF;
 CRLF; INDX := 0;
 WHILE (STADR < %6900) AND (MEM[STADR] <> STOP) DO
  BEGIN FMT (INDX, 10); WRITE ('   '); INDX := INDX + 1;
  NUM := MEM[STADR];
  CASE NUM OF
   0     : WRITE ('LIT');
   1     : WRITE ('OPR');
   2,%12: WRITE ('LOD');
   3,%13: WRITE ('STO');
   4     : WRITE ('CAL');
   5     : WRITE ('INT');
   6     : WRITE ('JMP');
   7     : WRITE ('JPC');
   8     : WRITE ('CSP')
   ELSE BEGIN WRITE ('ILL'); MEM[STADR] := STOP END
  END; {CASE}
  IF (NUM=%12) OR (NUM=%13) THEN WRITE ('X')
   ELSE WRITE (32); WRITE (32);
  WRITE (MEM[STADR+1]#,',');
  NUM := MEM[STADR+3] SHL 8 + MEM[STADR+2];
  WRITE (NUM#); CRLF;
  IF INDX MOD 15 = 0 THEN BEGIN
   READ (NUM); IF NUM=%18 THEN CALL(EXIT) END;
  IF MEM[STADR] <> STOP THEN STADR := STADR + 4;
 END; {WHILE}
END. {MAIN}

>


P-CODE STARTS AT 2C00H
WANT CODE PRINTED? Y
   0 $DCOD$
   0  {PROGRAM DECODE}
   0  CONST STOP=%FF; EXIT=%6946;
            0  JMP   0  0
   1  VAR STADR, INDX, NUM: INTEGER;
   1  PROC CRLF;
   1   BEGIN WRITE (13) END;
            1  JMP   0  0
ADDR AT 1 CHANGED TO 2
            2  INT   0  0
            3  LIT   0  13
            4  CSP   0  1
            5  OPR   0  0
   6  PROC FMT (VAL, LEN);
```

```
   6   VAR I, J: INTEGER;
                 6  JMP   0  0
   7   BEGIN {FMT}
   7   J := VAL;
ADDR AT 6 CHANGED TO 7
                 7  INT   0  2
                 8  LOD   0  -5
                 9  STO   0  1
  10   FOR I := 2 + (J=0) TO LEN DO
                10  LIT   0  2
                11  LOD   0  1
                12  LIT   0  0
                13  OPR   0  8
                14  OPR   0  2
                15  STO   0  0
                16  LOD   0  -4
                17  OPR   0  21
                18  LOD   0  0
                19  OPR   0  11
                20  JPC   0  0
  21    IF J=0 THEN WRITE (32) ELSE J := J DIV 10;
                21  LOD   0  1
                22  LIT   0  0
                23  OPR   0  8
                24  JPC   0  0
                25  LIT   0  32
                26  CSP   0  1
                27  JMP   0  0
ADDR AT 24 CHANGED TO 28
                28  LOD   0  1
                29  LIT   0  10
                30  OPR   0  5
                31  STO   0  1
ADDR AT 27 CHANGED TO 32
                32  LOD   0  0
                33  OPR   0  19
                34  STO   0  0
                35  JMP   0  17
ADDR AT 20 CHANGED TO 36
                36  INT   0  -1
  37   IF J>9 THEN WRITE ('&');
                37  LOD   0  1
                38  LIT   0  9
                39  OPR   0  12
                40  JPC   0  0
                41  LIT   0  38
                42  CSP   0  1
ADDR AT 40 CHANGED TO 43
  43   WRITE (VAL#)
                43  LOD   0  -5
                44  CSP   0  3
  45  END {FMT};
                45  OPR   0  0
  46  BEGIN {MAIN}
  46   WRITE (12, 'START DECODING AT '); READ (STADR%); CRLF;
ADDR AT 0 CHANGED TO 46
                46  INT   0  3
                47  LIT   0  12
                48  CSP   0  1
                49  LIT   0  83
                50  LIT   0  84
                51  LIT   0  65
                52  LIT   0  82
                53  LIT   0  84
                54  LIT   0  32
                55  LIT   0  68
                56  LIT   0  69
                57  LIT   0  67
```

```
         58  LIT   0  79
         59  LIT   0  68
         60  LIT   0  73
         61  LIT   0  78
         62  LIT   0  71
         63  LIT   0  32
         64  LIT   0  65
         65  LIT   0  84
         66  LIT   0  32
         67  LIT   0  18
         68  CSP   0  8
         69  CSP   0  4
         70  STO   0  0
         71  CAL   0  2
 72   CRLF; INDX := 0;
         72  CAL   0  2
         73  LIT   0  0
         74  STO   0  1
 75   WHILE (STADR < %6900) AND (MEM[STADR] <> STOP) DO
         75  LOD   0  0
         76  LIT   0  26880
         77  OPR   0  10
         78  LOD   0  0
         79  LOD   255  0
         80  LIT   0  255
         81  OPR   0  9
         82  OPR   0  15
         83  JPC   0  0
 84    BEGIN FMT (INDX, 10); WRITE ('   '); INDX := INDX + 1;
         84  LOD   0  1
         85  LIT   0  10
         86  CAL   0  7
         87  INT   0  -2
         88  LIT   0  32
         89  LIT   0  32
         90  LIT   0  32
         91  LIT   0  3
         92  CSP   0  8
         93  LOD   0  1
         94  LIT   0  1
         95  OPR   0  2
         96  STO   0  1
 97    NUM := MEM[STADR];
         97  LOD   0  0
         98  LOD   255  0
         99  STO   0  2
100    CASE NUM OF
        100  LOD   0  2
101     0    : WRITE ('LIT');
        101  OPR   0  21
        102  LIT   0  0
        103  OPR   0  8
        104  JPC   0  0
        105  LIT   0  76
        106  LIT   0  73
        107  LIT   0  84
        108  LIT   0  3
        109  CSP   0  8
        110  JMP   0  0
ADDR AT 104 CHANGED TO 111
111     1    : WRITE ('OPR');
        111  OPR   0  21
        112  LIT   0  1
        113  OPR   0  8
        114  JPC   0  0
        115  LIT   0  79
        116  LIT   0  80
        117  LIT   0  82
```

```
                 118  LIT   0  3
                 119  CSP   0  8
                 120  JMP   0  0
ADDR AT 114 CHANGED TO 121
 121      2,%12: WRITE ('LOD');
                 121  OPR   0  21
                 122  LIT   0  2
                 123  OPR   0  8
                 124  JPC   1  0
                 125  OPR   0  21
                 126  LIT   0  18
                 127  OPR   0  8
                 128  JPC   0  0
ADDR AT 124 CHANGED TO 129
                 129  LIT   0  76
                 130  LIT   0  79
                 131  LIT   0  68
                 132  LIT   0  3
                 133  CSP   0  8
                 134  JMP   0  0
ADDR AT 128 CHANGED TO 135
 135      3,%13: WRITE ('STO');
                 135  OPR   0  21
                 136  LIT   0  3
                 137  OPR   0  8
                 138  JPC   1  0
                 139  OPR   0  21
                 140  LIT   0  19
                 141  OPR   0  8
                 142  JPC   0  0
ADDR AT 138 CHANGED TO 143
                 143  LIT   0  83
                 144  LIT   0  84
                 145  LIT   0  79
                 146  LIT   0  3
                 147  CSP   0  8
                 148  JMP   0  0
ADDR AT 142 CHANGED TO 149
 149      4    : WRITE ('CAL');
                 149  OPR   0  21
                 150  LIT   0  4
                 151  OPR   0  8
                 152  JPC   0  0
                 153  LIT   0  67
                 154  LIT   0  65
                 155  LIT   0  76
                 156  LIT   0  3
                 157  CSP   0  8
                 158  JMP   0  0
ADDR AT 152 CHANGED TO 159
 159      5    : WRITE ('INT');
                 159  OPR   0  21
                 160  LIT   0  5
                 161  OPR   0  8
                 162  JPC   0  0
                 163  LIT   0  73
                 164  LIT   0  78
                 165  LIT   0  84
                 166  LIT   0  3
                 167  CSP   0  8
                 168  JMP   0  0
ADDR AT 162 CHANGED TO 169
 169      6    : WRITE ('JMP');
                 169  OPR   0  21
                 170  LIT   0  6
                 171  OPR   0  8
                 172  JPC   0  0
                 173  LIT   0  74
```

```
            174  LIT    0   77
            175  LIT    0   80
            176  LIT    0   3
            177  CSP    0   8
            178  JMP    0   0
ADDR AT 172 CHANGED TO 179
 179     7      : WRITE ('JPC');
            179  OPR    0   21
            180  LIT    0   7
            181  OPR    0   8
            182  JPC    0   0
            183  LIT    0   74
            184  LIT    0   80
            185  LIT    0   67
            186  LIT    0   3
            187  CSP    0   8
            188  JMP    0   0
ADDR AT 182 CHANGED TO 189
 189     8      : WRITE ('CSP')
            189  OPR    0   21
            190  LIT    0   8
            191  OPR    0   8
            192  JPC    0   0
            193  LIT    0   67
            194  LIT    0   83
            195  LIT    0   80
            196  LIT    0   3
            197  CSP    0   8
 198       ELSE BEGIN WRITE ('ILL'); MEM[STADR] := STOP END
            198  JMP    0   0
ADDR AT 192 CHANGED TO 199
            199  LIT    0   73
            200  LIT    0   76
            201  LIT    0   76
            202  LIT    0   3
            203  CSP    0   8
            204  LOD    0   0
            205  LIT    0   255
            206  STO    255  0
 207      END; {CASE}
ADDR AT 198 CHANGED TO 207
ADDR AT 188 CHANGED TO 207
ADDR AT 178 CHANGED TO 207
ADDR AT 168 CHANGED TO 207
ADDR AT 158 CHANGED TO 207
ADDR AT 148 CHANGED TO 207
ADDR AT 134 CHANGED TO 207
ADDR AT 120 CHANGED TO 207
ADDR AT 110 CHANGED TO 207
            207  INT    0   -1
 208      IF (NUM=%12) OR (NUM=%13) THEN WRITE ('X')
            208  LOD    0   2
            209  LIT    0   18
            210  OPR    0   8
            211  LOD    0   2
            212  LIT    0   19
            213  OPR    0   8
            214  OPR    0   14
            215  JPC    0   0
            216  LIT    0   88
 218        217  CSP    0   1
           ELSE WRITE (32); WRITE (32);
            218  JMP    0   0
ADDR AT 215 CHANGED TO 219
            219  LIT    0   32
            220  CSP    0   1
ADDR AT 218 CHANGED TO 221
            221  LIT    0   32
```

```
            222  CSP   0  1
 223     WRITE (MEM[STADR+1]#,',');
            223  LOD   0  0
            224  LIT   0  1
            225  OPR   0  2
            226  LOD   255  0
            227  CSP   0  3
            228  LIT   0  44
            229  CSP   0  1
 230     NUM := MEM[STADR+3] SHL 8 + MEM[STADR+2];
            230  LOD   0  0
            231  LIT   0  3
            232  OPR   0  2
            233  LOD   255  0
            234  LIT   0  8
            235  OPR   0  17
            236  LOD   0  0
            237  LIT   0  2
            238  OPR   0  2
            239  LOD   255  0
            240  OPR   0  2
            241  STO   0  2
 242     WRITE (NUM#); CRLF;
            242  LOD   0  2
            243  CSP   0  3
            244  CAL   0  2
 245     IF INDX MOD 15 = 0 THEN BEGIN
            245  LOD   0  1
            246  LIT   0  15
            247  OPR   0  7
            248  LIT   0  0
            249  OPR   0  8
            250  JPC   0  0
 251      READ (NUM); IF NUM=%18 THEN CALL(EXIT) END;
            251  CSP   0  0
            252  STO   0  2
            253  LOD   0  2
            254  LIT   0  24
            255  OPR   0  8
            256  JPC   0  0
            257  LIT   0  26950
            258  CAL   255  0
ADDR AT 256 CHANGED TO 259
ADDR AT 250 CHANGED TO 259
 259     IF MEM[STADR] <> STOP THEN STADR := STADR + 4;
            259  LOD   0  0
            260  LOD   255  0
            261  LIT   0  255
            262  OPR   0  9
            263  JPC   0  0
            264  LOD   0  0
            265  LIT   0  4
            266  OPR   0  2
            267  STO   0  0
ADDR AT 263 CHANGED TO 268
 268    END; {WHILE}
            268  JMP   0  75
ADDR AT 83 CHANGED TO 269
 269   END. {MAIN}
            269  OPR   0  0
FILE ENDS AT 3039
INTERPRET(I), OR TRANSLATE(T)? T
G
```

```
***** P-CODE TO 8080 TRANSLATION *****
       ADDRESS OF RUNTIME MODULE? %6900
       P-CODE START ADDRESS? %2C00
       OBJECT-CODE START ADDRESS? %1000
       STACK START ADDRESS? %0000
```
DEFAULTS USED

```
40 REFERENCES
27 DIFFERENT LABELS

  0   100F 12 12 12 18 1B 1E 1E 22 28 2E 34 3A 3F 42 45 4B 51 54 5A
 20   105D 64 6A 6F 72 79 7F 82 85 8B 91 94 9A A0 A3 A9 AC AE B4 BA
 40   10BD C4 CA CD D3 D6 D9 DF E5 E8 EE F4 FA 00 06 0C 12 18 1E 24
 60   112A 30 36 3C 42 48 4E 54 5A FF 02 08 0E 14 19 1F 25 2B 2E 34
 80   1137 3D 40 43 4A 50 56 5C 60 66 6C 72 78 68 6E 74 71 77 7D 80
100   1186 88 8B 90 93 9A A0 A6 AC B2 A2 A5 A8 AE B1 B8 BE C4 CA D0
120   11C0 C3 C6 CC CF D6 D9 DF E2 E9 EF F5 FB 01 F1 F4 F7 FD 00 07
140   120A 10 13 1A 20 26 2C 32 22 25 28 2E 31 38 3E 44 4A 50 40 43
160   1246 4C 4F 56 5C 62 68 6E 5E 61 64 6A 6D 74 7A 80 86 8C 7C 7F
180   1282 88 8B 92 98 9E A4 AA 9A 9D A0 A6 A9 B0 B6 BC C2 C8 B8 BB
200   12C1 C7 CD D3 C3 C9 CF D2 D4 DA E0 E3 E9 EF F2 F5 FC 02 05 08
220   130E 11 17 1A 20 26 23 26 29 2F 32 38 3E 41 44 4A 4D 53 59 59
240   135C 5F 65 67 6A 70 76 7C 7F 84 87 8E 91 97 99 9F A2 A9 AF B2
260   13B8 BB C1 C4 CB D1 D7 DA E0 E3 E6
31 FORWARD REFERENCES

270 P-CODES TRANSLATED (TOTAL 0438H BYTES)
03E6H BYTES OF OBJECT CODE PRODUCED - CODE ENDS AT 13E6
```

```
1000 AF D3 04 31 00 10 21 E6 13 11 01 97 CD 00 69 C3
1010 D9 10 01 0D 00 CD 6C 6B CD 00 6B C3 25 6C 13 13
1020 13 13 01 F6 FF CD 8D 6B 01 02 00 CD B5 6B 01 02
1030 00 CD 6C 6B 01 02 00 CD 8D 6B AF 13 12 13 12 CD
1040 B0 6C CD 4E 6C 01 00 00 CD B5 6B 01 F8 FF CD 8D
1050 6B CD 60 6D 01 00 00 CD 8D 6B CD CA 6C 1A 1B 1B
1060 1F D2 AC 10 01 02 00 CD 8D 6B AF 13 12 13 12 CD
1070 B0 6C 1A 1B 1B 1F D2 85 10 01 20 00 CD 6C 6B CD
1080 00 6B C3 9A 10 01 02 00 CD 8D 6B 01 0A 00 CD 6C
1090 6B CD 90 6C 01 02 00 CD B5 6B 01 00 00 CD 8D 6B
10A0 CD 4C 6D 01 00 00 CD B5 6B C3 51 10 1B 1B 01 02
10B0 00 CD 8D 6B 01 09 00 CD 6C 6B CD F9 6C 1A 1B 1B
10C0 1F D2 CD 10 01 26 00 CD 6C 6B CD 00 6B 01 F6 FF
10D0 CD 8D 6B CD 10 6B C3 25 6C 21 06 00 CD 73 6B 01
10E0 0C 00 CD 6C 6B CD 00 6B 0E 12 CD 52 6B 53 54 41
10F0 52 54 20 44 45 43 4F 44 49 4E 47 20 41 54 20 CD
1100 3C 6B 01 00 00 CD B5 6B CD E9 6B C3 12 10 CD E9
1110 6B C3 12 10 AF 13 12 13 12 01 02 00 CD B5 6B 01
1120 00 00 CD 8D 6B 01 00 69 CD 6C 6B CD F3 6C 01 00
1130 00 CD 8D 6B CD 0E 6C 01 FF 00 CD 6C 6B CD C6 6C
1140 CD 0F 6D 1A 1B 1B 1F D2 E3 13 01 02 00 CD 8D 6B
1150 01 0A 00 CD 6C 6B CD E9 6B C3 1E 10 1B 1B 1B 1B
1160 0E 03 CD 52 6B 20 20 20 01 02 00 CD 8D 6B CD 4C
1170 6D 01 02 00 CD B5 6B 01 00 00 CD 8D 6B CD 0E 6C
1180 01 04 00 CD B5 6B 13 13 CD 60 6D AF 13 12 13 12
1190 CD B0 6C 1A 1B 1B 1F D2 A5 11 0E 03 CD 52 6B 4C
11A0 49 54 C3 D2 12 CD 60 6D 01 01 00 CD 6C 6B CD B0
11B0 6C 1A 1B 1B 1F D2 C3 11 0E 03 CD 52 6B 4F 50 52
11C0 C3 D2 12 CD 60 6D 01 02 00 CD 6C 6B CD B0 6C 1A
11D0 1B 1B 1F DA E9 11 CD 60 6D 01 12 00 CD 6C 6B CD
11E0 B0 6C 1A 1B 1B 1F D2 F4 11 0E 03 CD 52 6B 4C 4F
11F0 44 C3 D2 12 CD 60 6D 01 03 00 CD 6C 6B CD B0 6C
1200 1A 1B 1B 1F DA 1A 12 CD 60 6D 01 13 00 CD 6C 6B
1210 CD B0 6C 1A 1B 1B 1F D2 25 12 0E 03 CD 52 6B 53
1220 54 4F C3 D2 12 CD 60 6D 01 04 00 CD 6C 6B CD B0
1230 6C 1A 1B 1B 1F D2 43 12 0E 03 CD 52 6B 43 41 4C
1240 C3 D2 12 CD 60 6D 01 05 00 CD 6C 6B CD B0 6C 1A
```

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1250 1B 1B 1F D2 61 12 0E 03 CD 52 6B 49 4E 54 C3 D2
1260 12 CD 60 6D 01 06 00 CD 6C 6B CD B0 6C 1A 1B 1B
1270 1F D2 7F 12 0E 03 CD 52 6B 4A 4D 50 C3 D2 12 CD
1280 60 6D 01 07 00 CD 6C 6B CD B0 6C 1A 1B 1B 1F D2
1290 9D 12 0E 03 CD 52 6B 4A 50 43 C3 D2 12 CD 60 6D
12A0 01 08 00 CD 6C 6B CD B0 6C 1A 1B 1B 1F D2 BB 12
12B0 0E 03 CD 52 6B 43 53 50 C3 D2 12 0E 03 CD 52 6B
12C0 49 4C 4C 01 00 00 CD 8D 6B 01 FF 00 CD 6C 6B CD
12D0 19 6C 1B 1B 01 04 00 CD 8D 6B 01 12 00 CD 6C 6B
12E0 CD B0 6C 01 04 00 CD 8D 6B 01 13 00 CD 6C 6B CD
12F0 B0 6C CD 04 6D 1A 1B 1B 1F D2 08 13 01 58 00 CD
1300 6C 6B CD 00 6B C3 11 13 01 20 00 CD 6C 6B CD 00
1310 6B 01 20 00 CD 6C 6B CD 00 6B 01 00 00 CD 8D 6B
1320 CD 4C 6D CD 0E 6C CD 10 6B 01 2C 00 CD 6C 6B CD
1330 00 6B 01 00 00 CD 8D 6B CD 4C 6D CD 4C 6D CD 4C
1340 6D CD 0E 6C 01 08 00 CD 6C 6B CD 23 6D 01 00 00
1350 CD 8D 6B CD 4C 6D CD 4C 6D CD 0E 6C CD 4E 6C 01
1360 04 00 CD B5 6B 13 13 CD 10 6B CD E9 6B C3 12 10
1370 01 02 00 CD 8D 6B 01 0F 00 CD 6C 6B CD A4 6C AF
1380 13 12 13 12 CD B0 6C 1A 1B 1B 1F D2 B2 13 CD F7
1390 6A 01 04 00 CD B5 6B 13 13 01 18 00 CD 6C 6B CD
13A0 B0 6C 1A 1B 1B 1F D2 B2 13 01 46 69 CD 6C 6B CD
13B0 21 6C 01 00 00 CD 8D 6B CD 0E 6C 01 FF 00 CD 6C
13C0 6B CD C6 6C 1A 1B 1B 1F D2 E0 13 01 00 00 CD 8D
13D0 6B 01 04 00 CD 6C 6B CD 4E 6C 01 00 00 CD B5 6B
13E0 C3 1F 11 C3 25 6C 20
>

1000 AF          Z1000H  XRA    A
1001 D3 04               OUT    004H
1003 31 00 10            LXI    P,01000H
1006 21 E6 13            LXI    H,013E6H
1009 11 01 97            LXI    D,09701H
100C CD 00 69            CALL   06900H
100F C3 D9 10            JMP    010D9H
1012 01 0D 00    Z1012H  LXI    B,0000DH
1015 CD 6C 6B            CALL   06B6CH
1018 CD 00 6B            CALL   06B00H
101B C3 25 6C            JMP    06C25H
101E 13          Z101EH  INX    D
101F 13                  INX    D
1020 13                  INX    D
1021 13                  INX    D
1022 01 F6 FF            LXI    B,0FFF6H
1025 CD 8D 6B            CALL   06B8DH
1028 01 02 00            LXI    B,00002H
102B CD B5 6B            CALL   06BB5H
102E 01 02 00            LXI    B,00002H
1031 CD 6C 6B            CALL   06B6CH
1034 01 02 00            LXI    B,00002H
1037 CD 8D 6B            CALL   06B8DH
103A AF                  XRA    A
103B 13                  INX    D
103C 12                  STAX   D
103D 13                  INX    D
103E 12                  STAX   D
103F CD B0 6C            CALL   06CB0H
1042 CD 4E 6C            CALL   06C4EH
1045 01 00 00            LXI    B,00000H
1048 CD B5 6B            CALL   06BB5H
104B 01 F8 FF            LXI    B,0FFF8H
104E CD 8D 6B            CALL   06B8DH
1051 CD 60 6D    Z1051H  CALL   06D60H
1054 01 00 00            LXI    B,00000H
1057 CD 8D 6B            CALL   06B8DH
105A CD CA 6C            CALL   06CCAH
105D 1A                  LDAX   D
105E 1B                  DCX    D
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```
105F 1B                   DCX    D
1060 1F                   RAR
1061 D2 AC 10             JNC    010ACH
1064 01 02 00             LXI    B,00002H
1067 CD 8D 6B             CALL   06B8DH
106A AF                   XRA    A
106B 13                   INX    D
106C 12                   STAX   D
106D 13                   INX    D
106E 12                   STAX   D
106F CD B0 6C             CALL   06CB0H
1072 1A                   LDAX   D
1073 1B                   DCX    D
1074 1B                   DCX    D
1075 1F                   RAR
1076 D2 85 10             JNC    01085H
1079 01 20 00             LXI    B,00020H
107C CD 6C 6B             CALL   06B6CH
107F CD 00 6B             CALL   06B00H
1082 C3 9A 10             JMP    0109AH
1085 01 02 00    Z1085H   LXI    B,00002H
1088 CD 8D 6B             CALL   06B8DH
108B 01 0A 00             LXI    B,0000AH
108E CD 6C 6B             CALL   06B6CH
1091 CD 90 6C             CALL   06C90H
1094 01 02 00             LXI    B,00002H
1097 CD B5 6B             CALL   06BB5H
109A 01 00 00    Z109AH   LXI    B,00000H
109D CD 8D 6B             CALL   06B8DH
10A0 CD 4C 6D             CALL   06D4CH
10A3 01 00 00             LXI    B,00000H
10A6 CD B5 6B             CALL   06BB5H
10A9 C3 51 10             JMP    01051H
10AC 1B          Z10ACH   DCX    D
10AD 1B                   DCX    D
10AE 01 02 00             LXI    B,00002H
10B1 CD 8D 6B             CALL   06B8DH
10B4 01 09 00             LXI    B,00009H
10B7 CD 6C 6B             CALL   06B6CH
10BA CD F9 6C             CALL   06CF9H
10BD 1A                   LDAX   D
10BE 1B                   DCX    D
10BF 1B                   DCX    D
10C0 1F                   RAR
10C1 D2 CD 10             JNC    010CDH
10C4 01 26 00             LXI    B,00026H
10C7 CD 6C 6B             CALL   06B6CH
10CA CD 00 6B             CALL   06B00H
10CD 01 F6 FF    Z10CDH   LXI    B,0FFF6H
10D0 CD 8D 6B             CALL   06B8DH
10D3 CD 10 6B             CALL   06B10H
10D6 C3 25 6C             JMP    06C25H
10D9 21 06 00    Z10D9H   LXI    H,00006H
10DC CD 73 6B             CALL   06B73H
10DF 01 0C 00             LXI    B,0000CH
10E2 CD 6C 6B             CALL   06B6CH
10E5 CD 00 6B             CALL   06B00H
10E8 0E 12                MVI    C,012H
10EA CD 52 6B             CALL   06B52H
10ED 53                   MOV    D,E       S
10EE 54                   MOV    D,H       T
10EF 41                   MOV    B,C       A
10F0 52                   MOV    D,D       R
10F1 54                   MOV    D,H       T
10F2 20                   DB     020H
10F3 44                   MOV    B,H       D
10F4 45                   MOV    B,L       E
10F5 43                   MOV    B,E       C
```

```
10F6 4F                    MOV   C,A     O
10F7 44                    MOV   B,H     D
10F8 49                    MOV   C,C     I
10F9 4E                    MOV   C,M     N
10FA 47                    MOV   B,A     G
10FB 20                    DB    020H
10FC 41                    MOV   B,C     A
10FD 54                    MOV   D,H     T
10FE 20                    DB    020H
10FF CD 3C 6B              CALL  06B3CH
1102 01 00 00              LXI   B,00000H
1105 CD B5 6B              CALL  06BB5H
1108 CD E9 6B              CALL  06BE9H
110B C3 12 10              JMP   01012H
110E CD E9 6B              CALL  06BE9H
1111 C3 12 10              JMP   01012H
1114 AF                    XRA   A
1115 13                    INX   D
1116 12                    STAX  D
1117 13                    INX   D
1118 12                    STAX  D
1119 01 02 00              LXI   B,00002H
111C CD B5 6B              CALL  06BB5H
111F 01 00 00      Z111FH  LXI   B,00000H
1122 CD 8D 6B              CALL  06B8DH
1125 01 00 69              LXI   B,06900H
1128 CD 6C 6B              CALL  06B6CH
112B CD F3 6C              CALL  06CF3H
112E 01 00 00              LXI   B,00000H
1131 CD 8D 6B              CALL  06B8DH
1134 CD 0E 6C              CALL  06C0EH
1137 01 FF 00              LXI   B,000FFH
113A CD 6C 6B              CALL  06B6CH
113D CD C6 6C              CALL  06CC6H
1140 CD 0F 6D              CALL  06D0FH
1143 1A                    LDAX  D
1144 1B                    DCX   D
1145 1B                    DCX   D
1146 1F                    RAR
1147 D2 E3 13              JNC   013E3H
114A 01 02 00              LXI   B,00002H
114D CD 8D 6B              CALL  06B8DH
1150 01 0A 00              LXI   B,0000AH
1153 CD 6C 6B              CALL  06B6CH
1156 CD E9 6B              CALL  06BE9H
1159 C3 1E 10              JMP   0101EH
115C 1B                    DCX   D
115D 1B                    DCX   D
115E 1B                    DCX   D
115F 1B                    DCX   D
1160 0E 03                 MVI   C,003H
1162 CD 52 6B              CALL  06B52H
1165 20                    DB    020H
1166 20                    DB    020H
1167 20                    DB    020H
1168 01 02 00              LXI   B,00002H
116B CD 8D 6B              CALL  06B8DH
116E CD 4C 6D              CALL  06D4CH
1171 01 02 00              LXI   B,00002H
1174 CD B5 6B              CALL  06BB5H
1177 01 00 00              LXI   B,00000H
117A CD 8D 6B              CALL  06B8DH
117D CD 0E 6C              CALL  06C0EH
1180 01 04 00              LXI   B,00004H
1183 CD B5 6B              CALL  06BB5H
1186 13                    INX   D
1187 13                    INX   D
1188 CD 60 6D              CALL  06D60H
```

```
118B AF                     XRA   A
118C 13                     INX   D
118D 12                     STAX  D
118E 13                     INX   D
118F 12                     STAX  D
1190 CD B0 6C               CALL  06CB0H
1193 1A                     LDAX  D
1194 1B                     DCX   D
1195 1B                     DCX   D
1196 1F                     RAR
1197 D2 A5 11               JNC   011A5H
119A 0E 03                  MVI   C,003H
119C CD 52 6B               CALL  06B52H
119F 4C                     MOV   C,H
11A0 49                     MOV   C,C
11A1 54                     MOV   D,H
11A2 C3 D2 12               JMP   012D2H
11A5 CD 60 6D      Z11A5H   CALL  06D60H
11A8 01 01 00               LXI   B,00001H
11AB CD 6C 6B               CALL  06B6CH
11AE CD B0 6C               CALL  06CB0H
11B1 1A                     LDAX  D
11B2 1B                     DCX   D
11B3 1B                     DCX   D
11B4 1F                     RAR
11B5 D2 C3 11               JNC   011C3H
11B8 0E 03                  MVI   C,003H
11BA CD 52 6B               CALL  06B52H
11BD 4F                     MOV   C,A      O
11BE 50                     MOV   D,B      P
11BF 52                     MOV   D,D      R
11C0 C3 D2 12               JMP   012D2H
11C3 CD 60 6D      Z11C3H   CALL  06D60H
11C6 01 02 00               LXI   B,00002H
11C9 CD 6C 6B               CALL  06B6CH
11CC CD B0 6C               CALL  06CB0H
11CF 1A                     LDAX  D
11D0 1B                     DCX   D
11D1 1B                     DCX   D
11D2 1F                     RAR
11D3 DA E9 11               JC    011E9H
11D6 CD 60 6D               CALL  06D60H
11D9 01 12 00               LXI   B,00012H
11DC CD 6C 6B               CALL  06B6CH
11DF CD B0 6C               CALL  06CB0H
11E2 1A                     LDAX  D
11E3 1B                     DCX   D
11E4 1B                     DCX   D
11E5 1F                     RAR
11E6 D2 F4 11               JNC   011F4H
11E9 0E 03         Z11E9H   MVI   C,003H
11EB CD 52 6B               CALL  06B52H
11EE 4C                     MOV   C,H      L
11EF 4F                     MOV   C,A      O
11F0 44                     MOV   B,H      D
11F1 C3 D2 12               JMP   012D2H
11F4 CD 60 6D      Z11F4H   CALL  06D60H
11F7 01 03 00               LXI   B,00003H
11FA CD 6C 6B               CALL  06B6CH
11FD CD B0 6C               CALL  06CB0H
1200 1A                     LDAX  D
1201 1B                     DCX   D
1202 1B                     DCX   D
1203 1F                     RAR
1204 DA 1A 12               JC    0121AH
1207 CD 60 6D               CALL  06D60H
120A 01 13 00               LXI   B,00013H
120D CD 6C 6B               CALL  06B6CH
```

```
1210 CD B0 6C                CALL   06CB0H
1213 1A                      LDAX   D
1214 1B                      DCX    D
1215 1B                      DCX    D
1216 1F                      RAR
1217 D2 25 12                JNC    01225H
121A 0E 03          Z121AH   MVI    C,003H
121C CD 52 6B                CALL   06B52H
121F 53                      MOV    D,E       S
1220 54                      MOV    D,H       T
1221 4F                      MOV    C,A       O
1222 C3 D2 12                JMP    012D2H
1225 CD 60 6D       Z1225H   CALL   06D60H
1228 01 04 00                LXI    B,00004H
122B CD 6C 6B                CALL   06B6CH
122E CD B0 6C                CALL   06CB0H
1231 1A                      LDAX   D
1232 1B                      DCX    D
1233 1B                      DCX    D
1234 1F                      RAR
1235 D2 43 12                JNC    01243H
1238 0E 03                   MVI    C,003H
123A CD 52 6B                CALL   06B52H
123D 43                      MOV    B,E       C
123E 41                      MOV    B,C       A
123F 4C                      MOV    C,H       L
1240 C3 D2 12                JMP    012D2H
1243 CD 60 6D       Z1243H   CALL   06D60H
1246 01 05 00                LXI    B,00005H
1249 CD 6C 6B                CALL   06B6CH
124C CD B0 6C                CALL   06CB0H
124F 1A                      LDAX   D
1250 1B                      DCX    D
1251 1B                      DCX    D
1252 1F                      RAR
1253 D2 61 12                JNC    01261H
1256 0E 03                   MVI    C,003H
1258 CD 52 6B                CALL   06B52H
125B 49                      MOV    C,C       I
125C 4E                      MOV    C,M       N
125D 54                      MOV    D,H       T
125E C3 D2 12                JMP    012D2H
1261 CD 60 6D       Z1261H   CALL   06D60H
1264 01 06 00                LXI    B,00006H
1267 CD 6C 6B                CALL   06B6CH
126A CD B0 6C                CALL   06CB0H
126D 1A                      LDAX   D
126E 1B                      DCX    D
126F 1B                      DCX    D
1270 1F                      RAR
1271 D2 7F 12                JNC    0127FH
1274 0E 03                   MVI    C,003H
1276 CD 52 6B                CALL   06B52H
1279 4A                      MOV    C,D       J
127A 4D                      MOV    C,L       M
127B 50                      MOV    D,B       P
127C C3 D2 12                JMP    012D2H
127F CD 60 6D       Z127FH   CALL   06D60H
1282 01 07 00                LXI    B,00007H
1285 CD 6C 6B                CALL   06B6CH
1288 CD B0 6C                CALL   06CB0H
128B 1A                      LDAX   D
128C 1B                      DCX    D
128D 1B                      DCX    D
128E 1F                      RAR
128F D2 9D 12                JNC    0129DH
1292 0E 03                   MVI    C,003H
1294 CD 52 6B                CALL   06B52H
1297 4A                      MOV    C,D       J
```

```
1298 50                     MOV   D,B     P
1299 43                     MOV   B,E     C
129A C3 D2 12               JMP   012D2H
129D CD 60 6D      Z129DH   CALL  06D60H
12A0 01 08 00               LXI   B,00008H
12A3 CD 6C 6B               CALL  06B6CH
12A6 CD B0 6C               CALL  06CB0H
12A9 1A                     LDAX  D
12AA 1B                     DCX   D
12AB 1B                     DCX   D
12AC 1F                     RAR
12AD D2 BB 12               JNC   012BBH
12B0 0E 03                  MVI   C,003H
12B2 CD 52 6B               CALL  06B52H
12B5 43                     MOV   B,E     C
12B6 53                     MOV   D,E     S
12B7 50                     MOV   D,B     P
12B8 C3 D2 12               JMP   012D2H
12BB 0E 03         Z12BBH   MVI   C,003H
12BD CD 52 6B               CALL  06B52H
12C0 49                     MOV   C,C     I
12C1 4C                     MOV   C,H     L
12C2 4C                     MOV   C,H     L
12C3 01 00 00               LXI   B,00000H
12C6 CD 8D 6B               CALL  06B8DH
12C9 01 FF 00               LXI   B,000FFH
12CC CD 6C 6B               CALL  06B6CH
12CF CD 19 6C               CALL  06C19H
12D2 1B            Z12D2H   DCX   D
12D3 1B                     DCX   D
12D4 01 04 00               LXI   B,00004H
12D7 CD 8D 6B               CALL  06B8DH
12DA 01 12 00               LXI   B,00012H
12DD CD 6C 6B               CALL  06B6CH
12E0 CD B0 6C               CALL  06CB0H
12E3 01 04 00               LXI   B,00004H
12E6 CD 8D 6B               CALL  06B8DH
12E9 01 13 00               LXI   B,00013H
12EC CD 6C 6B               CALL  06B6CH
12EF CD B0 6C               CALL  06CB0H
12F2 CD 04 6D               CALL  06D04H
12F5 1A                     LDAX  D
12F6 1B                     DCX   D
12F7 1B                     DCX   D
12F8 1F                     RAR
12F9 D2 08 13               JNC   01308H
12FC 01 58 00               LXI   B,00058H
12FF CD 6C 6B               CALL  06B6CH
1302 CD 00 6B               CALL  06B00H
1305 C3 11 13               JMP   01311H
1308 01 20 00      Z1308H   LXI   B,00020H
130B CD 6C 6B               CALL  06B6CH
130E CD 00 6B               CALL  06B00H
1311 01 20 00      Z1311H   LXI   B,00020H
1314 CD 6C 6B               CALL  06B6CH
1317 CD 00 6B               CALL  06B00H
131A 01 00 00               LXI   B,00000H
131D CD 8D 6B               CALL  06B8DH
1320 CD 4C 6D               CALL  06D4CH
1323 CD 0E 6C               CALL  06C0EH
1326 CD 10 6B               CALL  06B10H
1329 01 2C 00               LXI   B,0002CH
132C CD 6C 6B               CALL  06B6CH
132F CD 00 6B               CALL  06B00H
1332 01 00 00               LXI   B,00000H
1335 CD 8D 6B               CALL  06B8DH
1338 CD 4C 6D               CALL  06D4CH
133B CD 4C 6D               CALL  06D4CH
133E CD 4C 6D               CALL  06D4CH
```

```
1341 CD 0E 6C      3830          CALL    06C0EH
1344 01 08 00      3840          LXI     B,00008H
1347 CD 6C 6B      3850          CALL    06B6CH
134A CD 23 6D      3860          CALL    06D23H
134D 01 00 00      3870          LXI     B,00000H
1350 CD 8D 6B      3880          CALL    06B8DH
1353 CD 4C 6D      3890          CALL    06D4CH
1356 CD 4C 6D      3900          CALL    06D4CH
1359 CD 0E 6C      3910          CALL    06C0EH
135C CD 4E 6C      3920          CALL    06C4EH
135F 01 04 00      3930          LXI     B,00004H
1362 CD B5 6B      3940          CALL    06BB5H
1365 13            3950          INX     D
1366 13            3960          INX     D
1367 CD 10 6B      3970          CALL    06B10H
136A CD E9 6B      3980          CALL    06BE9H
136D C3 12 10      3990          JMP     01012H
1370 01 02 00      4000          LXI     B,00002H
1373 CD 8D 6B      4010          CALL    06B8DH
1376 01 0F 00      4020          LXI     B,0000FH
1379 CD 6C 6B      4030          CALL    06B6CH
137C CD A4 6C      4040          CALL    06CA4H
137F AF            4050          XRA     A
1380 13            4060          INX     D
1381 12            4070          STAX    D
1382 13            4080          INX     D
1383 12            4090          STAX    D
1384 CD B0 6C      4100          CALL    06CB0H
1387 1A            4110          LDAX    D
1388 1B            4120          DCX     D
1389 1B            4130          DCX     D
138A 1F            4140          RAR
138B D2 B2 13      4150          JNC     013B2H
138E CD F7 6A      4160          CALL    06AF7H
1391 01 04 00      4170          LXI     B,00004H
1394 CD B5 6B      4180          CALL    06BB5H
1397 13            4190          INX     D
1398 13            4200          INX     D
1399 01 18 00      4210          LXI     B,00018H
139C CD 6C 6B      4220          CALL    06B6CH
139F CD B0 6C      4230          CALL    06CB0H
13A2 1A            4240          LDAX    D
13A3 1B            4250          DCX     D
13A4 1B            4260          DCX     D
13A5 1F            4270          RAR
13A6 D2 B2 13      4280          JNC     013B2H
13A9 01 46 69      4290          LXI     B,06946H
13AC CD 6C 6B      4300          CALL    06B6CH
13AF CD 21 6C      4310          CALL    06C21H
13B2 01 00 00      4320  Z13B2H  LXI     B,00000H
13B5 CD 8D 6B      4330          CALL    06B8DH
13B8 CD 0E 6C      4340          CALL    06C0EH
13BB 01 FF 00      4350          LXI     B,000FFH
13BE CD 6C 6B      4360          CALL    06B6CH
13C1 CD C6 6C      4370          CALL    06CC6H
13C4 1A            4380          LDAX    D
13C5 1B            4390          DCX     D
13C6 1B            4400          DCX     D
13C7 1F            4410          RAR
13C8 D2 E0 13      4420          JNC     013E0H
13CB 01 00 00      4430          LXI     B,00000H
13CE CD 8D 6B      4440          CALL    06B8DH
13D1 01 04 00      4450          LXI     B,00004H
13D4 CD 6C 6B      4460          CALL    06B6CH
13D7 CD 4E 6C      4470          CALL    06C4EH
13DA 01 00 00      4480          LXI     B,00000H
13DD CD B5 6B      4490          CALL    06BB5H
13E0 C3 1F 11      4500  Z13E0H  JMP     0111FH
13E3 C3 25 6C      4510  Z13E3H  JMP     06C25H
```

# Listing 2: 8080 Run Time Routines for Pascal Object Code

```
0000                 * RUN-TIME ROUTINES FOR PASCAL OBJECT CODE
0000                 ORGA EQU 6900H
0000                  ORG ORGA
6900 C3 6F 6D        RUN JMP ORGA+46FH
6903                 WH0 EQU 0C20H
6903                 INP EQU WH0
6903                 WH1 EQU 0C24H
6903                 OUTP EQU WH1
6903                 CRLF EQU 9F8H
6903                 CROUT EQU CRLF
6903                 OSEQ EQU 5ADH
6903                 BYTE1 EQU 0A11H
6903                 DEOUT1 EQU 0A0CH
6903                 BLK1 EQU 0A02H
6903                 CLEAR EQU 9FDH
6903                 POS EQU 0C0EH
6903                 POS1 EQU 727FH
6903                 MENTR EQU 7390H
6903                 ABUF DS 7
690A                 SFLG DS 1
690B                 SIGN EQU SFLG
690B                 STK2 DS 2
690D                 BB DS 2
690F 20 53 54 41     SM1 DB ' STACK'
6915 20 4F 56 45     SM2 DB ' OVERFLOW'
691E 0D               DB 13
691F 20 49 4E 50     MER1 DB ' INPUT ERROR'
692B 0D               DB 13
692C 20 53 49 5A     MER2 DB ' SIZE ERROR'
6937 0D               DB 13
6938 20 44 49 56     DM1 DB ' DIVIDE CHECK'
6945 0D               DB 13
6946 CD F8 09        EXIT CALL CRLF
6949 2A 0E 0C         LHLD POS
694C 22 7F 72         SHLD POS1
694F C3 90 73         JMP MENTR
6952 CD AD 05        PRINT CALL OSEQ
6955 C3 F8 09         JMP CRLF
6958 EB              POP XCHG
6959 4E               MOV C,M
695A 2B               DCX H
695B 46               MOV B,M
695C 2B               DCX H
695D 5E               MOV E,M
695E 2B               DCX H
695F 56               MOV D,M
6960 EB               XCHG
6961 C9               RET
6962 EB              PUSH XCHG
6963 72               MOV M,D
6964 23               INX H
6965 73               MOV M,E
6966 EB               XCHG
6967 C9               RET
6968 EB              POP1 XCHG
6969 5E               MOV E,M
696A 2B               DCX H
696B 56               MOV D,M
696C 2B               DCX H
696D EB               XCHG
696E C9               RET
696F AF              NEGH XRA A
```

```
6970 95          0630  SUB L
6971 6F          0640  MOV L,A
6972 9C          0650  SBB H
6973 95          0660  SUB L
6974 67          0670  MOV H,A
6975 D6 50       0680  SUI 80
6977 B5          0690  ORA L
6978 C0          0700  RNZ
6979 21 15 69    0710 OVFL LXI H,SM2
697C CD 52 69    0720  CALL PRINT
697F C3 62 69    0730  JMP PUSH
6982 AF          0740 NEGB XRA A
6983 91          0750  SUB C
6984 4F          0760  MOV C,A
6985 98          0770  SBB B
6986 91          0780  SUB C
6987 47          0790  MOV B,A
6988 D6 50       0800  SUI 80
698A B1          0810  ORA C
698B C0          0820  RNZ
698C C3 79 69    0830  JMP OVFL
698F 7A          0840 CMD MOV A,D
6990 2F          0850  CMA
6991 57          0860  MOV D,A
6992 7B          0870  MOV A,E
6993 2F          0880  CMA
6994 5F          0890  MOV E,A
6995 13          0900  INX D
6996 C9          0910  RET
6997 CD 20 0C    0920 GETC CALL WH0
699A 47          0930  MOV B,A
699B C3 24 0C    0940  JMP WH1
699E 21 03 69    0950 READ LXI H,ABUF
69A1 0E 00       0960  MVI C,0
69A3 CD 20 0C    0970 RLP CALL WH0
69A6 FE 7F       0980  CPI 7FH
69A8 CA D4 69    0990  JZ RUB
69AB FE 18       1000  CPI 18H
69AD CA E3 69    1010  JZ CAN
69B0 FE 0D       1020  CPI 0DH
69B2 CA B8 69    1030  JZ $+3
69B5 CD 24 0C    1040  CALL WH1
69B8 77          1050  MOV M,A
69B9 23          1060  INX H
69BA 0C          1070  INR C
69BB FE 0D       1080  CPI 0DH
69BD C8          1090  RZ
69BE 79          1100  MOV A,C
69BF FE 06       1110  CPI 6
69C1 C2 A3 69    1120  JNZ RLP
69C4 CD 20 0C    1130  CALL WH0
69C7 FE 7F       1140  CPI 7FH
69C9 CA D4 69    1150  JZ RUB
69CC FE 18       1160  CPI 18H
69CE CA E3 69    1170  JZ CAN
69D1 36 0D       1180  MVI M,0DH
69D3 C9          1190  RET
69D4 79          1200 RUB MOV A,C
69D5 B7          1210  ORA A
69D6 CA A3 69    1220  JZ RLP
69D9 3E 7F       1230  MVI A,7FH
69DB CD 24 0C    1240  CALL WH1
69DE 0D          1250  DCR C
69DF 2B          1260  DCX H
69E0 C3 A3 69    1270  JMP RLP
69E3 79          1280 CAN MOV A,C
69E4 B7          1290  ORA A
69E5 CA A3 69    1300  JZ RLP
69E8 3E 7F       1310  MVI A,7FH
69EA CD 24 0C    1320  CALL WH1
69ED 2B          1330  DCX H
69EE 0D          1340  DCR C
69EF C3 E3 69    1350  JMP CAN
69F2 D6 30       1360 DIGIT SUI 30H
69F4 D8          1370  RC
69F5 FE 0A       1380  CPI 0AH
69F7 3F          1390  CMC
69F8 C9          1400  RET
69F9 E5          1410 DECIN PUSH H
69FA C5          1420  PUSH B
69FB AF          1430  XRA A
69FC 32 0A 69    1440  STA SFLG
69FF 3E 23       1450  MVI A,'#'
6A01 CD 24 0C    1460  CALL WH1
6A04 CD 9E 69    1470  CALL READ
6A07 21 00 00    1480  LXI H,0
6A0A 01 03 69    1490  LXI B,ABUF
6A0D 0A          1500  LDAX B
6A0E 03          1510  INX B
6A0F FE 2D       1520  CPI '-'
6A11 C2 19 6A    1530  JNZ DECIL+2
6A14 32 0A 69    1540  STA SFLG
6A17 0A          1550 DECIL LDAX B
6A18 03          1560  INX B
6A19 CD F2 69    1570  CALL DIGIT
6A1C DA 31 6A    1580  JC DECID
6A1F 5D          1590  MOV E,L
6A20 54          1600  MOV D,H
6A21 29          1610  DAD H
6A22 29          1620  DAD H
6A23 19          1630  DAD D
6A24 29          1640  DAD H
6A25 85          1650  ADD L
6A26 6F          1660  MOV L,A
6A27 D2 17 6A    1670  JNC DECIL
6A2A 24          1680  INR H
6A2B FA 47 6A    1690  JM ER2
6A2E C3 17 6A    1700  JMP DECIL
6A31 FE DD       1710 DECID CPI 13-48
6A33 C2 41 6A    1720  JNZ ER1
6A36 EB          1730  XCHG
6A37 C1          1740  POP B
6A38 E1          1750  POP H
6A39 3A 0A 69    1760  LDA SFLG
6A3C B7          1770  ORA A
6A3D C8          1780  RZ
6A3E C3 8F 69    1790  JMP CMD
6A41 21 1F 69    1800 ER1 LXI H,MER1
6A44 C3 4A 6A    1810  JMP $+3
6A47 21 2C 69    1820 ER2 LXI H,MER2
6A4A CD 52 69    1830  CALL PRINT
6A4D C3 FB 69    1840  JMP DECIN+2
6A50 E5          1850 HEXIN PUSH H
6A51 C5          1860  PUSH B
6A52 AF          1870  XRA A
6A53 32 0A 69    1880  STA SFLG
6A56 3E 25       1890  MVI A,'%'
6A58 CD 24 0C    1900  CALL WH1
6A5B CD 9E 69    1910  CALL READ
6A5E 21 00 00    1920  LXI H,0
6A61 01 03 69    1930  LXI B,ABUF
6A64 0A          1940  LDAX B
6A65 03          1950  INX B
6A66 FE 2D       1960  CPI '-'
6A68 C2 70 6A    1970  JNZ HEXIL+2
6A6B 32 0A 69    1980  STA SFLG
6A6E 0A          1990 HEXIL LDAX B
6A6F 03          2000  INX B
6A70 CD F2 69    2010  CALL DIGIT
6A73 D2 82 6A    2020  JNC HEX16
6A76 D6 07       2030  SUI 7
6A78 FE 0A       2040  CPI 0AH
6A7A DA 8F 6A    2050  JC HEXID
6A7D FE 10       2060  CPI 10H
6A7F D2 8F 6A    2070  JNC HEXID
6A82 29          2080 HEX16 DAD H
6A83 29          2090  DAD H
6A84 29          2100  DAD H
6A85 29          2110  DAD H
6A86 85          2120  ADD L
```

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6A87 6F          2130   MOV L,A
6A88 D2 6E 6A    2140   JNC HEXIL
6A8B 24          2150   INR H
6A8C C3 6E 6A    2160   JMP HEXIL
6A8F FE D6       2170 HEXID CPI 13-37H
6A91 C2 9F 6A    2180   JNZ HER1
6A94 EB          2190   XCHG
6A95 C1          2200   POP B
6A96 E1          2210   POP H
6A97 3A 0A 69    2220   LDA SFLG
6A9A B7          2230   ORA A
6A9B C8          2240   RZ
6A9C C3 8F 69    2250   JMP CMD
6A9F 21 1F 69    2260 HER1 LXI H,MER1
6AA2 CD 52 69    2270   CALL PRINT
6AA5 C3 52 6A    2280   JMP HEXIN+2
6AA8 21 38 69    2290 DVCK LXI H,DM1
6AAB CD 52 69    2300   CALL PRINT
6AAE 21 00 00    2310   LXI H,0
6AB1 54          2320   MOV D,H
6AB2 5D          2330   MOV E,L
6AB3 C9          2340   RET
6AB4 78          2350 DIV16 MOV A,B
6AB5 B1          2360   ORA C
6AB6 CA A8 6A    2370   JZ DVCK
6AB9 AF          2380   XRA A
6ABA 80          2390   ADD B
6ABB F5          2400   PUSH P
6ABC F4 82 69    2410   CP NEGB
6ABF AF          2420   XRA A
6AC0 84          2430   ADD H
6AC1 F5          2440   PUSH P
6AC2 FC 6F 69    2450   CM NEGH
6AC5 EB          2460   XCHG
6AC6 21 00 00    2470   LXI H,0
6AC9 3E 10       2480   MVI A,10H
6ACB 29          2490 D2 DAD H
6ACC EB          2500   XCHG
6ACD 29          2510   DAD H
6ACE EB          2520   XCHG
6ACF D2 D3 6A    2530   JNC D3
6AD2 23          2540   INX H
6AD3 E5          2550 D3 PUSH H
6AD4 09          2560   DAD B
6AD5 D2 E2 6A    2570   JNC D4
6AD8 1C          2580   INR E
6AD9 33          2590   INX P
6ADA 33          2600   INX P
6ADB 3D          2610   DCR A
6ADC C2 CB 6A    2620   JNZ D2
6ADF C3 E7 6A    2630   JMP D4A
6AE2 E1          2640 D4 POP H
6AE3 3D          2650   DCR A
6AE4 C2 CB 6A    2660   JNZ D2
6AE7 EB          2670 D4A XCHG
6AE8 C1          2680   POP B
6AE9 F1          2690   POP P
6AEA A8          2700   XRA B
6AEB FC 6F 69    2710   CM NEGH
6AEE 7A          2720   MOV A,D
6AEF B3          2730   ORA E
6AF0 C8          2740   RZ
6AF1 AF          2750   XRA A
6AF2 80          2760   ADD B
6AF3 F0          2770   RP
6AF4 C3 8F 69    2780   JMP CMD
6AF7 13          2790 SYS0 INX D
6AF8 AF          2800   XRA A
6AF9 12          2810   STAX D
6AFA 13          2820   INX D
6AFB CD 20 0C    2830   CALL INP
6AFE 12          2840   STAX D
6AFF C9          2850   RET
6B00 1A          2860 SYS1 LDAX D
6B01 1B          2870   DCX D
6B02 1B          2880   DCX D
6B03 C3 24 0C    2890   JMP OUTP
6B06 D5          2900 SYS2 PUSH D
6B07 CD F9 69    2910   CALL DECIN
6B0A EB          2920   XCHG
6B0B D1          2930   POP D
6B0C 13          2940   INX D
6B0D C3 62 69    2950   JMP PUSH
6B10 CD 68 69    2960 SYS3 CALL POP1
6B13 D5          2970   PUSH D
6B14 AF          2980   XRA A
6B15 3D          2990   DCR A
6B16 F5          3000   PUSH P
6B17 A4          3010   ANA H
6B18 F2 23 6B    3020   JP Y3
6B1B 3E 2D       3030   MVI A,'-'
6B1D CD 24 0C    3040   CALL OUTP
6B20 CD 6F 69    3050   CALL NEGH
6B23 01 0A 00    3060 Y3 LXI B,10
6B26 CD B4 6A    3070   CALL DIV16
6B29 3E 30       3080   MVI A,30H
6B2B 83          3090   ADD E
6B2C F5          3100   PUSH P
6B2D 7C          3110   MOV A,H
6B2E B5          3120   ORA L
6B2F C2 23 6B    3130   JNZ Y3
6B32 F1          3140   POP P
6B33 CD 24 0C    3150 WR CALL OUTP
6B36 F1          3160   POP P
6B37 F2 33 6B    3170   JP WR
6B3A D1          3180   POP D
6B3B C9          3190   RET
6B3C D5          3200 SYS4 PUSH D
6B3D CD 50 6A    3210   CALL HEXIN
6B40 EB          3220   XCHG
6B41 D1          3230   POP D
6B42 13          3240   INX D
6B43 C3 62 69    3250   JMP PUSH
6B46 1A          3260 SYS5 LDAX D
6B47 6F          3270   MOV L,A
6B48 1B          3280   DCX D
6B49 1A          3290   LDAX D
6B4A 1B          3300   DCX D
6B4B CD 11 0A    3310   CALL BYTE1
6B4E 7D          3320   MOV A,L
6B4F C3 11 0A    3330   JMP BYTE1
6B52 E1          3340 SYS8 POP H
6B53 7E          3350   MOV A,M
6B54 CD 24 0C    3360   CALL OUTP
6B57 23          3370   INX H
6B58 0D          3380   DCR C
6B59 C2 53 6B    3390   JNZ SYS8+1
6B5C E9          3400   PCHL
6B5D D5          0010 BASE PUSH D
6B5E 11 FA FF    0020 BS1 LXI D,-6
6B61 19          0030   DAD D
6B62 5E          0040   MOV E,M
6B63 2B          0050   DCX H
6B64 56          0060   MOV D,M
6B65 EB          0070   XCHG
6B66 3D          0080   DCR A
6B67 C2 5E 6B    0090   JNZ BS1
6B6A D1          0100   POP D
6B6B C9          0110   RET
6B6C EB          0120 LIT XCHG
6B6D 23          0130   INX H
6B6E 70          0140   MOV M,B
6B6F 23          0150   INX H
6B70 71          0160   MOV M,C
6B71 EB          0170   XCHG
6B72 C9          0180   RET
6B73 19          0190 INT DAD D
6B74 EB          0200   XCHG
6B75 2A 0B 69    0210   LHLD STK2
6B78 19          0220   DAD D
```

```
6B79 D0        0230        RNC
6B7A 21 0F 69  0240 STKOV  LXI H,SM1
6B7D CD 52 69  0250        CALL PRINT
6B80 E1        0260        POP H
6B81 C3 46 69  0270        JMP EXIT
6B84 2A 0D 69  0280 LOD1   LHLD BB
6B87 CD 5D 6B  0290        CALL BASE
6B8A C3 90 6B  0300        JMP $+3
6B8D 2A 0D 69  0310 LOD    LHLD BB
6B90 13        0320        INX D
6B91 09        0330        DAD B
6B92 2B        0340        DCX H
6B93 7E        0350        MOV A,M
6B94 12        0360        STAX D
6B95 23        0370        INX H
6B96 7E        0380        MOV A,M
6B97 13        0390        INX D
6B98 12        0400        STAX D
6B99 C9        0410        RET
6B9A AF        0420 LODX   XRA A
6B9B 2A 0D 69  0430 LODX1  LHLD BB
6B9E B7        0440        ORA A
6B9F C4 5D 6B  0450        CNZ BASE
6BA2 09        0460        DAD B
6BA3 EB        0470        XCHG
6BA4 4E        0480        MOV C,M
6BA5 2B        0490        DCX H
6BA6 46        0500        MOV B,M
6BA7 EB        0510        XCHG
6BA8 09        0520        DAD B
6BA9 C3 91 6B  0530        JMP LOD+4
6BAC 2A 0D 69  0540 STO1   LHLD BB
6BAF CD 5D 6B  0550        CALL BASE
6BB2 C3 B8 6B  0560        JMP $+3
6BB5 2A 0D 69  0570 STO    LHLD BB
6BB8 09        0580        DAD B
6BB9 1A        0590        LDAX D
6BBA 77        0600        MOV M,A
6BBB 2B        0610        DCX H
6BBC 1B        0620        DCX D
6BBD 1A        0630        LDAX D
6BBE 77        0640        MOV M,A
6BBF 1B        0650        DCX D
6BC0 C9        0660        RET
6BC1 AF        0670 STOX   XRA A
6BC2 EB        0680 STOX1  XCHG
6BC3 5E        0690        MOV E,M
6BC4 2B        0700        DCX H
6BC5 56        0710        MOV D,M
6BC6 2B        0720        DCX H
6BC7 D5        0730        PUSH D
6BC8 5E        0740        MOV E,M
6BC9 2B        0750        DCX H
6BCA 56        0760        MOV D,M
6BCB 2B        0770        DCX H
6BCC EB        0780        XCHG
6BCD 29        0790        DAD H
6BCE 09        0800        DAD B
6BCF 44        0810        MOV B,H
6BD0 4D        0820        MOV C,L
6BD1 2A 0D 69  0830        LHLD BB
6BD4 B7        0840        ORA A
6BD5 C4 5D 6B  0850        CNZ BASE
6BD8 09        0860        DAD B
6BD9 C1        0870        POP B
6BDA 71        0880        MOV M,C
6BDB 2B        0890        DCX H
6BDC 70        0900        MOV M,B
6BDD C9        0910        RET
6BDE 2A 0D 69  0920 CAL1   LHLD BB
6BE1 44        0930        MOV B,H
6BE2 4D        0940        MOV C,L
6BE3 CD 5D 6B  0950        CALL BASE
6BE6 C3 EE 6B  0960        JMP $+5
6BE9 2A 0D 69  0970 CAL    LHLD BB
6BEC 44        0980        MOV B,H
6BED 4D        0990        MOV C,L
6BEE D5        1000        PUSH D
6BEF EB        1010        XCHG
6BF0 23        1020        INX H
6BF1 72        1030        MOV M,D
6BF2 23        1040        INX H
6BF3 73        1050        MOV M,E
6BF4 D1        1060        POP D
6BF5 13        1070        INX D
6BF6 13        1080        INX D
6BF7 13        1090        INX D
6BF8 13        1100        INX D
6BF9 13        1110        INX D
6BFA 13        1120        INX D
6BFB 23        1130        INX H
6BFC 70        1140        MOV M,B
6BFD 23        1150        INX H
6BFE 71        1160        MOV M,C
6BFF C1        1170        POP B
6C00 C5        1180        PUSH B
6C01 03        1190        INX B
6C02 03        1200        INX B
6C03 03        1210        INX B
6C04 23        1220        INX H
6C05 70        1230        MOV M,B
6C06 23        1240        INX H
6C07 71        1250        MOV M,C
6C08 23        1260        INX H
6C09 23        1270        INX H
6C0A 22 0D 69  1280        SHLD BB
6C0D C9        1290        RET
6C0E EB        1300 LODA   XCHG
6C0F 5E        1310        MOV E,M
6C10 2B        1320        DCX H
6C11 56        1330        MOV D,M
6C12 36 00     1340        MVI M,0
6C14 1A        1350        LDAX D
6C15 23        1360        INX H
6C16 77        1370        MOV M,A
6C17 EB        1380        XCHG
6C18 C9        1390        RET
6C19 1A        1400 STOA   LDAX D
6C1A 1B        1410        DCX D
6C1B 1B        1420        DCX D
6C1C CD 68 69  1430        CALL POP1
6C1F 77        1440        MOV M,A
6C20 C9        1450        RET
6C21 CD 68 69  1460 CALA   CALL POP1
6C24 E9        1470        PCHL
6C25 2A 0D 69  1480 P00    LHLD BB
6C28 11 FB FF  1490        LXI D,-5
6C2B 19        1500        DAD D
6C2C 56        1510        MOV D,M
6C2D 23        1520        INX H
6C2E 5E        1530        MOV E,M
6C2F EB        1540        XCHG
6C30 22 0D 69  1550        SHLD BB
6C33 EB        1560        XCHG
6C34 23        1570        INX H
6C35 56        1580        MOV D,M
6C36 23        1590        INX H
6C37 5E        1600        MOV E,M
6C38 01 FA FF  1610        LXI B,-6
6C3B 09        1620        DAD B
6C3C EB        1630        XCHG
6C3D E9        1640        PCHL
6C3E CD 82 69  1650 SUB1   CALL NEGB
6C41 78        1660 ADD16  MOV A,B
6C42 AC        1670 SU2    XRA H
6C43 09        1680        DAD B
6C44 4F        1690        MOV C,A
6C45 1F        1700        RAR
6C46 A9        1710        XRA C
6C47 AC        1720        XRA H
```

```
6C48 F2 62 69    1730  JP PUSH
6C4B C3 79 69    1740  JMP OVFL
6C4E CD 58 69    1750 P02 CALL POP
6C51 C3 41 6C    1760  JMP ADD16
6C54 CD 58 69    1770 P03 CALL POP
6C57 78          1780 SUB16 MOV A,B
6C58 D6 50       1790  SUI 80
6C5A B1          1800  ORA C
6C5B C2 3E 6C    1810  JNZ SUB1
6C5E 79          1820  MOV A,C
6C5F C3 42 6C    1830  JMP SU2
6C62 EB          1840 P01 XCHG
6C63 AF          1850  XRA A
6C64 96          1860  SUB M
6C65 77          1870  MOV M,A
6C66 4F          1880  MOV C,A
6C67 2B          1890  DCX H
6C68 9E          1900  SBB M
6C69 91          1910  SUB C
6C6A 77          1920  MOV M,A
6C6B 23          1930  INX H
6C6C EB          1940  XCHG
6C6D C9          1950  RET
6C6E 16 08       1960 MUL8 MVI D,8
6C70 29          1970  DAD H
6C71 07          1980  RLC
6C72 D2 76 6C    1990  JNC $+1
6C75 09          2000  DAD B
6C76 15          2010  DCR D
6C77 C2 70 6C    2020  JNZ MUL8+2
6C7A C9          2030  RET
6C7B CD 58 69    2040 P04 CALL POP
6C7E D5          2050  PUSH D
6C7F 7C          2060  MOV A,H
6C80 5D          2070  MOV E,L
6C81 21 00 00    2080  LXI H,0
6C84 B7          2090  ORA A
6C85 C4 6E 6C    2100  CNZ MUL8
6C88 7B          2110  MOV A,E
6C89 CD 6E 6C    2120  CALL MUL8
6C8C D1          2130  POP D
6C8D C3 62 69    2140  JMP PUSH
6C90 CD 58 69    2150 P05 CALL POP
6C93 D5          2160  PUSH D
6C94 CD B4 6A    2170  CALL DIV16
6C97 D1          2180  POP D
6C98 C3 62 69    2190  JMP PUSH
6C9B 1A          2200 P06 LDAX D
6C9C E6 01       2210  ANI 1
6C9E 12          2220  STAX D
6C9F AF          2230  XRA A
6CA0 1B          2240  DCX D
6CA1 12          2250  STAX D
6CA2 13          2260  INX D
6CA3 C9          2270  RET
6CA4 CD 58 69    2280 P07 CALL POP
6CA7 D5          2290  PUSH D
6CA8 CD B4 6A    2300  CALL DIV16
6CAB EB          2310  XCHG
6CAC D1          2320  POP D
6CAD C3 62 69    2330  JMP PUSH
6CB0 3E 01       2340 P08 MVI A,1
6CB2 F5          2350 EQUAL PUSH P
6CB3 CD 58 69    2360  CALL POP
6CB6 AF          2370  XRA A
6CB7 12          2380  STAX D
6CB8 13          2390  INX D
6CB9 7D          2400  MOV A,L
6CBA B9          2410  CMP C
6CBB C2 DF 6C    2420  JNZ FALSE
6CBE 7C          2430  MOV A,H
6CBF B8          2440  CMP B
6CC0 C2 DF 6C    2450  JNZ FALSE
6CC3 F1          2460 TRUE POP P
6CC4 12          2470  STAX D
6CC5 C9          2480  RET
6CC6 AF          2490 P09 XRA A
6CC7 C3 B2 6C    2500  JMP EQUAL
6CCA 06 00       2510 P11 MVI B,0
6CCC 48          2520  MOV C,B
6CCD C5          2530 LESS PUSH B
6CCE CD 58 69    2540  CALL POP
6CD1 AF          2550  XRA A
6CD2 12          2560  STAX D
6CD3 13          2570  INX D
6CD4 7C          2580  MOV A,H
6CD5 B8          2590  CMP B
6CD6 CA E4 6C    2600  JZ EQH
6CD9 1F          2610  RAR
6CDA AC          2620  XRA H
6CDB A8          2630  XRA B
6CDC FA C3 6C    2640  JM TRUE
6CDF F1          2650 FALSE POP P
6CE0 EE 01       2660  XRI 1
6CE2 12          2670  STAX D
6CE3 C9          2680  RET
6CE4 7D          2690 EQH MOV A,L
6CE5 B9          2700  CMP C
6CE6 DA C3 6C    2710  JC TRUE
6CE9 C1          2720  POP B
6CEA 78          2730  MOV A,B
6CEB C2 EF 6C    2740  JNZ $+1
6CEE A9          2750  XRA C
6CEF EE 01       2760  XRI 1
6CF1 12          2770  STAX D
6CF2 C9          2780  RET
6CF3 01 00 01    2790 P10 LXI B,100H
6CF6 C3 CD 6C    2800  JMP LESS
6CF9 01 01 00    2810 P12 LXI B,1
6CFC C3 CD 6C    2820  JMP LESS
6CFF 06 01       2830 P13 MVI B,1
6D01 C3 CC 6C    2840  JMP LESS-1
6D04 CD 58 69    2850 P14 CALL POP
6D07 7C          2860  MOV A,H
6D08 B0          2870  ORA B
6D09 12          2880  STAX D
6D0A 7D          2890  MOV A,L
6D0B B1          2900  ORA C
6D0C 13          2910  INX D
6D0D 12          2920  STAX D
6D0E C9          2930  RET
6D0F CD 58 69    2940 P15 CALL POP
6D12 7C          2950  MOV A,H
6D13 A0          2960  ANA B
6D14 12          2970  STAX D
6D15 7D          2980  MOV A,L
6D16 A1          2990  ANA C
6D17 13          3000  INX D
6D18 12          3010  STAX D
6D19 C9          3020  RET
6D1A 1A          3030 P16 LDAX D
6D1B 2F          3040  CMA
6D1C 12          3050  STAX D
6D1D 1B          3060  DCX D
6D1E 1A          3070  LDAX D
6D1F 2F          3080  CMA
6D20 12          3090  STAX D
6D21 13          3100  INX D
6D22 C9          3110  RET
6D23 CD 58 69    3120 P17 CALL POP
6D26 AF          3130  XRA A
6D27 81          3140  ADD C
6D28 CA 62 69    3150  JZ PUSH
6D2B FA 42 6D    3160  JM SR1
6D2E 29          3170 SL1 DAD H
6D2F 3D          3180  DCR A
6D30 C2 2E 6D    3190  JNZ SL1
6D33 C3 62 69    3200  JMP PUSH
6D36 CD 58 69    3210 P18 CALL POP
6D39 AF          3220  XRA A
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6D3A 91          3230  SUB C
6D3B CA 62 69    3240  JZ PUSH
6D3E F2 2E 6D    3250  JP SL1
6D41 4F          3260  MOV C,A
6D42 AF          3270 SR1 XRA A
6D43 B4          3280  ORA H
6D44 1F          3290  RAR
6D45 67          3300  MOV H,A
6D46 7D          3310  MOV A,L
6D47 1F          3320  RAR
6D48 6F          3330  MOV L,A
6D49 0C          3340  INR C
6D4A C2 42 6D    3350  JNZ SR1
6D4D C3 62 69    3360  JMP PUSH
6D50 1A          3370 P19 LDAX D
6D51 C6 01       3380  ADI 1
6D53 12          3390  STAX D
6D54 D0          3400  RNC
6D55 62          3410  MOV H,D
6D56 6B          3420  MOV L,E
6D57 2B          3430  DCX H
6D58 34          3440  INR M
6D59 C9          3450  RET
6D5A 1A          3460 P20 LDAX D
6D5B D6 01       3470  SUI 1
6D5D 12          3480  STAX D
6D5E D0          3490  RNC
6D5F 62          3500  MOV H,D
6D60 6B          3510  MOV L,E
6D61 2B          3520  DCX H
6D62 35          3530  DCR M
6D63 C9          3540  RET
6D64 62          3550 P21 MOV H,D
6D65 6B          3560  MOV L,E
6D66 13          3570  INX D
6D67 2B          3580  DCX H
6D68 7E          3590  MOV A,M
6D69 12          3600  STAX D
6D6A 13          3610  INX D
6D6B 23          3620  INX H
6D6C 7E          3630  MOV A,M
6D6D 12          3640  STAX D
6D6E C9          3650  RET
6D6F AF          3660 INIT XRA A
6D70 D3 04       3670  OUT 4
6D72 E5          3680  PUSH H
6D73 2A 7F 72    3690  LHLD POS1
6D76 22 0E 0C    3700  SHLD POS
6D79 E1          3710  POP H
6D7A 01 07 00    3720  LXI B,7
6D7D 09          3730  DAD B
6D7E 22 0D 69    3740  SHLD BB
6D81 2B          3750  DCX H
6D82 2B          3760  DCX H
6D83 EB          3770  XCHG
6D84 22 0B 69    3780  SHLD STK2
6D87 6B          3790  MOV L,E
6D88 62          3800  MOV H,D
6D89 01 46 69    3810  LXI B,EXIT
6D8C 71          3820  MOV M,C
6D8D 2B          3830  DCX H
6D8E 70          3840  MOV M,B
6D8F C9          3850  RET
6D90             3860 RUNEND EQU $-1
```

# Listing 3: P-Code to 8080 Translator Routines

```
6D90           * P-CODE TO 8080 TRANSLATOR
6D90           ORGA2 EQU 5A00H
6D90            ORG ORGA2
5A00 C3 F7 64  TRANS JMP ORGA2+0AF7H
5A03           O2 EQU 21
5A03           S1 EQU 500
5A03           S2 EQU 400
5A03           PCDEF EQU 2C00H
5A03           OBDEF EQU 1000H
5A03           STK1 EQU 0
5A03           STAK2 EQU RUN-1
5A03           TST DS S1+1
5BF8           DST DS S2+1
5D89           EA DS S2+2
5F1B           Y12 DS 30
5F39           Z12 DS 58
5F73           AST DS 2
5F75           BOST DS 2
5F77           X DS 2
5F79           X0 DS 2
5F7B           X1 DS 2
5F7D           PT DS 2
5F7F           P0 DS 2
5F81           P1 DS 2
5F83           C1 DS 1
5F84           C2 DS 1
5F85           F DS 1
5F86           R0 DS 1
5F87           V DS 1
5F88           ML DS 1
5F89           G DS 2
5F8B           I DS 2
5F8D           J DS 2
5F8F           K DS 2
5F91           K1 DS 2
5F93           L0 DS 2
5F95           L1 DS 2
5F97           N DS 2
5F99           U DS 2
5F9B           W DS 2
5F9D           W0 DS 2
5F9F 6C 02     YST DW LIT-RUN
5FA1 8D 02      DW LOD-RUN
5FA3 84 02      DW LOD1-RUN
5FA5 9A 02      DW LODX-RUN
5FA7 9B 02      DW LODX1-RUN
5FA9 0E 03      DW LODA-RUN
5FAB B5 02      DW STO-RUN
5FAD AC 02      DW STO1-RUN
5FAF C1 02      DW STOX-RUN
5FB1 C2 02      DW STOX1-RUN
5FB3 19 03      DW STOA-RUN
5FB5 E9 02      DW CAL-RUN
5FB7 DE 02      DW CAL1-RUN
5FB9 21 03      DW CALA-RUN
5FBB 73 02      DW INT-RUN
5FBD 25 03     ZST DW P00-RUN
5FBF 62 03      DW P01-RUN
5FC1 4E 03      DW P02-RUN
5FC3 54 03      DW P03-RUN
5FC5 7B 03      DW P04-RUN
5FC7 90 03      DW P05-RUN
5FC9 9B 03      DW P06-RUN
```

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5FCB A4 03        0640  DW P07-RUN
5FCD B0 03        0650  DW P08-RUN
5FCF C6 03        0660  DW P09-RUN
5FD1 F3 03        0670  DW P10-RUN
5FD3 CA 03        0680  DW P11-RUN
5FD5 F9 03        0690  DW P12-RUN
5FD7 FF 03        0700  DW P13-RUN
5FD9 04 04        0710  DW P14-RUN
5FDB 0F 04        0720  DW P15-RUN
5FDD 1A 04        0730  DW P16-RUN
5FDF 23 04        0740  DW P17-RUN
5FE1 36 04        0750  DW P18-RUN
5FE3 50 04        0760  DW P19-RUN
5FE5 5A 04        0770  DW P20-RUN
5FE7 64 04        0780  DW P21-RUN
5FE9 F7 01        0790  DW SYS0-RUN
5FEB 00 02        0800  DW SYS1-RUN
5FED 06 02        0810  DW SYS2-RUN
5FEF 10 02        0820  DW SYS3-RUN
5FF1 3C 02        0830  DW SYS4-RUN
5FF3 46 02        0840  DW SYS5-RUN
5FF5 52 02        0850  DW SYS8-RUN
5FF7 0C           0860 GOMSG DB 12
5FF8 2A 2A 2A 2A  0870  DB '***** P-CODE TO 8080 TRANSLATION *****'
601E 0D           0880  DB 13
601F 09           0890  DB 9
6020 41 44 44 52  0900  DB 'ADDRESS OF RUNTIME MODULE? '
603B 0D           0910  DB 13
603C 00 69        0920  DW RUN
603E 09           0930 PCMSG DB 9
603F 50 2D 43 4F  0940  DB 'P-CODE START ADDRESS? '
6055 0D           0950  DB 13
6056 00 2C        0960  DW PCDEF
6058 09           0970 DSTMSG DB 9
6059 4F 42 4A 45  0980  DB 'OBJECT-CODE START ADDRESS? '
6074 0D           0990  DB 13
6075 00 10        1000  DW OBDEF
6077 09           1010 STKMS1 DB 9
6078 53 54 41 43  1020  DB 'STACK START ADDRESS? '
608D 0D           1030  DB 13
608E 00 00        1040  DW STK1
6090 FF 68        1050  DW STAK2
6092 09           1060 STKMS2 DB 9
6093 53 54 41 43  1070  DB 'STACK END ADDRESS? '
60A6 0D           1080  DB 13
60A7 FF 68        1090  DW STAK2
60A9 20 52 45 46  1100 REFMSG DB ' REFERENCES'
60B4 0D           1110  DB 13
60B5 20 44 49 46  1120 LABMSG DB ' DIFFERENT LABELS'
60C6 0D           1130  DB 13
60C7 20 46 4F 52  1140 FWDMSG DB ' FORWARD REFERENCES'
60DA 0D           1150  DB 13
60DB 20 50 2D 43  1160 FINMSG DB ' P-CODES TRANSLATED (TOTAL '
60F6 0D           1170  DB 13
60F7 48 20 42 59  1180  DB 'H BYTES)'
60FF 0D           1190  DB 13
6100 48 20 42 59  1200  DB 'H BYTES OF OBJECT CODE PRODUCED - CODE E
NDS AT '
612F 0D           1210  DB 13
6130 7C           1220 HDCMP MOV A,H
6131 BA           1230  CMP D
6132 C0           1240  RNZ
6133 7D           1250  MOV A,L
6134 93           1260  SUB E
6135 C8           1270  RZ
6136 1F           1280  RAR
6137 B7           1290  ORA A
6138 17           1300  RAL
6139 F8           1310  RM
613A AF           1320  XRA A
613B 3C           1330  INR A
613C C9           1340  RET
613D CD AD 05     1350 ADDRIN CALL OSEQ
6140 E5           1360  PUSH H
6141 CD 50 6A     1370  CALL HEXIN
```

```
6144 E1          1380  POP H
6145 7B          1390  MOV A,E
6146 B2          1400  ORA D
6147 F5          1410  PUSH P
6148 C2 52 61    1420  JNZ $+7
614B 23          1430  INX H
614C 5E          1440  MOV E,M
614D 23          1450  INX H
614E 56          1460  MOV D,M
614F CD 0C 0A    1470  CALL DEOUT1
6152 CD F8 09    1480  CALL CRLF
6155 F1          1490  POP P
6156 EB          1500  XCHG
6157 C9          1510  RET
6158 2A 7D 5F    1520 FNG LHLD PT
615B 70          1530  MOV M,B
615C 23          1540  INX H
615D 71          1550  MOV M,C
615E 23          1560  INX H
615F 72          1570  MOV M,D
6160 23          1580  INX H
6161 22 7D 5F    1590  SHLD PT
6164 C9          1600  RET
6165 21 1B 5F    1610 FNQ LXI H,Y12
6168 3D          1620  DCR A
6169 87          1630  ADD A
616A 85          1640  ADD L
616B 6F          1650  MOV L,A
616C D2 70 61    1660  JNC $+1
616F 24          1670  INR H
6170 4E          1680  MOV C,M
6171 23          1690  INX H
6172 56          1700  MOV D,M
6173 C3 58 61    1710  JMP FNG
6176             1720 * LIT
6176 21 83 5F    1730 L800 LXI H,C1
6179 7E          1740  MOV A,M
617A 23          1750  INX H
617B B6          1760  ORA M
617C CA 8E 61    1770  JZ L830
617F 56          1780  MOV D,M
6180 2B          1790  DCX H
6181 4E          1800  MOV C,M
6182 06 01       1810  MVI B,1
6184 CD 58 61    1820  CALL FNG
6187 3E 01       1830  MVI A,1
6189 06 CD       1840  MVI B,205
618B C3 65 61    1850  JMP FNQ
618E 01 13 AF    1860 L830 LXI B,0AF13H
6191 16 12       1870  MVI D,18
6193 CD 58 61    1880  CALL FNG
6196 01 12 13    1890  LXI B,1312H
6199 16 00       1900  MVI D,0
619B CD 58 61    1910  CALL FNG
619E 2B          1920  DCX H
619F 22 7D 5F    1930  SHLD PT
61A2 C9          1940  RET
61A3             1950 * OPR
61A3 21 CD 00    1960 L850 LXI H,205
61A6 22 8D 5F    1970  SHLD J
61A9 3A 83 5F    1980  LDA C1
61AC FE 04       1990  CPI 4
61AE F2 0F 62    2000  JP L890
61B1 B7          2010  ORA A
61B2 CA 09 62    2020  JZ L885
61B5 2A 77 5F    2030  LHLD X
61B8 2B          2040  DCX H
61B9 2B          2050  DCX H
61BA 2B          2060  DCX H
61BB 2B          2070  DCX H
61BC 7E          2080  MOV A,M
61BD B7          2090  ORA A
61BE C2 0F 62    2100  JNZ L890
61C1 3A 83 5F    2110  LDA C1
61C4 FE 02       2120  CPI 2
61C6 F2 DD 61    2130  JP L870
61C9 2A 7D 5F    2140  LHLD PT
61CC 2B          2150  DCX H
61CD 2B          2160  DCX H
61CE 2B          2170  DCX H
61CF 2B          2180  DCX H
61D0 2B          2190  DCX H
61D1 7E          2200  MOV A,M
61D2 2F          2210  CMA
61D3 C6 01       2220  ADI 1
61D5 77          2230  MOV M,A
61D6 23          2240  INX H
61D7 7E          2250  MOV A,M
61D8 2F          2260  CMA
61D9 CE 00       2270  ACI 0
61DB 77          2280  MOV M,A
61DC C9          2290  RET
61DD 2A 77 5F    2300 L870 LHLD X
61E0 2B          2310  DCX H
61E1 7E          2320  MOV A,M
61E2 3D          2330  DCR A
61E3 F2 0F 62    2340  JP L890
61E6 2B          2350  DCX H
61E7 7E          2360  MOV A,M
61E8 FE 04       2370  CPI 4
61EA F2 0F 62    2380  JP L890
61ED 5F          2390  MOV E,A
61EE 2A 7D 5F    2400  LHLD PT
61F1 01 FA FF    2410  LXI B,-6
61F4 09          2420  DAD B
61F5 22 7D 5F    2430  SHLD PT
61F8 2A 8D 5F    2440  LHLD J
61FB 45          2450  MOV B,L
61FC 3A 83 5F    2460  LDA C1
61FF C6 21       2470  ADI 33
6201 CD 65 61    2480  CALL FNQ
6204 1D          2490  DCR E
6205 C2 FC 61    2500  JNZ $-12
6208 C9          2510  RET
6209 21 C3 00    2520 L885 LXI H,195
620C C3 12 62    2530  JMP $+3
620F 2A 8D 5F    2540 L890 LHLD J
6212 45          2550  MOV B,L
6213 3A 83 5F    2560  LDA C1
6216 C6 10       2570  ADI 16
6218 C3 65 61    2580  JMP FNQ
621B             2590 * LOD
621B 3E 02       2600 L900 MVI A,2
621D 32 85 5F    2610  STA F
6220 21 04 00    2620 L925 LXI H,4
6223 22 8D 5F    2630  SHLD J
6226 2A 77 5F    2640  LHLD X
6229 23          2650  INX H
622A 6E          2660  MOV L,M
622B 26 00       2670  MVI H,0
622D 22 93 5F    2680  SHLD L0
6230 7D          2690  MOV A,L
6231 3C          2700  INR A
6232 CA DF 62    2710  JZ L1040
6235 3A 85 5F    2720  LDA F
6238 FE 02       2730  CPI 2
623A C2 9D 62    2740  JNZ L930
623D 3A 86 5F    2750  LDA R0
6240 47          2760  MOV B,A
6241 3A 87 5F    2770  LDA V
6244 B0          2780  ORA B
6245 C2 9D 62    2790  JNZ L930
6248 2A 91 5F    2800  LHLD K1
624B 23          2810  INX H
624C EB          2820  XCHG
624D 2A 8F 5F    2830  LHLD K
6250 CD 30 61    2840  CALL HDCMP
6253 CA 59 62    2850  JZ $+3
6256 F2 9D 62    2860  JP L930
6259 2A 95 5F    2870  LHLD L1
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625C EB          2880  XCHG
625D 2A 93 5F    2890  LHLD L0
6260 CD 30 61    2900  CALL HDCMP
6263 C2 9D 62    2910  JNZ L930
6266 2A 77 5F    2920  LHLD X
6269 2B          2930  DCX H
626A 3A 84 5F    2940  LDA C2
626D BE          2950  CMP M
626E C2 9D 62    2960  JNZ L930
6271 2B          2970  DCX H
6272 3A 83 5F    2980  LDA C1
6275 BE          2990  CMP M
6276 C2 9D 62    3000  JNZ L930
6279 E5          3010  PUSH H
627A 2A 8F 5F    3020  LHLD K
627D 22 91 5F    3030  SHLD K1
6280 E1          3040  POP H
6281 2B          3050  DCX H
6282 2B          3060  DCX H
6283 7E          3070  MOV A,M
6284 FE 02       3080  CPI 2
6286 CA 96 62    3090  JZ L920
6289 01 13 13    3100  LXI B,1313H
628C 16 00       3110  MVI D,0
628E CD 58 61    3120  CALL FNG
6291 2B          3130  DCX H
6292 22 7D 5F    3140  SHLD PT
6295 C9          3150  RET
6296 06 CD       3160 L920 MVI B,205
6298 3E 25       3170  MVI A,37
629A C3 65 61    3180  JMP FNQ
629D 2A 83 5F    3190 L930 LHLD C1
62A0 29          3200  DAD H
62A1 06 01       3210  MVI B,1
62A3 4D          3220  MOV C,L
62A4 54          3230  MOV D,H
62A5 CD 58 61    3240  CALL FNG
62A8 21 02 00    3250  LXI H,2
62AB 22 8D 5F    3260  SHLD J
62AE 3A 87 5F    3270  LDA V
62B1 B7          3280  ORA A
62B2 2A 93 5F    3290  LHLD L0
62B5 7D          3300  MOV A,L
62B6 C2 C8 62    3310  JNZ L960
62B9 22 95 5F    3320  SHLD L1
62BC 21 00 00    3330  LXI H,0
62BF 22 8D 5F    3340  SHLD J
62C2 2A 8F 5F    3350  LHLD K
62C5 22 91 5F    3360  SHLD K1
62C8 B7          3370 L960 ORA A
62C9 CA DF 62    3380  JZ L1040
62CC 2A 8D 5F    3390  LHLD J
62CF 23          3400  INX H
62D0 22 8D 5F    3410  SHLD J
62D3 06 3E       3420  MVI B,62
62D5 4F          3430  MOV C,A
62D6 16 00       3440  MVI D,0
62D8 CD 58 61    3450  CALL FNG
62DB 2B          3460  DCX H
62DC 22 7D 5F    3470  SHLD PT
62DF 3A 85 5F    3480 L1040 LDA F
62E2 2A 8D 5F    3490  LHLD J
62E5 85          3500  ADD L
62E6 06 CD       3510  MVI B,205
62E8 C3 65 61    3520  JMP FNQ
62EB             0010 * STO
62EB 3E 07       0020 L1100 MVI A,7
62ED 32 85 5F    0030  STA F
62F0 C3 20 62    0040  JMP L925
62F3             0050 * CAL
62F3 2A 77 5F    0060 L1200 LHLD X
62F6 23          0070  INX H
62F7 7E          0080  MOV A,M
62F8 32 93 5F    0090  STA L0
62FB B7          0100  ORA A
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62FC C2 09 63    0110  JNZ L1225
62FF 06 CD       0120  MVI B,205
6301 3E 0C       0130  MVI A,12
6303 CD 65 61    0140  CALL FNQ
6306 C3 39 63    0150  JMP L1260
6309 3C          0160 L1225 INR A
630A C2 14 63    0170  JNZ L1230
630D 06 CD       0180  MVI B,205
630F 3E 0E       0190  MVI A,14
6311 C3 65 61    0200  JMP FNQ
6314 06 3E       0210 L1230 MVI B,62
6316 3A 93 5F    0220  LDA L0
6319 4F          0230  MOV C,A
631A 16 00       0240  MVI D,0
631C CD 58 61    0250  CALL FNG
631F 2B          0260  DCX H
6320 22 7D 5F    0270  SHLD PT
6323 06 CD       0280  MVI B,205
6325 3E 0D       0290  MVI A,13
6327 CD 65 61    0300  CALL FNQ
632A C3 39 63    0310  JMP L1260
632D             0320 * JMP
632D 2A 8F 5F    0330 L1250 LHLD K
6330 23          0340  INX H
6331 EB          0350  XCHG
6332 2A 83 5F    0360  LHLD C1
6335 CD 30 61    0370  CALL HDCMP
6338 C8          0380  RZ
6339 CD 49 63    0390 L1260 CALL S1300
633C 06 C3       0400  MVI B,195
633E 3A 8B 5F    0410  LDA I
6341 4F          0420  MOV C,A
6342 3A 8D 5F    0430  LDA J
6345 57          0440  MOV D,A
6346 C3 58 61    0450  JMP FNG
6349 2A 83 5F    0460 S1300 LHLD C1
634C 22 73 5F    0470  SHLD AST
634F 21 01 00    0480  LXI H,1
6352 22 8B 5F    0490  SHLD I
6355 2A 9D 5F    0500  LHLD W0
6358 22 8D 5F    0510  SHLD J
635B 2A 8B 5F    0520 L1320 LHLD I
635E EB          0530  XCHG
635F 2A 8D 5F    0540  LHLD J
6362 19          0550  DAD D
6363 AF          0560  XRA A
6364 B4          0570  ORA H
6365 1F          0580  RAR
6366 67          0590  MOV H,A
6367 7D          0600  MOV A,L
6368 1F          0610  RAR
6369 F6 01       0620  ORI 1
636B 6F          0630  MOV L,A
636C 22 97 5F    0640  SHLD N
636F 11 03 5A    0650  LXI D,TST
6372 19          0660  DAD D
6373 5E          0670  MOV E,M
6374 23          0680  INX H
6375 56          0690  MOV D,M
6376 2A 73 5F    0700  LHLD AST
6379 CD 30 61    0710  CALL HDCMP
637C CA A2 63    0720  JZ L1360
637F F2 8D 63    0730  JP $+11
6382 2A 97 5F    0740  LHLD N
6385 2B          0750  DCX H
6386 2B          0760  DCX H
6387 22 8D 5F    0770  SHLD J
638A C3 95 63    0780  JMP L1350
638D 2A 97 5F    0790  LHLD N
6390 23          0800  INX H
6391 23          0810  INX H
6392 22 8B 5F    0820  SHLD I
6395 2A 8B 5F    0830 L1350 LHLD I
6398 EB          0840  XCHG
6399 2A 8D 5F    0850  LHLD J
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639C CD 30 61    0860  CALL HDCMP
639F F2 5B 63    0870  JP L1320
63A2 2A 97 5F    0880 L1360 LHLD N
63A5 11 F8 5B    0890  LXI D,DST
63A8 19          0900  DAD D
63A9 5E          0910  MOV E,M
63AA 23          0920  INX H
63AB 56          0930  MOV D,M
63AC 21 20 20    0940  LXI H,2020H
63AF CD 30 61    0950  CALL HDCMP
63B2 C2 E0 63    0960  JNZ L1400
63B5 2A 89 5F    0970  LHLD G
63B8 23          0980  INX H
63B9 22 89 5F    0990  SHLD G
63BC 29          1000  DAD H
63BD 11 89 5D    1010  LXI D,EA
63C0 19          1020  DAD D
63C1 EB          1030  XCHG
63C2 2A 7D 5F    1040  LHLD PT
63C5 23          1050  INX H
63C6 EB          1060  XCHG
63C7 73          1070  MOV M,E
63C8 23          1080  INX H
63C9 72          1090  MOV M,D
63CA 2A 97 5F    1100  LHLD N
63CD 6C          1110  MOV L,H
63CE 26 00       1120  MVI H,0
63D0 22 8D 5F    1130  SHLD J
63D3 65          1140  MOV H,L
63D4 CD 6F 69    1150  CALL NEGH
63D7 EB          1160  XCHG
63D8 2A 97 5F    1170  LHLD N
63DB 19          1180  DAD D
63DC 22 8B 5F    1190  SHLD I
63DF C9          1200  RET
63E0 2A 97 5F    1210 L1400 LHLD N
63E3 11 F8 5B    1220  LXI D,DST
63E6 19          1230  DAD D
63E7 5E          1240  MOV E,M
63E8 23          1250  INX H
63E9 6E          1260  MOV L,M
63EA 26 00       1270  MVI H,0
63EC 22 8D 5F    1280  SHLD J
63EF 6B          1290  MOV L,E
63F0 22 8B 5F    1300  SHLD I
63F3 C9          1310  RET
63F4             1320 * INT
63F4 2A 83 5F    1330 L1500 LHLD C1
63F7 7D          1340  MOV A,L
63F8 B4          1350  ORA H
63F9 C8          1360  RZ
63FA 29          1370  DAD H
63FB 11 04 00    1380  LXI D,4
63FE CD 30 61    1390  CALL HDCMP
6401 CA 10 64    1400  JZ L1515
6404 FA 10 64    1410  JM L1515
6407 11 FA FF    1420  LXI D,-6
640A CD 30 61    1430  CALL HDCMP
640D DA 44 64    1440  JC L1530
6410 EB          1450 L1515 XCHG
6411 21 13 00    1460  LXI H,19
6414 22 8D 5F    1470  SHLD J
6417 EB          1480  XCHG
6418 7C          1490  MOV A,H
6419 B7          1500  ORA A
641A F2 28 64    1510  JP L1520
641D CD 6F 69    1520  CALL NEGH
6420 EB          1530  XCHG
6421 21 1B 00    1540  LXI H,27
6424 22 8D 5F    1550  SHLD J
6427 EB          1560  XCHG
6428 7D          1570 L1520 MOV A,L
6429 E6 FE       1580  ANI 0FEH
642B 6F          1590  MOV L,A
642C 7D          1600 L1521 MOV A,L
642D B4          1610  ORA H
642E C8          1620  RZ
642F E5          1630  PUSH H
6430 2A 8D 5F    1640  LHLD J
6433 45          1650  MOV B,L
6434 4D          1660  MOV C,L
6435 16 00       1670  MVI D,0
6437 CD 58 61    1680  CALL FNG
643A 2B          1690  DCX H
643B 22 7D 5F    1700  SHLD PT
643E E1          1710  POP H
643F 2B          1720  DCX H
6440 2B          1730  DCX H
6441 C3 2C 64    1740  JMP L1521
6444 4D          1750 L1530 MOV C,L
6445 54          1760  MOV D,H
6446 06 21       1770  MVI B,33
6448 CD 58 61    1780  CALL FNG
644B 06 CD       1790  MVI B,205
644D 3E 0F       1800  MVI A,15
644F C3 65 61    1810  JMP FNQ
6452             1820 * JPC
6452 2A 8F 5F    1830 L1550 LHLD K
6455 23          1840  INX H
6456 EB          1850  XCHG
6457 2A 83 5F    1860  LHLD C1
645A CD 30 61    1870  CALL HDCMP
645D C8          1880  RZ
645E 06 1A       1890  MVI B,26
6460 0E 1B       1900  MVI C,27
6462 51          1910  MOV D,C
6463 CD 58 61    1920  CALL FNG
6466 36 1F       1930  MVI M,31
6468 23          1940  INX H
6469 22 7D 5F    1950  SHLD PT
646C CD 49 63    1960  CALL S1300
646F 06 D2       1970  MVI B,210
6471 2A 77 5F    1980  LHLD X
6474 23          1990  INX H
6475 7E          2000  MOV A,M
6476 3D          2010  DCR A
6477 FA 7C 64    2020  JM $+2
647A 06 DA       2030  MVI B,218
647C 3A 8B 5F    2040  LDA I
647F 4F          2050  MOV C,A
6480 3A 8D 5F    2060  LDA J
6483 57          2070  MOV D,A
6484 C3 58 61    2080  JMP FNG
6487             2090 * CSP
6487 3A 83 5F    2100 L1600 LDA C1
648A C6 15       2110  ADI 02
648C 3C          2120  INR A
648D F5          2130  PUSH P
648E 3A 83 5F    2140  LDA C1
6491 FE 08       2150  CPI 8
6493 CA 9E 64    2160  JZ L1620
6496 F1          2170  POP P
6497 C6 10       2180  ADI 16
6499 06 CD       2190  MVI B,205
649B C3 65 61    2200  JMP FNQ
649E 2A 77 5F    2210 L1620 LHLD X
64A1 2B          2220  DCX H
64A2 2B          2230  DCX H
64A3 6E          2240  MOV L,M
64A4 26 00       2250  MVI H,0
64A6 22 8D 5F    2260  SHLD J
64A9 CD 6F 69    2270  CALL NEGH
64AC 29          2280  DAD H
64AD 5D          2290  MOV E,L
64AE 54          2300  MOV D,H
64AF 29          2310  DAD H
64B0 E5          2320  PUSH H
64B1 19          2330  DAD D
64B2 11 FA FF    2340  LXI D,-6
64B5 19          2350  DAD D
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64B6 EB           2360  XCHG
64B7 2A 7D 5F     2370  LHLD PT
64BA 19           2380  DAD D
64BB 22 7D 5F     2390  SHLD PT
64BE D1           2400  POP D
64BF 2A 77 5F     2410  LHLD X
64C2 19           2420  DAD D
64C3 2B           2430  DCX H
64C4 2B           2440  DCX H
64C5 22 7B 5F     2450  SHLD X1
64C8 06 0E        2460  MVI B,14
64CA 3A 8D 5F     2470  LDA J
64CD 4F           2480  MOV C,A
64CE 16 00        2490  MVI D,0
64D0 CD 58 61     2500  CALL FNG
64D3 2B           2510  DCX H
64D4 22 7D 5F     2520  SHLD PT
64D7 F1           2530  POP P
64D8 C6 0E        2540  ADI 14
64DA 06 CD        2550  MVI B,205
64DC CD 65 61     2560  CALL FNQ
64DF EB           2570  XCHG
64E0 3A 8D 5F     2580  LDA J
64E3 4F           2590  MOV C,A
64E4 2A 7B 5F     2600  LHLD X1
64E7 7E           2610 L1640 MOV A,M
64E8 12           2620  STAX D
64E9 13           2630  INX D
64EA 23           2640  INX H
64EB 23           2650  INX H
64EC 23           2660  INX H
64ED 23           2670  INX H
64EE 0D           2680  DCR C
64EF C2 E7 64     2690  JNZ L1640
64F2 EB           2700  XCHG
64F3 22 7D 5F     2710  SHLD PT
64F6 C9           2720  RET
64F7              2730 * MAIN PROGRAM
64F7 AF           2740 BEGIN XRA A
64F8 D3 04        2750  OUT 4
64FA 21 03 5A     2760  LXI H,TST
64FD 11 9C 05     2770  LXI D,YST-TST
6500 36 00        2780 ZERO MVI M,0
6502 23           2790  INX H
6503 1B           2800  DCX D
6504 7B           2810  MOV A,E
6505 B2           2820  ORA D
6506 C2 00 65     2830  JNZ ZERO
6509 21 F7 5F     2840  LXI H,GOMSG
650C CD AD 05     2850  CALL OSEQ
650F CD F8 09     2860  CALL CRLF
6512 23           2870  INX H
6513 CD 3D 61     2880  CALL ADDRIN
6516 22 75 5F     2890  SHLD BOST
6519 E5           2900  PUSH H
651A 11 1B 5F     2910  LXI D,Y12
651D 21 9F 5F     2920  LXI H,YST
6520 3E 2C        2930  MVI A,44
6522 4E           2940 SETL MOV C,M
6523 23           2950  INX H
6524 46           2960  MOV B,M
6525 23           2970  INX H
6526 E3           2980  XTHL
6527 E5           2990  PUSH H
6528 09           3000  DAD B
6529 EB           3010  XCHG
652A 73           3020  MOV M,E
652B 23           3030  INX H
652C 72           3040  MOV M,D
652D 23           3050  INX H
652E EB           3060  XCHG
652F E1           3070  POP H
6530 E3           3080  XTHL
6531 3D           3090  DCR A
6532 C2 22 65     3100  JNZ SETL
6535 E1           3110  POP H
6536 21 3E 60     3120  LXI H,PCMSG
6539 CD 3D 61     3130  CALL ADDRIN
653C 22 77 5F     3140  SHLD X
653F 22 79 5F     3150  SHLD X0
6542 21 58 60     3160  LXI H,DSTMSG
6545 CD 3D 61     3170  CALL ADDRIN
6548 22 7F 5F     3180  SHLD P0
654B 22 7D 5F     3190  SHLD PT
654E 01 D3 AF     3200  LXI B,0AFD3H
6551 16 04        3210  MVI D,4
6553 CD 58 61     3220  CALL FNG
6556 01 00 31     3230  LXI B,3100H
6559 16 10        3240  MVI D,10H
655B CD 58 61     3250  CALL FNG
655E 21 77 60     3260  LXI H,STKMS1
6561 CD 3D 61     3270  CALL ADDRIN
6564 E5           3280  PUSH H
6565 C2 71 65     3290  JNZ $+9
6568 EB           3300  XCHG
6569 23           3310  INX H
656A 5E           3320  MOV E,M
656B 23           3330  INX H
656C 56           3340  MOV D,M
656D EB           3350  XCHG
656E C3 77 65     3360  JMP $+6
6571 21 92 60     3370  LXI H,STKMS2
6574 CD 3D 61     3380  CALL ADDRIN
6577 CD F8 09     3390  CALL CRLF
657A CD 6F 69     3400  CALL NEGH
657D 06 11        3410  MVI B,17
657F 4D           3420  MOV C,L
6580 54           3430  MOV D,H
6581 2A 7D 5F     3440  LHLD PT
6584 23           3450  INX H
6585 23           3460  INX H
6586 23           3470  INX H
6587 22 7D 5F     3480  SHLD PT
658A CD 58 61     3490  CALL FNG
658D 2A 75 5F     3500  LHLD BOST
6590 06 CD        3510  MVI B,205
6592 4D           3520  MOV C,L
6593 54           3530  MOV D,H
6594 CD 58 61     3540  CALL FNG
6597 E1           3550  POP H
6598 22 75 5F     3560  SHLD BOST
659B              0010 * FIRST PASS
659B 21 01 00     0020 L400 LXI H,1
659E 22 9B 5F     0030  SHLD W
65A1 2A 77 5F     0040  LHLD X
65A4 7E           0050 L420 MOV A,M
65A5 3C           0060  INR A
65A6 CA D6 65     0070  JZ L470
65A9 23           0080  INX H
65AA 23           0090  INX H
65AB 23           0100  INX H
65AC 23           0110  INX H
65AD 3D           0120  DCR A
65AE FE 04        0130  CPI 4
65B0 DA A4 65     0140  JC L420
65B3 FE 05        0150  CPI 5
65B5 CA A4 65     0160  JZ L420
65B8 FE 08        0170  CPI 8
65BA D2 A4 65     0180  JNC L420
65BD E5           0190  PUSH H
65BE 2B           0200  DCX H
65BF 46           0210  MOV B,M
65C0 2B           0220  DCX H
65C1 4E           0230  MOV C,M
65C2 2A 9B 5F     0240  LHLD W
65C5 23           0250  INX H
65C6 23           0260  INX H
65C7 22 9B 5F     0270  SHLD W
65CA 11 03 5A     0280  LXI D,TST
65CD 19           0290  DAD D
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65CE 2B          0300  DCX H
65CF 70          0310  MOV M,B
65D0 2B          0320  DCX H
65D1 71          0330  MOV M,C
65D2 E1          0340  POP H
65D3 C3 A4 65    0350  JMP L420
65D6 22 77 5F    0360 L470 SHLD X
65D9 2A 9B 5F    0370  LHLD W
65DC 2B          0380  DCX H
65DD AF          0390  XRA A
65DE B4          0400  ORA H
65DF 1F          0410  RAR
65E0 54          0420  MOV D,H
65E1 7D          0430  MOV A,L
65E2 1F          0440  RAR
65E3 5F          0450  MOV E,A
65E4 EB          0460  XCHG
65E5 CD 13 6B    0470  CALL SYS3+3
65E8 EB          0480  XCHG
65E9 2B          0490  DCX H
65EA 22 9B 5F    0500  SHLD W
65ED EB          0510  XCHG
65EE 21 A9 60    0520  LXI H,REFMSG
65F1 CD AD 05    0530  CALL OSEQ
65F4 CD F8 09    0540  CALL CRLF
65F7 EB          0550  XCHG
65F8 11 A0 00    0560  LXI D,160
65FB CD 30 61    0570  CALL HDCMP
65FE DA 5B 66    0580  JC L500
6601             0590 * PRE-COMPRESSION
6601 44          0600  MOV B,H
6602 4D          0610  MOV C,L
6603 21 05 00    0620  LXI H,5
6606 22 8D 5F    0630  SHLD J
6609 23          0640 L483 INX H
660A 23          0650  INX H
660B 22 8B 5F    0660  SHLD I
660E C5          0670  PUSH B
660F 0E 03       0680  MVI C,3
6611 2A 8D 5F    0690  LHLD J
6614 2B          0700  DCX H
6615 2B          0710  DCX H
6616 2B          0720  DCX H
6617 2B          0730  DCX H
6618 E5          0740 L486 PUSH H
6619 2A 8B 5F    0750  LHLD I
661C 11 03 5A    0760  LXI D,TST
661F 19          0770  DAD D
6620 7E          0780  MOV A,M
6621 23          0790  INX H
6622 66          0800  MOV H,M
6623 6F          0810  MOV L,A
6624 E3          0820  XTHL
6625 EB          0830  XCHG
6626 19          0840  DAD D
6627 7E          0850  MOV A,M
6628 23          0860  INX H
6629 66          0870  MOV H,M
662A 6F          0880  MOV L,A
662B EB          0890  XCHG
662C E3          0900  XTHL
662D CD 30 61    0910  CALL HDCMP
6630 CA 48 66    0920  JZ L489
6633 EB          0930  XCHG
6634 E1          0940  POP H
6635 23          0950  INX H
6636 23          0960  INX H
6637 0D          0970  DCR C
6638 C2 18 66    0980  JNZ L486
663B 22 8D 5F    0990  SHLD J
663E 01 03 5A    1000  LXI B,TST
6641 09          1010  DAD B
6642 73          1020  MOV M,E
6643 23          1030  INX H
6644 72          1040  MOV M,D
6645 C3 49 66    1050  JMP L490
6648 E1          1060 L489 POP H
6649 C1          1070 L490 POP B
664A 59          1080  MOV E,C
664B 50          1090  MOV D,B
664C 2A 8B 5F    1100  LHLD I
664F CD 30 61    1110  CALL HDCMP
6652 C2 09 66    1120  JNZ L483
6655 2A 8D 5F    1130  LHLD J
6658 22 9B 5F    1140  SHLD W
665B 2B          1150 L500 DCX H
665C 2B          1160  DCX H
665D 4D          1170  MOV C,L
665E 44          1180  MOV B,H
665F 21 01 00    1190  LXI H,1
6662 22 8B 5F    1200 L505 SHLD I
6665 59          1210  MOV E,C
6666 50          1220  MOV D,B
6667 CD 30 61    1230  CALL HDCMP
666A CA 70 66    1240  JZ $+3
666D F2 C1 66    1250  JP L600
6670 AF          1260  XRA A
6671 32 73 5F    1270  STA AST
6674 EB          1280  XCHG
6675 22 8D 5F    1290 L515 SHLD J
6678 EB          1300  XCHG
6679 2A 8B 5F    1310  LHLD I
667C CD 30 61    1320  CALL HDCMP
667F CA 85 66    1330  JZ $+3
6682 F2 B2 66    1340  JP L555
6685 21 03 5A    1350  LXI H,TST
6688 19          1360  DAD D
6689 5E          1370  MOV E,M
668A 23          1380  INX H
668B 56          1390  MOV D,M
668C 23          1400  INX H
668D 7E          1410  MOV A,M
668E 23          1420  INX H
668F E5          1430  PUSH H
6690 66          1440  MOV H,M
6691 6F          1450  MOV L,A
6692 EB          1460  XCHG
6693 CD 30 61    1470  CALL HDCMP
6696 DA A9 66    1480  JC L550
6699 EB          1490  XCHG
669A E3          1500  XTHL
669B 72          1510  MOV M,D
669C 2B          1520  DCX H
669D 73          1530  MOV M,E
669E D1          1540  POP D
669F 2B          1550  DCX H
66A0 72          1560  MOV M,D
66A1 2B          1570  DCX H
66A2 73          1580  MOV M,E
66A3 3E FF       1590  MVI A,-1
66A5 32 73 5F    1600  STA AST
66A8 E5          1610  PUSH H
66A9 E1          1620 L550 POP H
66AA 2A 8D 5F    1630  LHLD J
66AD 2B          1640  DCX H
66AE 2B          1650  DCX H
66AF C3 75 66    1660  JMP L515
66B2 3A 73 5F    1670 L555 LDA AST
66B5 B7          1680  ORA A
66B6 CA C1 66    1690  JZ L600
66B9 2A 8B 5F    1700  LHLD I
66BC 23          1710  INX H
66BD 23          1720  INX H
66BE C3 62 66    1730  JMP L505
66C1 21 01 00    1740 L600 LXI H,1
66C4 22 8D 5F    1750  SHLD J
66C7 21 03 00    1760  LXI H,3
66CA 22 8B 5F    1770 L605 SHLD I
66CD EB          1780  XCHG
66CE 2A 9B 5F    1790  LHLD W
```

```
66D1 CD 30 61   1800   CALL HDCMP
66D4 FA 0A 67   1810   JM L635
66D7 21 03 5A   1820   LXI H,TST
66DA 19         1830   DAD D
66DB 5E         1840   MOV E,M
66DC 23         1850   INX H
66DD 56         1860   MOV D,M
66DE 23         1870   INX H
66DF D5         1880   PUSH D
66E0 2A 8D 5F   1890   LHLD J
66E3 11 03 5A   1900   LXI D,TST
66E6 19         1910   DAD D
66E7 5E         1920   MOV E,M
66E8 23         1930   INX H
66E9 56         1940   MOV D,M
66EA E1         1950   POP H
66EB CD 30 61   1960   CALL HDCMP
66EE CA 02 67   1970   JZ L630
66F1 E5         1980   PUSH H
66F2 2A 8D 5F   1990   LHLD J
66F5 23         2000   INX H
66F6 23         2010   INX H
66F7 22 8D 5F   2020   SHLD J
66FA 11 03 5A   2030   LXI D,TST
66FD 19         2040   DAD D
66FE D1         2050   POP D
66FF 73         2060   MOV M,E
6700 23         2070   INX H
6701 72         2080   MOV M,D
6702 2A 8B 5F   2090 L630 LHLD I
6705 23         2100   INX H
6706 23         2110   INX H
6707 C3 CA 66   2120   JMP L605
670A 2A 8D 5F   2130 L635 LHLD J
670D 22 9D 5F   2140   SHLD W0
6710 23         2150   INX H
6711 23         2160   INX H
6712 36 FF      2170   MVI M,-1
6714 23         2180   INX H
6715 36 FF      2190   MVI M,-1
6717 2A 8D 5F   2200   LHLD J
671A 29         2210   DAD H
671B EB         2220   XCHG
671C 21 F9 5B   2230   LXI H,DST+1
671F 36 20      2240 L670 MVI M,'
6721 23         2250   INX H
6722 1B         2260   DCX D
6723 7B         2270   MOV A,E
6724 B2         2280   ORA D
6725 C2 1F 67   2290   JNZ L670
6728 2A 8D 5F   2300   LHLD J
672B 23         2310   INX H
672C AF         2320   XRA A
672D B4         2330   ORA H
672E 1F         2340   RAR
672F 67         2350   MOV H,A
6730 7D         2360   MOV A,L
6731 1F         2370   RAR
6732 6F         2380   MOV L,A
6733 CD 13 6B   2390   CALL SYS3+3
6736 21 B5 60   2400   LXI H,LABMSG
6739 CD AD 05   2410   CALL OSEQ
673C CD F8 09   2420   CALL CROUT
673F            2430 * PASS 1 ENDS
673F 2A 79 5F   2440   LHLD X0
6742 2B         2450   DCX H
6743 2B         2460   DCX H
6744 2B         2470   DCX H
6745 2B         2480   DCX H
6746 22 77 5F   2490   SHLD X
6749 21 FF FF   2500   LXI H,-1
674C 22 8F 5F   2510   SHLD K
674F 23         2520   INX H
6750 22 89 5F   2530   SHLD G
6753 22 91 5F   2540   SHLD K1
```

```
6756 22 95 5F   2550   SHLD L1
6759 23         2560   INX H
675A 22 9B 5F   2570   SHLD W
675D 21 03 5A   2580   LXI H,TST
6760 23         2590   INX H
6761 6E         2600   MOV L,M
6762 26 00      2610   MVI H,0
6764 22 99 5F   2620   SHLD U
6767 3E 14      2630   MVI A,20
6769 32 88 5F   2640   STA ML
676C 21 6C 67   2650 L710 LXI H,L710
676F E5         2660   PUSH H
6770 2A 77 5F   2670   LHLD X
6773 23         2680   INX H
6774 23         2690   INX H
6775 23         2700   INX H
6776 23         2710   INX H
6777 22 77 5F   2720   SHLD X
677A 2A 8F 5F   2730   LHLD K
677D 23         2740   INX H
677E 22 8F 5F   2750   SHLD K
6781 AF         2760   XRA A
6782 32 86 5F   2770   STA R0
6785 2A 7D 5F   2780   LHLD PT
6788 3A 88 5F   2790   LDA ML
678B 3C         2800   INR A
678C FE 14      2810   CPI 20
678E DA CF 67   2820   JC L715
6791 CD F8 09   2830   CALL CRLF
6794 EB         2840   XCHG
6795 2A 8F 5F   2850   LHLD K
6798 EB         2860   XCHG
6799 E5         2870   PUSH H
679A 21 E7 03   2880   LXI H,999
679D CD 30 61   2890   CALL HDCMP
67A0 DA BE 67   2900   JC CSYS
67A3 CD 02 0A   2910   CALL BLK1
67A6 21 63 00   2920   LXI H,99
67A9 CD 30 61   2930   CALL HDCMP
67AC DA BE 67   2940   JC CSYS
67AF CD 02 0A   2950   CALL BLK1
67B2 21 09 00   2960   LXI H,9
67B5 CD 30 61   2970   CALL HDCMP
67B8 DA BE 67   2980   JC CSYS
67BB CD 02 0A   2990   CALL BLK1
67BE E1         3000 CSYS POP H
67BF EB         3010   XCHG
67C0 CD 13 6B   3020   CALL SYS3+3
67C3 EB         3030   XCHG
67C4 CD 02 0A   3040   CALL BLK1
67C7 CD 02 0A   3050   CALL BLK1
67CA 7C         3060   MOV A,H
67CB CD 11 0A   3070   CALL BYTE1
67CE AF         3080   XRA A
67CF 32 88 5F   3090 L715 STA ML
67D2 7D         3100   MOV A,L
67D3 CD 11 0A   3110   CALL BYTE1
67D6 CD 02 0A   3120   CALL BLK1
67D9 2A 77 5F   3130   LHLD X
67DC 7E         3140   MOV A,M
67DD 32 85 5F   3150   STA F
67E0 23         3160   INX H
67E1 23         3170   INX H
67E2 7E         3180   MOV A,M
67E3 32 83 5F   3190   STA C1
67E6 23         3200   INX H
67E7 7E         3210   MOV A,M
67E8 32 84 5F   3220   STA C2
67EB 2A 99 5F   3230   LHLD U
67EE EB         3240   XCHG
67EF 2A 8F 5F   3250   LHLD K
67F2 CD 30 61   3260   CALL HDCMP
67F5 C2 20 68   3270   JNZ L765
67F8 2A 9B 5F   3280   LHLD W
67FB 23         3290   INX H
```

```
67FC 23          INX H
67FD 22 9B 5F    SHLD W
6800 11 F8 5B    LXI D,DST
6803 19          DAD D
6804 EB          XCHG
6805 2A 7D 5F    LHLD PT
6808 EB          XCHG
6809 2B          DCX H
680A 72          MOV M,D
680B 2B          DCX H
680C 73          MOV M,E
680D 3E 01       MVI A,1
680F 32 86 5F    STA R0
6812 2A 9B 5F    LHLD W
6815 11 03 5A    LXI D,TST
6818 19          DAD D
6819 5E          MOV E,M
681A 23          INX H
681B 56          MOV D,M
681C EB          XCHG
681D 22 99 5F    SHLD U
6820 AF         L765 XRA A
6821 32 87 5F    STA V
6824 3A 85 5F    LDA F
6827 FE 09       CPI 9
6829 DA 35 68    JC L780
682C D6 10       SUI 16
682E 32 85 5F    STA F
6831 21 87 5F    LXI H,V
6834 34          INR M
6835 B7         L780 ORA A
6836 CA 76 61    JZ L800
6839 3D          DCR A
683A CA A3 61    JZ L850
683D 3D          DCR A
683E CA 1B 62    JZ L900
6841 3D          DCR A
6842 CA EB 62    JZ L1100
6845 3D          DCR A
6846 CA F3 62    JZ L1200
6849 3D          DCR A
684A CA F4 63    JZ L1500
684D 3D          DCR A
684E CA 2D 63    JZ L1250
6851 3D          DCR A
6852 CA 52 64    JZ L1550
6855 3D          DCR A
6856 CA 87 64    JZ L1600
6859            * FORWARD REFERENCE CORRECTION
6859 E1         L1700 POP H
685A CD F8 09    CALL CRLF
685D 2A 89 5F    LHLD G
6860 5D          MOV E,L
6861 54          MOV D,H
6862 CD 13 6B    CALL SYS3+3
6865 21 C7 60    LXI H,FWDMSG
6868 CD AD 05    CALL OSEQ
686B CD F8 09    CALL CRLF
686E 2A 7D 5F    LHLD PT
6871 22 81 5F    SHLD P1
6874 21 89 5D    LXI H,EA
6877 E5          PUSH H
6878 19          DAD D
6879 19          DAD D
687A 23          INX H
687B 23          INX H
687C EB          XCHG
687D E1          POP H
687E 23         L1780 INX H
687F 23          INX H
6880 CD 30 61    CALL HDCMP
6883 D2 A1 68    JNC L1850
6886 E5          PUSH H
6887 D5          PUSH D
6888 5E          MOV E,M
```

```
6889 23          0280  INX H
688A 56          0290  MOV D,M
688B EB          0300  XCHG
688C E5          0310  PUSH H
688D 5E          0320  MOV E,M
688E 23          0330  INX H
688F 56          0340  MOV D,M
6890 EB          0350  XCHG
6891 11 F8 5B    0360  LXI D,DST
6894 19          0370  DAD D
6895 5E          0380  MOV E,M
6896 23          0390  INX H
6897 56          0400  MOV D,M
6898 E1          0410  POP H
6899 73          0420  MOV M,E
689A 23          0430  INX H
689B 72          0440  MOV M,D
689C D1          0450  POP D
689D E1          0460  POP H
689E C3 7E 68    0470  JMP L1780
68A1 2A 75 5F    0480 L1850 LHLD BOST
68A4 7C          0490  MOV A,H
68A5 B5          0500  ORA L
68A6 C2 AC 68    0510  JNZ $+3
68A9 2A 81 5F    0520  LHLD P1
68AC 4D          0530  MOV C,L
68AD 54          0540  MOV D,H
68AE 06 21       0550  MVI B,33
68B0 2A 7F 5F    0560  LHLD P0
68B3 23          0570  INX H
68B4 23          0580  INX H
68B5 23          0590  INX H
68B6 23          0600  INX H
68B7 23          0610  INX H
68B8 23          0620  INX H
68B9 22 7D 5F    0630  SHLD PT
68BC CD 58 61    0640  CALL FNG
68BF CD F8 09    0650  CALL CRLF
68C2 2A 8F 5F    0660  LHLD K
68C5 5D          0670  MOV E,L
68C6 54          0680  MOV D,H
68C7 CD 13 6B    0690  CALL SYS3+3
68CA 21 DB 60    0700  LXI H,FINMSG
68CD CD AD 05    0710  CALL OSEQ
68D0 23          0720  INX H
68D1 EB          0730  XCHG
68D2 29          0740  DAD H
68D3 29          0750  DAD H
68D4 EB          0760  XCHG
68D5 CD 0C 0A    0770  CALL DEOUT1
68D8 CD AD 05    0780  CALL OSEQ
68DB CD F8 09    0790  CALL CRLF
68DE 23          0800  INX H
68DF E5          0810  PUSH H
68E0 2A 7F 5F    0820  LHLD P0
68E3 CD 6F 69    0830  CALL NEGH
68E6 EB          0840  XCHG
68E7 2A 81 5F    0850  LHLD P1
68EA EB          0860  XCHG
68EB 19          0870  DAD D
68EC EB          0880  XCHG
68ED CD 0C 0A    0890  CALL DEOUT1
68F0 E3          0900  XTHL
68F1 CD AD 05    0910  CALL OSEQ
68F4 D1          0920  POP D
68F5 CD 0C 0A    0930  CALL DEOUT1
68F8 CD F8 09    0940  CALL CRLF
68FB C3 46 69    0950  JMP EXIT
68FE             0960 LSTBYT EQU $-1
```

*Symbol Table for listing 3.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ORGA | 6900 | RUN | 6900 | WHO | 0C20 | INP | 0C20 |
| WH1 | 0C24 | OUTP | 0C24 | CRLF | 09F8 | CROUT | 09F8 |
| OSEQ | 05AD | BYTE1 | 0A11 | DEOUT1 | 0A0C | BLK1 | 0A02 |
| CLEAR | 09FD | POS | 0C0E | POS1 | 727F | MENTR | 7390 |
| ABUF | 6903 | SFLG | 690A | SIGN | 690A | STK2 | 690B |
| BB | 690D | SM1 | 690F | SM2 | 6915 | MER1 | 691F |
| MER2 | 692C | DM1 | 6938 | EXIT | 6946 | PRINT | 6952 |
| POP | 6958 | PUSH | 6962 | POP1 | 6968 | NEGH | 696F |
| OVFL | 6979 | NEGB | 6982 | CMD | 698F | GETC | 6997 |
| READ | 699E | RLP | 69A3 | RUB | 69D4 | CAN | 69E3 |
| DIGIT | 69F2 | DECIN | 69F9 | DECIL | 6A17 | DECID | 6A31 |
| ER1 | 6A41 | ER2 | 6A47 | HEXIN | 6A50 | HEXIL | 6A6E |
| HEX16 | 6A82 | HEXID | 6A8F | HER1 | 6A9F | DVCK | 6AA8 |
| DIV16 | 6AB4 | D2 | 6ACB | D3 | 6AD3 | D4 | 6AE2 |
| D4A | 6AE7 | SYS0 | 6AF7 | SYS1 | 6B00 | SYS2 | 6B06 |
| SYS3 | 6B10 | Y3 | 6B23 | WR | 6B33 | SYS4 | 6B3C |
| SYS5 | 6B46 | SYS8 | 6B52 | BASE | 6B5D | BS1 | 6B5E |
| LIT | 6B6C | INT | 6B73 | STKOV | 6B7A | LOD1 | 6B84 |
| LOD | 6B8D | LODX | 6B9A | LODX1 | 6B9B | STO1 | 6BAC |
| STO | 6BB5 | STOX | 6BC1 | STOX1 | 6BC2 | CAL1 | 6BDE |
| CAL | 6BE9 | LODA | 6C0E | STOA | 6C19 | CALA | 6C21 |
| P00 | 6C25 | SUB1 | 6C3E | ADD16 | 6C41 | SU2 | 6C42 |
| P02 | 6C4E | P03 | 6C54 | SUB16 | 6C57 | P01 | 6C62 |
| MUL8 | 6C6E | P04 | 6C7B | P05 | 6C90 | P06 | 6C9B |
| P07 | 6CA4 | P08 | 6CB0 | EQUAL | 6CB2 | TRUE | 6CC3 |
| P09 | 6CC6 | P11 | 6CCA | LESS | 6CCD | FALSE | 6CDF |
| EQH | 6CE4 | P10 | 6CF3 | P12 | 6CF9 | P13 | 6CFF |
| P14 | 6D04 | P15 | 6D0F | P16 | 6D1A | P17 | 6D23 |
| SL1 | 6D2E | P18 | 6D36 | SR1 | 6D42 | P19 | 6D50 |
| P20 | 6D5A | P21 | 6D64 | INIT | 6D6F | RUNEND | 6DBF |
| ORGA2 | 5A00 | TRANS | 5A00 | 02 | 0015 | S1 | 01F4 |
| S2 | 0190 | PCDEF | 2C00 | OBDEF | 1000 | STK1 | 0000 |
| STAK2 | 68FF | TST | 5A03 | DST | 5BF8 | EA | 5D89 |
| Y12 | 5F1B | Z12 | 5F39 | AST | 5F73 | BOST | 5F75 |
| X | 5F77 | X0 | 5F79 | X1 | 5F7B | PT | 5F7D |
| P0 | 5F7F | P1 | 5F81 | C1 | 5F83 | C2 | 5F84 |
| F | 5F85 | R0 | 5F86 | V | 5F87 | ML | 5F88 |
| G | 5F89 | I | 5F8B | J | 5F8D | K | 5F8F |
| K1 | 5F91 | L0 | 5F93 | L1 | 5F95 | N | 5F97 |
| U | 5F99 | W | 5F9B | W0 | 5F9D | YST | 5F9F |
| ZST | 5FBD | GOMSG | 5FF7 | PCMSG | 603E | DSTMSG | 6058 |
| STKMS1 | 6077 | STKMS2 | 6092 | REFMSG | 60A9 | LABMSG | 60B5 |
| FWDMSG | 60C7 | FINMSG | 60DB | HDCMP | 6130 | ADDRIN | 613D |
| FNG | 6158 | FNQ | 6165 | L800 | 6176 | L830 | 618E |
| L850 | 61A3 | L870 | 61DD | L885 | 6209 | L890 | 620F |
| L900 | 621B | L925 | 6220 | L920 | 6296 | L930 | 629D |
| L960 | 62C8 | L1040 | 62DF | L1100 | 62EB | L1200 | 62F3 |
| L1225 | 6309 | L1230 | 6314 | L1250 | 632D | L1260 | 6339 |
| S1300 | 6349 | L1320 | 635B | L1350 | 6395 | L1360 | 63A2 |
| L1400 | 63E0 | L1500 | 63F4 | L1515 | 6410 | L1520 | 6428 |
| L1521 | 642C | L1530 | 6444 | L1550 | 6452 | L1600 | 6487 |
| L1620 | 649E | L1640 | 64E7 | BEGIN | 64F7 | ZERO | 6500 |
| SETL | 6522 | L400 | 659B | L420 | 65A4 | L470 | 65D6 |
| L483 | 6609 | L486 | 6618 | L489 | 6648 | L490 | 6649 |
| L500 | 665B | L505 | 6662 | L515 | 6675 | L550 | 66A9 |
| L555 | 66B2 | L600 | 66C1 | L605 | 66CA | L630 | 6702 |
| L635 | 670A | L670 | 671F | L710 | 676C | CSYS | 67BE |
| L715 | 67CF | L765 | 6820 | L780 | 6835 | L1700 | 6859 |
| L1780 | 687E | L1850 | 68A1 | LSTBYT | 68FD | | |

# Listing 4: P-Code Interpreter

```
5000                 *P-CODE INTERPRETER
5000                 * 1979-I-23
5000                 ORGA EQU 5000H
5000                  ORG ORGA
5000 C3 D1 5C        COLDST JMP ORGA+0CD1H
5003 C3 62 5E        WARMST JMP ORGA+0E62H
5006                 U EQU 13
5006                 WHO EQU 0C20H
5006                 WH1 EQU 0C24H
5006                 BLK1 EQU 0A02H
5006                 DEOUT1 EQU 0A0CH
5006                 OSEQ EQU 05ADH
5006                 BPLIM EQU 5
5006                 SIZE EQU 500
5006                 SIZE1 EQU 480
5006                 Z DS 2
5008                 IP DS 2
500A                 BASED DS 2
500C                 T DS 2
500E                 BP DS 2
5010                 FO DS 2
5012                 TP DS 2
5014                 CMND DS 2
5016                 I DS 2
5018                 J DS 2
501A                 K DS 2
501C                 STOP DS 2
501E                 N DS 2
5020                 S DS SIZE+SIZE+2
540A                 TRACE DS U+U+2
5426                 MN DS 54
545C                 BREAK DS BPLIM+BPLIM+2
5468                 BI DS 2
546A                 X DS 2
546C                 EA DS 2
546E                 EL DS 2
5470                 F DS 2
5472                 IDX DS 2
5474                 RES DS 2
5476                 SFLG DS 1
5477                 ABUF DS 7
547E 49 4C 4C 45     ILLOPC DB 'ILLEGAL OPCODE'
548C 0D               DB 0DH
548D 49 4C 4C 45     ILLOPR DB 'ILLEGAL OPERAND'
549C 0D               DB 0DH
549D 53 54 41 43     STOVFL DB 'STACK OVERFLOW'
54AB 0D               DB 0DH
54AC 49 4C 4C 45     ILLCSP DB 'ILLEGAL CSP'
54B7 0D               DB 0DH
54B8 20 42 52 45     BREAKM DB ' BREAK:'
54BF 0D               DB 0DH
54C0 53 54 41 52     ADDRM DB 'START ADDRESS? '
54CF 0D               DB 0DH
54D0 20 20 20 50 20  XMSG DB '   P ='
54D5 0D               DB 0DH
54D6 20 42 20 3D      DB ' B ='
54DA 0D               DB 0DH
54DB 20 54 20 3D      DB ' T ='
54DF 0D               DB 0DH
54E0 20 53 5B 54      DB ' S[T] ='
54E7 0D               DB 0DH
54E8 20 53 5B 54      DB ' S[T-1] ='
54F1 0D               DB 0DH
```

```
54F2 20 2A 20 54   0640 TRCMSG DB ' * TRACE *'
54FC 0D            0650  DB 0DH
54FD 45 4E 44 20   0660 FINMSG DB 'END OF EXECUTION'
550D 0D            0670  DB 0DH
550E 4C 49 54 4F   0680 MNEM DB 'LITOPRLODSTOCALINTJMPJPCCSP'
5529 2A 0C 50      0690 TM1 LHLD T
552C 2B            0700  DCX H
552D 22 0C 50      0710  SHLD T
5530 C9            0720  RET
5531 2A 0C 50      0730 STGET LHLD T
5534 EB            0740  XCHG
5535 21 20 50      0750  LXI H,S
5538 E5            0760 ARRAY PUSH H
5539 6B            0770  MOV L,E
553A 62            0780  MOV H,D
553B 19            0790  DAD D
553C EB            0800  XCHG
553D E1            0810  POP H
553E 19            0820  DAD D
553F 5E            0830  MOV E,M
5540 23            0840  INX H
5541 56            0850  MOV D,M
5542 2B            0860  DCX H
5543 C9            0870  RET
5544 7B            0880 CMD MOV A,E
5545 2F            0890  CMA
5546 C6 01         0900  ADI 1
5548 5F            0910  MOV E,A
5549 7A            0920  MOV A,D
554A 2F            0930  CMA
554B CE 00         0940  ACI 0
554D 57            0950  MOV D,A
554E C9            0960  RET
554F C5            0970 SHL PUSH B
5550 4F            0980  MOV C,A
5551 29            0990 SH1 DAD H
5552 0D            1000  DCR C
5553 C2 51 55      1010  JNZ SH1
5556 C1            1020  POP B
5557 C9            1030  RET
5558 78            1040 BHCMP MOV A,B
5559 BC            1050  CMP H
555A C0            1060  RNZ
555B 79            1070  MOV A,C
555C 95            1080  SUB L
555D C8            1090  RZ
555E 1F            1100  RAR
555F B7            1110  ORA A
5560 17            1120  RAL
5561 F8            1130  RM
5562 AF            1140  XRA A
5563 3C            1150  INR A
5564 C9            1160  RET
5565 CD 31 55      1170 COMP CALL STGET
5568 42            1180  MOV B,D
5569 4B            1190  MOV C,E
556A CD 29 55      1200  CALL TM1
556D CD 31 55      1210  CALL STGET
5570 EB            1220  XCHG
5571 CD 58 55      1230  CALL BHCMP
5574 EB            1240  XCHG
5575 11 00 00      1250  LXI D,0
5578 C9            1260  RET
5579 21 77 54      1270 READ LXI H,ABUF
557C 0E 00         1280  MVI C,0
557E CD 20 0C      1290 RLP CALL WH0
5581 FE 7F         1300  CPI 7FH
5583 CA AF 55      1310  JZ RUB
5586 FE 18         1320  CPI 18H
5588 CA BE 55      1330  JZ CAN
558B FE 0D         1340  CPI 0DH
558D CA 93 55      1350  JZ $+3
5590 CD 24 0C      1360  CALL WH1
5593 77            1370  MOV M,A
5594 23            1380  INX H
```

```
5595 0C          INR C
5596 FE 0D       CPI 0DH
5598 C8          RZ
5599 79          MOV A,C
559A FE 06       CPI 6
559C C2 7E 55    JNZ RLP
559F CD 20 0C    CALL WH0
55A2 FE 7F       CPI 7FH
55A4 CA AF 55    JZ RUB
55A7 FE 18       CPI 18H
55A9 CA BE 55    JZ CAN
55AC 36 0D       MVI M,0DH
55AE C9          RET
55AF 79         RUB MOV A,C
55B0 B7          ORA A
55B1 CA 7E 55    JZ RLP
55B4 3E 7F       MVI A,7FH
55B6 CD 24 0C    CALL WH1
55B9 0D          DCR C
55BA 2B          DCX H
55BB C3 7E 55    JMP RLP
55BE 79         CAN MOV A,C
55BF B7          ORA A
55C0 CA 7E 55    JZ RLP
55C3 3E 7F       MVI A,7FH
55C5 CD 24 0C    CALL WH1
55C8 2B          DCX H
55C9 0D          DCR C
55CA C3 BE 55    JMP CAN
55CD D6 30      DIGIT SUI 30H
55CF D8          RC
55D0 FE 0A       CPI 0AH
55D2 3F          CMC
55D3 C9          RET
55D4 AF         DECIN XRA A
55D5 32 76 54    STA SFLG
55D8 E5          PUSH H
55D9 C5          PUSH B
55DA 3E 23       MVI A,'#'
55DC CD 24 0C    CALL WH1
55DF CD 79 55    CALL READ
55E2 21 00 00    LXI H,0
55E5 01 77 54    LXI B,ABUF
55E8 0A          LDAX B
55E9 03          INX B
55EA FE 2D       CPI '-'
55EC C2 F4 55    JNZ DECIL+2
55EF 32 76 54    STA SFLG
55F2 0A         DECIL LDAX B
55F3 03          INX B
55F4 CD CD 55    CALL DIGIT
55F7 DA 09 56    JC DECID
55FA 5D          MOV E,L
55FB 54          MOV D,H
55FC 29          DAD H
55FD 29          DAD H
55FE 19          DAD D
55FF 29          DAD H
5600 85          ADD L
5601 6F          MOV L,A
5602 D2 F2 55    JNC DECIL
5605 24          INR H
5606 C3 F2 55    JMP DECIL
5609 EB         DECID XCHG
560A C1          POP B
560B E1          POP H
560C 3A 76 54    LDA SFLG
560F B7          ORA A
5610 C8          RZ
5611 C3 44 55    JMP CMD
5614 AF         HEXIN XRA A
5615 32 76 54    STA SFLG
5618 E5          PUSH H
5619 C5          PUSH B
561A 3E 25       MVI A,'%'
561C CD 24 0C    CALL WH1
561F CD 79 55    CALL READ
5622 21 00 00    LXI H,0
5625 01 77 54    LXI B,ABUF
5628 0A          LDAX B
5629 03          INX B
562A FE 2D       CPI '-'
562C C2 34 56    JNZ HEXIL+2
562F 32 76 54    STA SFLG
5632 0A         HEXIL LDAX B
5633 03          INX B
5634 CD CD 55    CALL DIGIT
5637 D2 46 56    JNC HEX16
563A D6 07       SUI 7
563C FE 0A       CPI 0AH
563E DA 53 56    JC HEXID
5641 FE 10       CPI 10H
5643 D2 53 56    JNC HEXID
5646 29         HEX16 DAD H
5647 29          DAD H
5648 29          DAD H
5649 29          DAD H
564A 85          ADD L
564B 6F          MOV L,A
564C D2 32 56    JNC HEXIL
564F 24          INR H
5650 C3 32 56    JMP HEXIL
5653 EB         HEXID XCHG
5654 C1          POP B
5655 E1          POP H
5656 3A 76 54    LDA SFLG
5659 B7          ORA A
565A C8          RZ
565B C3 44 55    JMP CMD
565E 06 00      DCALC MVI B,0
5660 19          DAD D
5661 04          INR B
5662 7C          MOV A,H
5663 B7          ORA A
5664 F2 60 56    JP $-7
5667 CD 44 55    CALL CMD
566A 19          DAD D
566B 05          DCR B
566C 78          MOV A,B
566D B9          CMP C
566E C8          RZ
566F 0D          DCR C
5670 C6 30       ADI 30H
5672 C9          RET
5673 7A         DECOUT MOV A,D
5674 B7          ORA A
5675 F2 80 56    JP CDEC
5678 3E 2D       MVI A,'-'
567A CD 24 0C    CALL WH1
567D CD 44 55    CALL CMD
5680 E5         CDEC PUSH H
5681 21 77 54    LXI H,ABUF
5684 E5          PUSH H
5685 EB          XCHG
5686 11 F0 D8    LXI D,-10000
5689 0E 00       MVI C,0
568B CD 5E 56    CALL DCALC
568E CA 95 56    JZ $+4
5691 E3          XTHL
5692 77          MOV M,A
5693 23          INX H
5694 E3          XTHL
5695 11 18 FC    LXI D,-1000
5698 CD 5E 56    CALL DCALC
569B CA A2 56    JZ $+4
569E E3          XTHL
569F 77          MOV M,A
56A0 23          INX H
56A1 E3          XTHL
56A2 11 9C FF    LXI D,-100
```

```
56A5 CD 5E 56     2890  CALL DCALC
56A8 CA AF 56     2900  JZ $+4
56AB E3           2910  XTHL
56AC 77           2920  MOV M,A
56AD 23           2930  INX H
56AE E3           2940  XTHL
56AF 11 F6 FF     2950  LXI D,-10
56B2 CD 5E 56     2960  CALL DCALC
56B5 CA BC 56     2970  JZ $+4
56B8 E3           2980  XTHL
56B9 77           2990  MOV M,A
56BA 23           3000  INX H
56BB E3           3010  XTHL
56BC 7D           3020  MOV A,L
56BD E1           3030  POP H
56BE C6 30        3040  ADI 30H
56C0 77           3050  MOV M,A
56C1 23           3060  INX H
56C2 36 0D        3070  MVI M,0DH
56C4 21 77 54     3080  LXI H,ABUF
56C7 CD AD 05     3090  CALL OSEQ
56CA E1           3100  POP H
56CB C9           3110  RET
56CC              3120 HEXOUT EQU DEOUT1

56CC 2A 0A 50     0010 BASE LHLD BASEB
56CF 22 68 54     0020  SHLD B1
56D2 7B           0030 BA1 MOV A,E
56D3 B2           0040  ORA D
56D4 CA EE 56     0050  JZ BA2
56D7 D5           0060  PUSH D
56D8 2A 68 54     0070  LHLD B1
56DB 2B           0080  DCX H
56DC 2B           0090  DCX H
56DD 2B           0100  DCX H
56DE EB           0110  XCHG
56DF 21 20 50     0120  LXI H,S
56E2 CD 38 55     0130  CALL ARRAY
56E5 EB           0140  XCHG
56E6 22 68 54     0150  SHLD B1
56E9 D1           0160  POP D
56EA 1B           0170  DCX D
56EB C3 D2 56     0180  JMP BA1
56EE 2A 68 54     0190 BA2 LHLD B1
56F1 EB           0200  XCHG
56F2 C9           0210  RET
56F3 21 00 00     0220 INIT LXI H,0
56F6 22 08 50     0230  SHLD IP
56F9 22 1C 50     0240  SHLD STOP
56FC 22 10 50     0250  SHLD P0
56FF 22 1A 50     0260  SHLD K
5702 22 22 50     0270  SHLD S+2
5705 22 24 50     0280  SHLD S+4
5708 2B           0290  DCX H
5709 22 26 50     0300  SHLD S+6
570C 21 03 00     0310  LXI H,3
570F 22 0C 50     0320  SHLD T
5712 2C           0330  INR L
5713 22 0A 50     0340  SHLD BASEB
5716 21 0D 00     0350  LXI H,U
5719 22 12 50     0360  SHLD TP
571C 29           0370  DAD H
571D EB           0380  XCHG
571E 21 0A 54     0390  LXI H,TRACE
5721 36 FF        0400 INI1 MVI M,-1
5723 23           0410  INX H
5724 1B           0420  DCX D
5725 7B           0430  MOV A,E
5726 B2           0440  ORA D
5727 C2 21 57     0450  JNZ INI1
572A C9           0460  RET
572B              0470 CRLF EQU 09F8H
572B              0480 *CODE FOR CASES OF EA IN CASF1
572B 2A 0A 50     0490 EA1C0 LHLD BASEB
572E 2B           0500  DCX H
```

```
572F 2B          DCX H
5730 2B          DCX H
5731 2B          DCX H
5732 22 0C 50    SHLD T
5735 23          INX H
5736 23          INX H
5737 EB          XCHG
5738 21 20 50    LXI H,S
573B CD 38 55    CALL ARRAY
573E EB          XCHG
573F 22 0A 50    SHLD BASEB
5742 13          INX D
5743 13          INX D
5744 1A          LDAX D
5745 32 08 50    STA IP
5748 13          INX D
5749 1A          LDAX D
574A 32 09 50    STA IP+1
574D C9          RET
574E CD 31 55   EA1C1 CALL STGET
5751 CD 44 55    CALL CMD
5754 73          MOV M,E
5755 23          INX H
5756 72          MOV M,D
5757 C9          RET
5758 CD 31 55   EA1C2 CALL STGET
575B 42          MOV B,D
575C 4B          MOV C,E
575D CD 29 55    CALL TM1
5760 CD 31 55    CALL STGET
5763 EB          XCHG
5764 09          DAD B
5765 EB          XCHG
5766 73          MOV M,E
5767 23          INX H
5768 72          MOV M,D
5769 C9          RET
576A CD 31 55   EA1C3 CALL STGET
576D CD 44 55    CALL CMD
5770 C3 5B 57    JMP EA1C2+3
5773 7A         SIGND MOV A,D
5774 E6 80       ANI 80H
5776 C8          RZ
5777 3A 76 54    LDA SFLG
577A 2F          CMA
577B 32 76 54    STA SFLG
577E C3 44 55    JMP CMD
5781 CD 31 55   EA1C4 CALL STGET
5784 AF          XRA A
5785 32 76 54    STA SFLG
5788 CD 73 57    CALL SIGND
578B 42          MOV B,D
578C 4B          MOV C,E
578D CD 29 55    CALL TM1
5790 CD 31 55    CALL STGET
5793 CD 73 57    CALL SIGND
5796 E5          PUSH H
5797 21 00 00    LXI H,0
579A 79          MOV A,C
579B CD AF 57    CALL X8BIT
579E 78          MOV A,B
579F CD AF 57    CALL X8BIT
57A2 EB         EA1C4D XCHG
57A3 3A 76 54    LDA SFLG
57A6 B7          ORA A
57A7 C4 44 55    CNZ CMD
57AA E1          POP H
57AB 73          MOV M,E
57AC 23          INX H
57AD 72          MOV M,D
57AE C9          RET
57AF 0E 08      X8BIT MVI C,8
57B1 1F         X8BL RAR
57B2 D2 B6 57    JNC $+1
57B5 19          DAD D
57B6 EB          XCHG
57B7 29          DAD H
57B8 EB          XCHG
57B9 0D          DCR C
57BA C2 B1 57    JNZ X8BL
57BD C9          RET
57BE CD 31 55   EA1C5 CALL STGET
57C1 7B          MOV A,E
57C2 B2          ORA D
57C3 C2 CC 57    JNZ NOTO
57C6 21 8D 54    LXI H,ILLOPR
57C9 C3 13 59    JMP ERR
57CC AF         NOTO XRA A
57CD 32 76 54    STA SFLG
57D0 CD 73 57    CALL SIGND
57D3 D5          PUSH D
57D4 CD 29 55    CALL TM1
57D7 CD 31 55    CALL STGET
57DA CD 73 57    CALL SIGND
57DD 42          MOV B,D
57DE 4B          MOV C,E
57DF D1          POP D
57E0 E5          PUSH H
57E1 21 00 00    LXI H,0
57E4 22 74 54    SHLD RES
57E7 EB         EA1C5L XCHG
57E8 CD 58 55    CALL BHCMP
57EB FA 28 58    JM EA1C5D
57EE 5D          MOV E,L
57EF 54          MOV D,H
57F0 E5          PUSH H
57F1 21 01 00    LXI H,1
57F4 E3          XTHL
57F5 CD 58 55   C5I CALL BHCMP
57F8 FA 02 58    JM C5ID
57FB 29          DAD H
57FC E3          XTHL
57FD 29          DAD H
57FE E3          XTHL
57FF C3 F5 57    JMP C5I
5802 37         C5ID STC
5803 3F          CMC
5804 7C          MOV A,H
5805 1F          RAR
5806 67          MOV H,A
5807 7D          MOV A,L
5808 1F          RAR
5809 6F          MOV L,A
580A EB          XCHG
580B CD 44 55    CALL CMD
580E EB          XCHG
580F 09          DAD B
5810 44          MOV B,H
5811 4D          MOV C,L
5812 E1          POP H
5813 EB          XCHG
5814 E5          PUSH H
5815 2A 74 54    LHLD RES
5818 37          STC
5819 3F          CMC
581A 7A          MOV A,D
581B 1F          RAR
581C 57          MOV D,A
581D 7B          MOV A,E
581E 1F          RAR
581F 5F          MOV E,A
5820 19          DAD D
5821 22 74 54    SHLD RES
5824 D1          POP D
5825 C3 E7 57    JMP EA1C5L
5828 E1         EA1C5D POP H
5829 E5          PUSH H
582A 23          INX H
582B 7E          MOV A,M
582C B7          ORA A
```

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582D 2A 74 54      2010  LHLD RES
5830 F2 A2 57      2020  JP EA1C4D
5833 59            2030  MOV E,C
5834 50            2040  MOV D,B
5835 CD 44 55      2050  CALL CMD
5838 42            2060  MOV B,D
5839 4B            2070  MOV C,E
583A C3 A2 57      2080  JMP EA1C4D
583D CD 31 55      2090 EA1C6 CALL STGET
5840 3E 01         2100  MVI A,1
5842 A3            2110  ANA E
5843 77            2120  MOV M,A
5844 23            2130  INX H
5845 36 00         2140  MVI M,0
5847 C9            2150  RET
5848 CD BE 57      2160 EA1C7 CALL EA1C5
584B 70            2170  MOV M,B
584C 2B            2180  DCX H
584D 71            2190  MOV M,C
584E C9            2200  RET
584F CD 65 55      2210 EA1C8 CALL COMP
5852 C2 56 58      2220  JNZ NO
5855 1C            2230 YES INR E
5856 73            2240 NO MOV M,E
5857 23            2250  INX H
5858 72            2260  MOV M,D
5859 C9            2270  RET
585A CD 65 55      2280 EA1C9 CALL COMP
585D CA 56 58      2290  JZ NO
5860 C3 55 58      2300  JMP YES
5863 CD 65 55      2310 EA1C10 CALL COMP
5866 CA 56 58      2320  JZ NO
5869 FA 56 58      2330  JM NO
586C C3 55 58      2340  JMP YES
586F CD 65 55      2350 EA1C11 CALL COMP
5872 CA 55 58      2360  JZ YES
5875 FA 55 58      2370  JM YES
5878 C3 56 58      2380  JMP NO
587B CD 65 55      2390 EA1C12 CALL COMP
587E FA 55 58      2400  JM YES
5881 C3 56 58      2410  JMP NO
5884 CD 65 55      2420 EA1C13 CALL COMP
5887 FA 56 58      2430  JM NO
588A C3 55 58      2440  JMP YES
588D CD 31 55      2450 EA1C14 CALL STGET
5890 42            2460  MOV B,D
5891 4B            2470  MOV C,E
5892 CD 29 55      2480  CALL TM1
5895 CD 31 55      2490  CALL STGET
5898 79            2500  MOV A,C
5899 B3            2510  ORA E
589A 77            2520  MOV M,A
589B 23            2530  INX H
589C 78            2540  MOV A,B
589D B2            2550  ORA D
589E 77            2560  MOV M,A
589F C9            2570  RET
58A0 CD 31 55      2580 EA1C15 CALL STGET
58A3 42            2590  MOV B,D
58A4 4B            2600  MOV C,E
58A5 CD 29 55      2610  CALL TM1
58A8 CD 31 55      2620  CALL STGET
58AB 79            2630  MOV A,C
58AC A3            2640  ANA E
58AD 77            2650  MOV M,A
58AE 23            2660  INX H
58AF 78            2670  MOV A,B
58B0 A2            2680  ANA D
58B1 77            2690  MOV M,A
58B2 C9            2700  RET
58B3 CD 31 55      2710 EA1C16 CALL STGET
58B6 7B            2720  MOV A,E
58B7 2F            2730  CMA
58B8 77            2740  MOV M,A
58B9 23            2750  INX H
```

```
58BA 7A          2760  MOV A,D
58BB 2F          2770  CMA
58BC 77          2780  MOV M,A
58BD C9          2790  RET
58BE CD 31 55    2800 EA1C17 CALL STGET
58C1 7B          2810  MOV A,E
58C2 E6 0F       2820  ANI 0FH
58C4 4F          2830  MOV C,A
58C5 CD 29 55    2840  CALL TM1
58C8 CD 31 55    2850  CALL STGET
58CB EB          2860  XCHG
58CC 79          2870  MOV A,C
58CD CD 4F 55    2880  CALL SHL
58D0 EB          2890  XCHG
58D1 73          2900  MOV M,E
58D2 23          2910  INX H
58D3 72          2920  MOV M,D
58D4 C9          2930  RET
58D5 CD 31 55    2940 EA1C18 CALL STGET
58D8 7B          2950  MOV A,E
58D9 E6 0F       2960  ANI 0FH
58DB 4F          2970  MOV C,A
58DC CD 29 55    2980  CALL TM1
58DF CD 31 55    2990  CALL STGET
58E2 79          3000 SHR MOV A,C
58E3 B7          3010  ORA A
58E4 CA F7 58    3020  JZ EA1C19+4
58E7 7A          3030  MOV A,D
58E8 37          3040  STC
58E9 3F          3050  CMC
58EA 1F          3060  RAR
58EB 57          3070  MOV D,A
58EC 7B          3080  MOV A,E
58ED 1F          3090  RAR
58EE 5F          3100  MOV E,A
58EF 0D          3110  DCR C
58F0 C3 E2 58    3120  JMP SHR
58F3 CD 31 55    3130 EA1C19 CALL STGET
58F6 13          3140  INX D
58F7 73          3150  MOV M,E
58F8 23          3160  INX H
58F9 72          3170  MOV M,D
58FA C9          3180  RET
58FB CD 31 55    3190 EA1C20 CALL STGET
58FE 1B          3200  DCX D
58FF 73          3210  MOV M,E
5900 23          3220  INX H
5901 72          3230  MOV M,D
5902 C9          3240  RET
5903 CD 31 55    3250 EA1C21 CALL STGET
5906 23          3260  INX H
5907 23          3270  INX H
5908 73          3280  MOV M,E
5909 23          3290  INX H
590A 72          3300  MOV M,D
590B 2A 0C 50    3310  LHLD T
590E 23          3320  INX H
590F 22 0C 50    3330  SHLD T
5912 C9          3340  RET
5913 CD AD 05    3350 ERR CALL OSEQ
5916 CD F8 09    3360  CALL CRLF
5919 21 01 00    3370  LXI H,1
591C 22 1C 50    3380  SHLD STOP
591F C9          3390  RET
5920             3400 *CODE FOR CASES OF EA IN CASF8
5920 2A 0C 50    3410 EA2C0 LHLD T
5923 23          3420  INX H
5924 22 0C 50    3430  SHLD T
5927 CD 31 55    3440  CALL STGET
592A CD 20 0C    3450  CALL WHO
592D 77          3460  MOV M,A
592E 23          3470  INX H
592F 36 00       3480  MVI M,0
5931 C9          3490  RET
5932 CD 31 55    3500 EA2C1 CALL STGET
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```
5935 7B         3510  MOV A,E
5936 CD 24 0C   3520  CALL WH1
5939 C3 29 55   3530  JMP TM1
593C 2A 0C 50   3540 EA2C2 LHLD T
593F 23         3550  INX H
5940 22 0C 50   3560  SHLD T
5943 CD 31 55   3570  CALL STGET
5946 CD D4 55   3580  CALL DECIN
5949 73         3590  MOV M,E
594A 23         3600  INX H
594B 72         3610  MOV M,D
594C C9         3620  RET
594D CD 31 55   3630 EA2C3 CALL STGET
5950 CD 73 56   3640  CALL DECOUT
5953 C3 29 55   3650  JMP TM1
5956 2A 0C 50   3660 EA2C4 LHLD T
5959 23         3670  INX H
595A 22 0C 50   3680  SHLD T
595D CD 31 55   3690  CALL STGET
5960 CD 14 56   3700  CALL HEXIN
5963 73         3710  MOV M,E
5964 23         3720  INX H
5965 72         3730  MOV M,D
5966 C9         3740  RET
5967 CD 31 55   3750 EA2C5 CALL STGET
596A CD 0C 0A   3760  CALL HEXOUT
596D C3 29 55   3770  JMP TM1
5970 CD 31 55   3780 EA2C8 CALL STGET
5973 2A 0C 50   3790  LHLD T
5976 CD 44 55   3800  CALL CMD
5979 19         3810  DAD D
597A 22 0C 50   3820  SHLD T
597D CD 44 55   3830  CALL CMD
5980 D5         3840  PUSH D
5981 CD 31 55   3850  CALL STGET
5984 D1         3860  POP D
5985 7E         3870 EA2C8L MOV A,M
5986 23         3880  INX H
5987 23         3890  INX H
5988 CD 24 0C   3900  CALL WH1
598B 1B         3910  DCX D
598C 7B         3920  MOV A,E
598D B2         3930  ORA D
598E C2 85 59   3940  JNZ EA2C8L
5991 C3 29 55   3950  JMP TM1

5994            0010 *CASES OF F IN EXEC
5994 2A 0C 50   0020 CASF0 LHLD T
5997 23         0030  INX H
5998 22 0C 50   0040  SHLD T
599B EB         0050  XCHG
599C 21 20 50   0060  LXI H,S
599F CD 38 55   0070  CALL ARRAY
59A2 EB         0080  XCHG
59A3 2A 6C 54   0090  LHLD EA
59A6 EB         0100  XCHG
59A7 73         0110  MOV M,E
59A8 23         0120  INX H
59A9 72         0130  MOV M,D
59AA C9         0140  RET
59AB 2A 6C 54   0150 CASF1 LHLD EA
59AE 7D         0160  MOV A,L
59AF B7         0170  ORA A
59B0 CA 2B 57   0180  JZ EA1C0
59B3 3D         0190  DCR A
59B4 CA 4E 57   0200  JZ EA1C1
59B7 3D         0210  DCR A
59B8 CA 58 57   0220  JZ EA1C2
59BB 3D         0230  DCR A
59BC CA 6A 57   0240  JZ EA1C3
59BF 3D         0250  DCR A
59C0 CA 81 57   0260  JZ EA1C4
59C3 3D         0270  DCR A
59C4 CA BE 57   0280  JZ EA1C5
59C7 3D         0290  DCR A
59C8 CA 3D 58   0300  JZ EA1C6
59CB 3D         0310  DCR A
59CC CA 48 58   0320  JZ EA1C7
59CF 3D         0330  DCR A
59D0 CA 4F 58   0340  JZ EA1C8
59D3 3D         0350  DCR A
59D4 CA 5A 58   0360  JZ EA1C9
59D7 3D         0370  DCR A
59D8 CA 63 58   0380  JZ EA1C10
59DB 3D         0390  DCR A
59DC CA 6F 58   0400  JZ EA1C11
59DF 3D         0410  DCR A
59E0 CA 7B 58   0420  JZ EA1C12
59E3 3D         0430  DCR A
59E4 CA 84 58   0440  JZ EA1C13
59E7 3D         0450  DCR A
59E8 CA 8D 58   0460  JZ EA1C14
59EB 3D         0470  DCR A
59EC CA A0 58   0480  JZ EA1C15
59EF 3D         0490  DCR A
59F0 CA B3 58   0500  JZ EA1C16
59F3 3D         0510  DCR A
59F4 CA BE 58   0520  JZ EA1C17
59F7 3D         0530  DCR A
59F8 CA D5 58   0540  JZ EA1C18
59FB 3D         0550  DCR A
59FC CA F3 58   0560  JZ EA1C19
59FF 3D         0570  DCR A
5A00 CA FB 58   0580  JZ EA1C20
5A03 3D         0590  DCR A
5A04 CA 03 59   0600  JZ EA1C21
5A07 21 8D 54   0610  LXI H,ILLOPR
5A0A C3 13 59   0620  JMP ERR
5A0D 2A 6A 54   0630 CASF2 LHLD X
5A10 23         0640  INX H
5A11 6E         0650  MOV L,M
5A12 26 00      0660  MVI H,0
5A14 22 6E 54   0670  SHLD EL
5A17 7D         0680  MOV A,L
5A18 3C         0690  INR A
5A19 CA 53 5A   0700  JZ F2FF
5A1C 2A 72 54   0710  LHLD IDX
5A1F 7D         0720  MOV A,L
5A20 B7         0730  ORA A
5A21 CA 31 5A   0740  JZ F20
5A24 CD 31 55   0750  CALL STGET
5A27 2A 6C 54   0760  LHLD EA
5A2A 19         0770  DAD D
5A2B 22 6C 54   0780  SHLD EA
5A2E C3 38 5A   0790  JMP F21
5A31 2A 0C 50   0800 F20 LHLD T
5A34 23         0810  INX H
5A35 22 0C 50   0820  SHLD T
5A38 2A 6E 54   0830 F21 LHLD EL
5A3B EB         0840  XCHG
5A3C CD CC 56   0850  CALL BASE
5A3F 2A 6C 54   0860  LHLD EA
5A42 19         0870  DAD D
5A43 EB         0880  XCHG
5A44 21 20 50   0890  LXI H,S
5A47 CD 38 55   0900  CALL ARRAY
5A4A D5         0910  PUSH D
5A4B CD 31 55   0920  CALL STGET
5A4E D1         0930  POP D
5A4F 73         0940  MOV M,E
5A50 23         0950  INX H
5A51 72         0960  MOV M,D
5A52 C9         0970  RET
5A53 CD 31 55   0980 F2FF CALL STGET
5A56 1A         0990  LDAX D
5A57 77         1000  MOV M,A
5A58 23         1010  INX H
5A59 36 00      1020  MVI M,0
5A5B C9         1030  RET
5A5C 2A 6A 54   1040 CASF3 LHLD X
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5A5F 23              INX H
5A60 6E              MOV L,M
5A61 26 00           MVI H,0
5A63 22 6E 54        SHLD EL
5A66 7D              MOV A,L
5A67 3C              INR A
5A68 CA A7 5A        JZ F3FF
5A6B 2A 72 54        LHLD IDX
5A6E 7D              MOV A,L
5A6F B7              ORA A
5A70 F5              PUSH P
5A71 CA 86 5A        JZ F30
5A74 2A 0C 50        LHLD T
5A77 2B              DCX H
5A78 EB              XCHG
5A79 21 20 50        LXI H,S
5A7C CD 38 55        CALL ARRAY
5A7F 2A 6C 54        LHLD EA
5A82 19              DAD D
5A83 22 6C 54        SHLD EA
5A86 CD 31 55     F30 CALL STGET
5A89 D5              PUSH D
5A8A 2A 6E 54        LHLD EL
5A8D EB              XCHG
5A8E CD CC 56        CALL BASE
5A91 2A 6C 54        LHLD EA
5A94 19              DAD D
5A95 EB              XCHG
5A96 21 20 50        LXI H,S
5A99 CD 38 55        CALL ARRAY
5A9C D1              POP D
5A9D 73              MOV M,E
5A9E 23              INX H
5A9F 72              MOV M,D
5AA0 F1              POP P
5AA1 C4 29 55        CNZ TM1
5AA4 C3 29 55        JMP TM1
5AA7 CD 31 55     F3FF CALL STGET
5AAA 4B              MOV C,E
5AAB CD 29 55        CALL TM1
5AAE CD 31 55        CALL STGET
5AB1 EB              XCHG
5AB2 71              MOV M,C
5AB3 C3 29 55        JMP TM1
5AB6 2A 6A 54     CASF4 LHLD X
5AB9 23              INX H
5ABA 6E              MOV L,M
5ABB 26 00           MVI H,0
5ABD 22 6E 54        SHLD EL
5AC0 7D              MOV A,L
5AC1 3C              INR A
5AC2 CA FF 5A        JZ F4FF
5AC5 EB              XCHG
5AC6 CD CC 56        CALL BASE
5AC9 D5              PUSH D
5ACA 2A 0C 50        LHLD T
5ACD 23              INX H
5ACE EB              XCHG
5ACF 21 20 50        LXI H,S
5AD2 CD 38 55        CALL ARRAY
5AD5 D1              POP D
5AD6 73              MOV M,E
5AD7 23              INX H
5AD8 72              MOV M,D
5AD9 23              INX H
5ADA EB              XCHG
5ADB 2A 0A 50        LHLD BASEB
5ADE EB              XCHG
5ADF 73              MOV M,E
5AE0 23              INX H
5AE1 72              MOV M,D
5AE2 23              INX H
5AE3 EB              XCHG
5AE4 2A 08 50        LHLD IP
5AE7 EB              XCHG
5AE8 73              MOV M,E
5AE9 23              INX H
5AEA 72              MOV M,D
5AEB 2A 0C 50        LHLD T
5AEE 23              INX H
5AEF 23              INX H
5AF0 23              INX H
5AF1 22 0C 50        SHLD T
5AF4 23              INX H
5AF5 22 0A 50        SHLD BASEB
5AF8 2A 6C 54        LHLD EA
5AFB 22 08 50        SHLD IP
5AFE C9              RET
5AFF CD 31 55     F4FF CALL STGET
5B02 21 29 55        LXI H,TM1
5B05 E5              PUSH H
5B06 EB              XCHG
5B07 E9              PCHL
5B08 2A 6C 54     CASF5 LHLD EA
5B0B EB              XCHG
5B0C CD 44 55        CALL CMD
5B0F 2A E0 01        LHLD SIZE1
5B12 19              DAD D
5B13 4D              MOV C,L
5B14 44              MOV B,H
5B15 2A 0C 50        LHLD T
5B18 CD 58 55        CALL BHCMP
5B1B FA 27 5B        JM OVER
5B1E EB              XCHG
5B1F 2A 6C 54        LHLD EA
5B22 19              DAD D
5B23 22 0C 50        SHLD T
5B26 C9              RET
5B27 21 9D 54     OVER LXI H,STOVFL
5B2A C3 13 59        JMP ERR
5B2D 2A 6C 54     CASF6 LHLD EA
5B30 22 08 50        SHLD IP
5B33 C9              RET
5B34 2A 6A 54     CASF7 LHLD X
5B37 23              INX H
5B38 4E              MOV C,M
5B39 CD 31 55        CALL STGET
5B3C 7B              MOV A,E
5B3D E6 01           ANI 1
5B3F B9              CMP C
5B40 C2 29 55        JNZ TM1
5B43 2A 6C 54        LHLD EA
5B46 22 08 50        SHLD IP
5B49 C3 29 55        JMP TM1
5B4C 2A 6C 54     CASF8 LHLD EA
5B4F 7D              MOV A,L
5B50 B7              ORA A
5B51 CA 20 59        JZ EA2C0
5B54 3D              DCR A
5B55 CA 32 59        JZ EA2C1
5B58 3D              DCR A
5B59 CA 3C 59        JZ EA2C2
5B5C 3D              DCR A
5B5D CA 4D 59        JZ EA2C3
5B60 3D              DCR A
5B61 CA 56 59        JZ EA2C4
5B64 3D              DCR A
5B65 CA 67 59        JZ EA2C5
5B68 D6 03           SUI 3
5B6A CA 70 59        JZ EA2C8
5B6D 21 AC 54        LXI H,ILLCSF
5B70 C3 13 59        JMP ERR
5B73 2A 08 50     EXEC LHLD IP
5B76 3E 02           MVI A,2
5B78 CD 4F 55        CALL SHL
5B7B EB              XCHG
5B7C 2A 06 50        LHLD Z
5B7F 19              DAD D
5B80 22 6A 54        SHLD X
5B83 23              INX H
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5B84 23          2550   INX H
5B85 7E          2560   MOV A,M
5B86 23          2570   INX H
5B87 66          2580   MOV H,M
5B88 6F          2590   MOV L,A
5B89 22 6C 54    2600   SHLD EA
5B8C 2A 12 50    2610   LHLD TP
5B8F 23          2620   INX H
5B90 3E 0D       2630   MVI A,U
5B92 BD          2640   CMP L
5B93 D2 99 5B    2650   JNC $+3
5B96 21 00 00    2660   LXI H,0
5B99 22 12 50    2670   SHLD TP
5B9C EB          2680   XCHG
5B9D 21 0A 54    2690   LXI H,TRACE
5BA0 CD 38 55    2700   CALL ARRAY
5BA3 EB          2710   XCHG
5BA4 2A 08 50    2720   LHLD IP
5BA7 EB          2730   XCHG
5BA8 73          2740   MOV M,E
5BA9 23          2750   INX H
5BAA 72          2760   MOV M,D
5BAB EB          2770   XCHG
5BAC 23          2780   INX H
5BAD 22 08 50    2790   SHLD IP
5BB0 22 10 50    2800   SHLD PO
5BB3 2A 1A 50    2810   LHLD K
5BB6 23          2820   INX H
5BB7 22 1A 50    2830   SHLD K
5BBA 2A 6A 54    2840   LHLD X
5BBD 6E          2850   MOV L,M
5BBE 26 00       2860   MVI H,0
5BC0 22 70 54    2870   SHLD F
5BC3 3E 08       2880   MVI A,8
5BC5 BD          2890   CMP L
5BC6 DA D1 5B    2900   JC FBIGR8
5BC9 2E 00       2910   MVI L,0
5BCB 22 72 54    2920   SHLD IDX
5BCE C3 E0 5B    2930   JMP CASF
5BD1 2E 01       2940 FBIGR8 MVI L,1
5BD3 22 72 54    2950   SHLD IDX
5BD6 2A 70 54    2960   LHLD F
5BD9 11 F0 FF    2970   LXI D,-16
5BDC 19          2980   DAD D
5BDD 22 70 54    2990   SHLD F
5BE0 2A 70 54    3000 CASF LHLD F
5BE3 7D          3010   MOV A,L
5BE4 B7          3020   ORA A
5BE5 CA 94 59    3030   JZ CASF0
5BE8 3D          3040   DCR A
5BE9 CA AB 59    3050   JZ CASF1
5BEC 3D          3060   DCR A
5BED CA 0D 5A    3070   JZ CASF2
5BF0 3D          3080   DCR A
5BF1 CA 5C 5A    3090   JZ CASF3
5BF4 3D          3100   DCR A
5BF5 CA B6 5A    3110   JZ CASF4
5BF8 3D          3120   DCR A
5BF9 CA 08 5B    3130   JZ CASF5
5BFC 3D          3140   DCR A
5BFD CA 2D 5B    3150   JZ CASF6
5C00 3D          3160   DCR A
5C01 CA 34 5B    3170   JZ CASF7
5C04 3D          3180   DCR A
5C05 CA 4C 5B    3190   JZ CASF8
5C08 21 7E 54    3200   LXI H,ILLOPC
5C0B C3 13 59    3210   JMP ERR

5C0E D5          0010 CODE PUSH D
5C0F EB          0020   XCHG
5C10 3E 02       0030   MVI A,2
5C12 CD 4F 55    0040   CALL SHL
5C15 EB          0050   XCHG
5C16 2A 06 50    0060   LHLD Z
5C19 19          0070   DAD D
5C1A 22 6A 54    0080   SHLD X
5C1D 7E          0090   MOV A,M
5C1E 6F          0100   MOV L,A
5C1F 26 00       0110   MVI H,0
5C21 29          0120   DAD H
5C22 85          0130   ADD L
5C23 6F          0140   MOV L,A
5C24 D2 28 5C    0150   JNC $+1
5C27 24          0160   INR H
5C28 22 1E 50    0170   SHLD N
5C2B 01 18 00    0180   LXI B,24
5C2E CD 58 55    0190   CALL BHCMP
5C31 3E 20       0200   MVI A,' '
5C33 F2 42 5C    0210   JP WRTCD
5C36 2A 1E 50    0220   LHLD N
5C39 01 D0 FF    0230   LXI B,-48
5C3C 09          0240   DAD B
5C3D 22 1E 50    0250   SHLD N
5C40 3E 58       0260   MVI A,'X'
5C42 F5          0270 WRTCD PUSH P
5C43 CD 02 0A    0280   CALL BLK1
5C46 CD 02 0A    0290   CALL BLK1
5C49 F1          0300   POP P
5C4A D1          0310   POP D
5C4B F5          0320   PUSH P
5C4C CD 73 56    0330   CALL DECOUT
5C4F CD 02 0A    0340   CALL BLK1
5C52 CD 02 0A    0350   CALL BLK1
5C55 2A 1E 50    0360   LHLD N
5C58 EB          0370   XCHG
5C59 21 0E 55    0380   LXI H,MNEM
5C5C 19          0390   DAD D
5C5D 7E          0400   MOV A,M
5C5E 23          0410   INX H
5C5F CD 24 0C    0420   CALL WH1
5C62 7E          0430   MOV A,M
5C63 23          0440   INX H
5C64 CD 24 0C    0450   CALL WH1
5C67 7E          0460   MOV A,M
5C68 CD 24 0C    0470   CALL WH1
5C6B F1          0480   POP P
5C6C CD 24 0C    0490   CALL WH1
5C6F CD 02 0A    0500   CALL BLK1
5C72 2A 6A 54    0510   LHLD X
5C75 23          0520   INX H
5C76 5E          0530   MOV E,M
5C77 16 00       0540   MVI D,0
5C79 CD 73 56    0550   CALL DECOUT
5C7C 3E 2C       0560   MVI A,','
5C7E CD 24 0C    0570   CALL WH1
5C81 23          0580   INX H
5C82 5E          0590   MOV E,M
5C83 23          0600   INX H
5C84 56          0610   MOV D,M
5C85 CD 73 56    0620   CALL DECOUT
5C88 C3 F8 09    0630   JMP CRLF
5C8B 2A 08 50    0640 CKBP LHLD IP
5C8E 7C          0650   MOV A,H
5C8F B7          0660   ORA A
5C90 FA CA 5C    0670   JM PLTO
5C93 EB          0680   XCHG
5C94 2A 0E 50    0690   LHLD BP
5C97 7C          0700   MOV A,H
5C98 B5          0710   ORA L
5C99 C8          0720   RZ
5C9A D5          0730   PUSH D
5C9B 01 01 00    0740   LXI B,1
5C9E 59          0750 CKBPL MOV E,C
5C9F 50          0760   MOV D,B
5CA0 21 5C 54    0770   LXI H,BREAK
5CA3 CD 38 55    0780   CALL ARRAY
5CA6 E1          0790   POP H
5CA7 E5          0800   PUSH H
5CA8 CD 44 55    0810   CALL CMD
5CAB 19          0820   DAD D
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5CAC 7C          0830  MOV A,H
5CAD B5          0840  ORA L
5CAE CA C0 5C    0850  JZ BFND
5CB1 03          0860  INX B
5CB2 2A 0E 50    0870  LHLD BP
5CB5 CD 58 55    0880  CALL BHCMP
5CB8 FA 9E 5C    0890  JM CKBPL
5CBB CA 9E 5C    0900  JZ CKBPL
5CBE E1          0910  POP H
5CBF C9          0920  RET
5CC0 21 B8 54    0930 BFND LXI H,BREAKM
5CC3 CD AD 05    0940  CALL OSEQ
5CC6 D1          0950  POP D
5CC7 CD 0E 5C    0960  CALL CODE
5CCA 21 01 00    0970 PLTO LXI H,1
5CCD 22 1C 50    0980  SHLD STOP
5CD0 C9          0990  RET
5CD1 31 00 10    1000 MAIN LXI P,1000H
5CD4 AF          1010  XRA A
5CD5 D3 04       1020  OUT 4
5CD7 21 26 54    1030  LXI H,MN
5CDA 11 0E 55    1040  LXI D,MNEM
5CDD 0E 1B       1050  MVI C,27
5CDF 1A          1060 MNLP LDAX D
5CE0 13          1070  INX D
5CE1 77          1080  MOV M,A
5CE2 23          1090  INX H
5CE3 36 00       1100  MVI M,0
5CE5 23          1110  INX H
5CE6 0D          1120  DCR C
5CE7 C2 DF 5C    1130  JNZ MNLP
5CEA 21 C0 54    1140  LXI H,ADDRM
5CED CD AD 05    1150  CALL OSEQ
5CF0 CD 14 56    1160  CALL HEXIN
5CF3 EB          1170  XCHG
5CF4 22 06 50    1180  SHLD Z
5CF7 CD F8 09    1190  CALL CRLF
5CFA CD F3 56    1200  CALL INIT
5CFD 2A 08 50    1210  LHLD IP
5D00 EB          1220  XCHG
5D01 CD 0E 5C    1230  CALL CODE
5D04 21 00 00    1240  LXI H,0
5D07 22 0E 50    1250  SHLD BP
5D0A C3 62 5E    1260  JMP BEGIN
5D0D 21 00 00    1270 CMR LXI H,0
5D10 22 1C 50    1280  SHLD STOP
5D13 CD 73 5B    1290 CMRL CALL EXEC
5D16 CD 8B 5C    1300  CALL CKBP
5D19 3A 1C 50    1310  LDA STOP
5D1C B7          1320  ORA A
5D1D CA 13 5D    1330  JZ CMRL
5D20 C9          1340  RET
5D21 CD 73 5B    1350 CMS CALL EXEC
5D24 2A 08 50    1360  LHLD IP
5D27 EB          1370  XCHG
5D28 CD 0E 5C    1380  CALL CODE
5D2B C9          1390  RET
5D2C 21 D0 54    1400 CMX LXI H,XMSG
5D2F CD AD 05    1410  CALL OSEQ
5D32 23          1420  INX H
5D33 EB          1430  XCHG
5D34 2A 08 50    1440  LHLD IP
5D37 EB          1450  XCHG
5D38 CD 73 56    1460  CALL DECOUT
5D3B CD AD 05    1470  CALL OSEQ
5D3E 23          1480  INX H
5D3F EB          1490  XCHG
5D40 2A 0A 50    1500  LHLD BASEB
5D43 EB          1510  XCHG
5D44 CD 73 56    1520  CALL DECOUT
5D47 CD AD 05    1530  CALL OSEQ
5D4A 23          1540  INX H
5D4B EB          1550  XCHG
5D4C 2A 0C 50    1560  LHLD T
5D4F EB          1570  XCHG
5D50 CD 73 56    1580  CALL DECOUT
5D53 CD AD 05    1590  CALL OSEQ
5D56 23          1600  INX H
5D57 E5          1610  PUSH H
5D58 CD 31 55    1620  CALL STGET
5D5B CD 73 56    1630  CALL DECOUT
5D5E E1          1640  POP H
5D5F CD AD 05    1650  CALL OSEQ
5D62 2A 0C 50    1660  LHLD T
5D65 2B          1670  DCX H
5D66 EB          1680  XCHG
5D67 21 20 50    1690  LXI H,S
5D6A CD 38 55    1700  CALL ARRAY
5D6D CD 73 56    1710  CALL DECOUT
5D70 C3 F8 09    1720  JMP CRLF
5D73 CD F3 56    1730 CMG CALL INIT
5D76 C3 13 5D    1740  JMP CMRL
5D79 21 F2 54    1750 CMT LXI H,TRCMSG
5D7C CD AD 05    1760  CALL OSEQ
5D7F CD F8 09    1770  CALL CRLF
5D82 0E 0E       1780  MVI C,U+1
5D84 2A 12 50    1790 CMTL LHLD TP
5D87 23          1800  INX H
5D88 3E 0D       1810  MVI A,U
5D8A BD          1820  CMP L
5D8B D2 91 5D    1830  JNC $+3
5D8E 21 00 00    1840  LXI H,0
5D91 22 12 50    1850  SHLD TP
5D94 EB          1860  XCHG
5D95 21 0A 54    1870  LXI H,TRACE
5D98 CD 38 55    1880  CALL ARRAY
5D9B 7A          1890  MOV A,D
5D9C B7          1900  ORA A
5D9D FA A5 5D    1910  JM $+5
5DA0 C5          1920  PUSH B
5DA1 CD 0E 5C    1930  CALL CODE
5DA4 C1          1940  POP B
5DA5 0D          1950  DCR C
5DA6 C2 84 5D    1960  JNZ CMTL
5DA9 C9          1970  RET
5DAA CD D4 55    1980 CMK CALL DECIN
5DAD 0E 07       1990  MVI C,7
5DAF C5          2000 CMKL PUSH B
5DB0 D5          2010  PUSH D
5DB1 21 20 50    2020  LXI H,S
5DB4 CD 38 55    2030  CALL ARRAY
5DB7 CD 02 0A    2040  CALL BLK1
5DBA CD 02 0A    2050  CALL BLK1
5DBD CD 73 56    2060  CALL DECOUT
5DC0 CD F8 09    2070  CALL CRLF
5DC3 D1          2080  POP D
5DC4 C1          2090  POP B
5DC5 13          2100  INX D
5DC6 0D          2110  DCR C
5DC7 C2 AF 5D    2120  JNZ CMKL
5DCA C9          2130  RET
5DCB 01 05 00    2140 CMB LXI B,BPLIM
5DCE 2A 0E 50    2150  LHLD BP
5DD1 CD 58 55    2160  CALL BHCMP
5DD4 C8          2170  RZ
5DD5 F8          2180  RM
5DD6 23          2190  INX H
5DD7 22 0E 50    2200  SHLD BP
5DDA EB          2210  XCHG
5DDB D5          2220  PUSH D
5DDC CD 73 56    2230  CALL DECOUT
5DDF 3E 3A       2240  MVI A,':'
5DE1 CD 24 0C    2250  CALL WH1
5DE4 CD 02 0A    2260  CALL BLK1
5DE7 D1          2270  POP D
5DE8 21 5C 54    2280  LXI H,BREAK
5DEB CD 38 55    2290  CALL ARRAY
5DEE CD D4 55    2300  CALL DECIN
5DF1 73          2310  MOV M,E
5DF2 23          2320  INX H
```

```
5DF3 72              MOV M,D
5DF4 C3 F8 09        JMP CRLF
5DF7 21 00 00     CMC LXI H,0
5DFA 22 0E 50        SHLD BP
5DFD C9              RET
5DFE 2A 0E 50     CMY LHLD BP
5E01 7D              MOV A,L
5E02 B4              ORA H
5E03 C8              RZ
5E04 4D              MOV C,L
5E05 21 5E 54        LXI H,BREAK+2
5E08 C5           CMYL PUSH B
5E09 5E              MOV E,M
5E0A 23              INX H
5E0B 56              MOV D,M
5E0C 23              INX H
5E0D CD 02 0A        CALL BLK1
5E10 CD 02 0A        CALL BLK1
5E13 CD 73 56        CALL DECOUT
5E16 CD F8 09        CALL CRLF
5E19 C1              POP B
5E1A 0D              DCR C
5E1B C2 08 5E        JNZ CMYL
5E1E C9              RET
5E1F CD D4 55     CME CALL DECIN
5E22 CD 0E 5C        CALL CODE
5E25 C9              RET
5E26 2A 10 50     CMU LHLD PO
5E29 2B              DCX H
5E2A 7C              MOV A,H
5E2B B5              ORA L
5E2C C8              RZ
5E2D F8              RM
5E2E 22 10 50        SHLD PO
5E31 EB              XCHG
5E32 CD 0E 5C        CALL CODE
5E35 C9              RET
5E36 2A 10 50     CMN LHLD PO
5E39 23              INX H
5E3A 22 10 50        SHLD PO
5E3D EB              XCHG
5E3E CD 0E 5C        CALL CODE
5E41 C9              RET
5E42 21 FF FF     CMQ LXI H,-1
5E45 22 08 50        SHLD IP
5E48 C9              RET
5E49 CD F8 09     FINISH CALL CRLF
5E4C 21 FD 54        LXI H,FINMSG
5E4F CD AD 05        CALL OSEQ
5E52 2A 1A 50        LHLD K
5E55 EB              XCHG
5E56 CD 73 56        CALL DECOUT
5E59 CD F8 09        CALL CRLF
5E5C CD 20 0C        CALL WHO
5E5F C3 90 73        JMP 7390H
5E62 31 00 10     BEGIN LXI P,1000H
5E65 AF              XRA A
5E66 D3 04           OUT 4
5E68 2A 08 50        LHLD IP
5E6B 7C              MOV A,H
5E6C B7              ORA A
5E6D FA 49 5E        JM FINISH
5E70 21 62 5E        LXI H,BEGIN
5E73 E5              PUSH H
5E74 3E 3E        PROMPT MVI A,'>'
5E76 CD 24 0C        CALL WH1
5E79 CD 20 0C        CALL WHO
5E7C CD 24 0C        CALL WH1
5E7F F5              PUSH P
5E80 CD F8 09        CALL CRLF
5E83 F1              POP P
5E84 32 14 50        STA CMND
5E87 D6 42           SUI 'B'
5E89 CA CB 5D        JZ CMB
5E8C 3D              DCR A
5E8D CA F7 5D        JZ CMC
5E90 D6 02           SUI 2
5E92 CA 1F 5E        JZ CME
5E95 D6 02           SUI 2
5E97 CA 73 5D        JZ CMG
5E9A D6 04           SUI 4
5E9C CA AA 5D        JZ CMK
5E9F D6 03           SUI 3
5EA1 CA 36 5E        JZ CMN
5EA4 D6 03           SUI 3
5EA6 CA 42 5E        JZ CMQ
5EA9 3D              DCR A
5EAA CA 0D 5D        JZ CMR
5EAD 3D              DCR A
5EAE CA 21 5D        JZ CMS
5EB1 3D              DCR A
5EB2 CA 79 5D        JZ CMT
5EB5 3D              DCR A
5EB6 CA 26 5E        JZ CMU
5EB9 D6 03           SUI 3
5EBB CA 2C 5D        JZ CMX
5EBE 3D              DCR A
5EBF CA FE 5D        JZ CMY
5EC2 3E 3F           MVI A,'?'
5EC4 CD 24 0C        CALL WH1
5EC7 CD 24 0C        CALL WH1
5ECA CD F8 09        CALL CRLF
5ECD C3 74 5E        JMP PROMPT
5ED0              LB EQU $-1
```

*Symbol Table for listing 4.*

| | |
|---|---|
| ORGA | 5000 |
| COLDST | 5000 |
| WARMST | 5003 |
| U | 000D |
| WH0 | 0C20 |
| WH1 | 0C24 |
| BLK1 | 0A02 |
| DEOUT1 | 0A0C |
| OSEQ | 05AD |
| BPLIM | 0005 |
| SIZE | 01F4 |
| SIZE1 | 01E0 |
| Z | 5006 |
| IP | 5008 |
| BASEB | 500A |
| T | 500C |
| BP | 500E |
| P0 | 5010 |
| TP | 5012 |
| CMND | 5014 |
| I | 5016 |
| J | 5018 |
| K | 501A |
| STOP | 501C |
| N | 501E |
| S | 5020 |
| TRACE | 540A |
| MN | 5426 |
| BREAK | 545C |
| B1 | 5468 |
| X | 546A |
| EA | 546C |
| EL | 546E |
| F | 5470 |
| IDX | 5472 |
| RES | 5474 |
| SFLG | 5476 |
| ABUF | 5477 |
| ILLOPC | 547E |
| ILLOPR | 548D |
| STOVFL | 549D |
| ILLCSP | 54AC |
| BREAKM | 54B8 |
| ADDRM | 54C0 |
| XMSG | 54D0 |
| TRCMSG | 54F2 |
| FINMSG | 54FD |
| MNEM | 550E |
| TM1 | 5529 |
| STGET | 5531 |
| ARRAY | 5538 |
| CMD | 5544 |
| SHL | 554F |
| SH1 | 5551 |
| BHCMP | 5558 |
| COMP | 5565 |
| READ | 5579 |
| RLP | 557E |
| RUB | 55AF |
| CAN | 55BE |
| DIGIT | 55CD |
| DECIN | 55D4 |
| DECIL | 55F2 |
| DECID | 5609 |
| HEXIN | 5614 |
| HEXIL | 5632 |
| HEX16 | 5646 |
| HEXID | 5653 |
| DCALC | 565E |
| DECOUT | 5673 |
| CDEC | 5680 |
| HEXOUT | 0A0C |
| BASE | 56CC |
| BA1 | 56D2 |
| BA2 | 56EE |
| INIT | 56F3 |
| INI1 | 5721 |
| CRLF | 09F8 |
| EA1C0 | 572B |
| EA1C1 | 574E |
| EA1C2 | 5758 |
| EA1C3 | 576A |
| SIGND | 5773 |
| EA1C4 | 5781 |
| EA1C4D | 57A2 |
| X8BIT | 57AF |
| X8BL | 57B1 |
| EA1C5 | 57BE |
| NOT0 | 57CC |
| EA1C5L | 57E7 |
| C5I | 57F5 |
| C5ID | 5802 |
| EA1C5D | 5828 |
| EA1C6 | 583D |
| EA1C7 | 5848 |
| EA1C8 | 584F |
| YES | 5855 |
| NO | 5856 |
| EA1C9 | 585A |
| EA1C10 | 5863 |
| EA1C11 | 586F |
| EA1C12 | 587B |
| EA1C13 | 5884 |
| EA1C14 | 588D |
| EA1C15 | 58A0 |
| EA1C16 | 58B3 |
| EA1C17 | 58BE |
| EA1C18 | 58D5 |
| SHR | 58E2 |
| EA1C19 | 58F3 |
| EA1C20 | 58FB |
| EA1C21 | 5903 |
| ERR | 5913 |
| EA2C0 | 5920 |
| EA2C1 | 5932 |
| EA2C2 | 593C |
| EA2C3 | 594D |
| EA2C4 | 5956 |
| EA2C5 | 5967 |
| EA2C8 | 5970 |
| EA2C8L | 5985 |
| CASF0 | 5994 |
| CASF1 | 59AB |
| CASF2 | 5A0D |
| F20 | 5A31 |
| F21 | 5A38 |
| F2FF | 5A53 |
| CASF3 | 5A5C |
| F30 | 5A86 |
| F3FF | 5AA7 |
| CASF4 | 5AB6 |
| F4FF | 5AFF |
| CASF5 | 5B08 |
| OVER | 5B27 |
| CASF6 | 5B2D |
| CASF7 | 5B34 |
| CASF8 | 5B4C |
| EXEC | 5B73 |
| FBIGR8 | 5BD1 |
| CASF | 5BE0 |
| CODE | 5C0E |
| WRTCD | 5C42 |
| CKBF | 5C8B |
| CKBFL | 5C9E |
| BFND | 5CC0 |
| PLT0 | 5CCA |
| MAIN | 5CD1 |
| MNLP | 5CDF |
| CMR | 5D0D |
| CMRL | 5D13 |
| CMS | 5D21 |
| CMX | 5D2C |
| CMG | 5D73 |
| CMT | 5D79 |
| CMTL | 5D84 |
| CMK | 5DAA |
| CMKL | 5DAF |
| CMB | 5DCB |
| CMC | 5DF7 |
| CMY | 5DFE |
| CMYL | 5E08 |
| CME | 5E1F |
| CMU | 5E26 |
| CMN | 5E36 |
| CMQ | 5E42 |
| FINISH | 5E49 |
| BEGIN | 5E62 |
| PROMPT | 5E74 |
| LB | 5ECF |

# Listing 5: Pascal to P-Code Interpreter

```
4F00                * PASCAL-TO-P-CODE COMPILER (FROM BASIC)
4F00                * 1978-XII-18
4F00                ORGA EQU 4F00H
4F00                 ORG ORGA
4F00 C3 E0 6C       START JMP ORGA+1DE0H (RUN)
4F03 C3 68 69       F3490 JMP ORGA+1A68H (S3490)
4F06 C3 E5 64       F4290 JMP ORGA+15E5H (L4290)
4F09 C3 48 6B       F5340 JMP ORGA+1C48H (S5340)
4F0C                PCODES EQU 2C00H
4F0C                MEMLIM EQU ORGA-1
4F0C                SRCFIL EQU 1000H
4F0C                N0 EQU 32
4F0C                T0 EQU 50
4F0C                N1 EQU 32767
4F0C                N2 EQU 8
4F0C                TST DS 400
509C                T0ST DS T0
50CE                LST DS 64
510E                AST DS N2+4
511A                BST DS N2
5122                S DS 200
51EA                SST DS 100
524E                CST DS 80
529E                OST DS 8
52A6                T1 DS T0+T0+2
530C                T2 DS T0+T0+2
5372                T3 DS T0+T0+2
53D8                XST DS 1
53D9                FNE1ST DS 5
53DE                YST DS 5
53E3                S0ST DS 5
53E8                KST DS 5
53ED                ZST DS 5
53F2                FPTR DS 2
53F4                BOFP DS 2
53F6                EOFP DS 2
53F8                P7 DS 2
53FA                P8 DS 2
53FC                P9 DS 2
53FE                Q9 DS 2
5400                S9 DS 2
5402                F5 DS 2
5404                Y9 DS 2
5406                Z DS 2
5408                C0 DS 2
540A                E9 DS 2
540C                L0 DS 2
540E                C1 DS 2
5410                K DS 2
5412                T DS 2
5414                I DS 2
5416                J DS 2
5418                N3 DS 2
541A                X DS 2
541C                I1 DS 2
541E                I2 DS 2
5420                L1 DS 2
5422                F9 DS 2
5424                L00 DS 2
5426                K1 DS 2
5428                K2 DS 2
542A                K3 DS 2
542C                D0 DS 2
```

```
542E                0640 N DS 2
5430                0650 NCHR DS 1
5431                0660 ADDS DS 2
5433 41 4E 44 20    0670 WOST DB 'AND  ARRAYBEGINCALL CASE CONSTDIV  D
O  '
545B 44 4F 57 4E    0680  DB 'DOWNTELSE END  FOR  FUNC IF   INTEGMEM
'
5483 4D 4F 44 20    0690  DB 'MOD  NOT  OF   OR   PROC READ REPEASHL
'
54AB 53 48 52 20    0700  DB 'SHR  THEN TO   TYPE UNTILVAR  WHILEWRITE
'
54D3 49 44 45 4E    0710 IDENT DB 'IDENT'
54D8 4E 55 4D 20    0720 NUM DB 'NUM  '
54DD 53 54 52 20    0730 STR DB 'STR  '
54E2 4C 49 54 4F    0740 MST DB 'LITOPRLODSTOCALINTJMPJPCCSP'
54FD 50 2D 43 4F    0750 L250 DB 'P-CODE STARTS AT 2C00H'
5513 0D             0760  DB 0DH
5514 57 41 4E 54    0770 L280 DB 'WANT CODE PRINTED? '
5527 0D             0780  DB 0DH
5528 46 49 4C 45    0790 L339 DB 'FILE ENDS AT '
5535 0D             0800  DB 0DH
5536 49 4E 54 45    0810 L340 DB 'INTERPRET(I), OR TRANSLATE(T)? '
5555 0D             0820  DB 0DH
5556 4C 44 47 4F    0830 L360 DB 'LDGO INTRP :0'
5563 4C 44 47 4F    0840 L370 DB 'LDGO TRANS :0'
5570 4D 45 4D 20    0850 L710 DB 'MEM FULL'
5578 0D             0860  DB 0DH
5579 43 4F 4E 53    0870 L720 DB 'CONST EXPECTED'
5587 0D             0880  DB 0DH
5588 22 3D 22 20    0890 L730 DB '"=" EXPECTED'
5594 0D             0900  DB 0DH
5595 49 44 45 4E    0910 L740 DB 'IDENTIFIER EXPECTED'
55A8 0D             0920  DB 0DH
55A9 22 3B 22 20    0930 L750 DB '";" OR ":" MISSING'
55BB 0D             0940  DB 0DH
55BC 22 2E 22 20    0950 L760 DB '"." EXPECTED'
55C8 0D             0960  DB 0DH
55C9 22 3B 22 20    0970 L770 DB '";" MISSING'
55D4 0D             0980  DB 0DH
55D5 55 4E 44 45    0990 L780 DB 'UNDECLARED IDENT'
55E5 0D             1000  DB 0DH
55E6 49 4C 4C 45    1010 L790 DB 'ILLEGAL IDENT'
55F3 0D             1020  DB 0DH
55F4 22 3A 3D 22    1030 L800 DB '":=" EXPECTED'
5601 0D             1040  DB 0DH
5602 22 54 48 45    1050 L810 DB '"THEN" EXPECTED'
5611 0D             1060  DB 0DH
5612 22 3B 22 20    1070 L820 DB '";" OR "END" EXPECTED'
5627 0D             1080  DB 0DH
5628 22 44 4F 22    1090 L830 DB '"DO" EXPECTED'
5635 0D             1100  DB 0DH
5636 49 4E 43 4F    1110 L840 DB 'INCORRECT SYMBOL'
5646 0D             1120  DB 0DH
5647 52 45 4C 41    1130 L850 DB 'RELATIONAL OPERATOR EXPECTED'
5663 0D             1140  DB 0DH
5664 55 53 45 20    1150 L860 DB 'USE OF PROC IDENT IN EXPR'
567D 0D             1160  DB 0DH
567E 22 29 22 20    1170 L870 DB '")" EXPECTED'
568A 0D             1180  DB 0DH
568B 49 4C 4C 45    1190 L880 DB 'ILLEGAL FACTOR'
5699 0D             1200  DB 0DH
569A 22 42 45 47    1210 L890 DB '"BEGIN" EXPECTED'
56AA 0D             1220  DB 0DH
56AB 22 4F 46 22    1230 L900 DB '"OF" EXPECTED'
56B8 0D             1240  DB 0DH
56B9 49 4C 4C 45    1250 L910 DB 'ILLEGAL HEX CONST'
56CA 0D             1260  DB 0DH
56CB 22 54 4F 22    1270 L920 DB '"TO" OR "DOWNTO" EXPECTED'
56E4 0D             1280  DB 0DH
56E5 4E 55 4D 42    1290 L930 DB 'NUMBER OUT OF RANGE'
56F8 0D             1300  DB 0DH
56F9 22 28 22 20    1310 L940 DB '"(" EXPECTED'
5705 0D             1320  DB 0DH
5706 22 5B 22 20    1330 L950 DB '"[" EXPECTED'
5712 0D             1340  DB 0DH
```

```
5713 22 5D 22 20    L960 DB '"]" EXPECTED'
571F 0D              DB 0DH
5720 50 41 52 41    L970 DB 'PARAMETERS MISMATCHED'
5735 0D              DB 0DH
5736 44 41 54 41    L980 DB 'DATA TYPE NOT RECOGNIZED'
574E 0D              DB 0DH
574F 42 55 47       L990 DB 'BUG'
5752 0D              DB 0DH
5753 41 44 44 52    L6570 DB 'ADDR AT'
575A 0D              DB 0DH
575B 43 48 41 4E     DB 'CHANGED TO'
5765 0D              DB 0DH
5766 70 55          ETAB DW L710
5768 79 55           DW L720
576A 88 55           DW L730
576C 95 55           DW L740
576E A9 55           DW L750
5770 4F 57           DW L990
5772 4F 57           DW L990
5774 4F 57           DW L990
5776 BC 55           DW L760
5778 C9 55           DW L770
577A D5 55           DW L780
577C E6 55           DW L790
577E F4 55           DW L800
5780 4F 57           DW L990
5782 4F 57           DW L990
5784 02 56           DW L810
5786 12 56           DW L820
5788 28 56           DW L830
578A 36 56           DW L840
578C 47 56           DW L850
578E 64 56           DW L860
5790 7E 56           DW L870
5792 8B 56           DW L880
5794 4F 57           DW L990
5796 9A 56           DW L890
5798 AB 56           DW L900
579A B9 56           DW L910
579C CB 56           DW L920
579E 4F 57           DW L990
57A0 E5 56           DW L930
57A2 F9 56           DW L940
57A4 4F 57           DW L990
57A6 06 57           DW L950
57A8 13 57           DW L960
57AA 20 57           DW L970
57AC 36 57           DW L980
57AE 20 20 20 20    L1300 DB
57BA                WH0 EQU 0C20H
57BA                WH1 EQU 0C24H
57BA                MOVE EQU 100H
57BA                OSEQ EQU 5ADH
57BA                CROUT EQU 09F8H
57BA                CRLF EQU CROUT
57BA                CLEAR EQU 09FDH
57BA                KBUF EQU 0C0CH
57BA                FLAG EQU 0
57BA                BLK1 EQU 0A02H
57BA                DEOUT EQU 0A0CH
57BA E5             ARRAY PUSH H
57BB 6B              MOV L,E
57BC 62              MOV H,D
57BD 19              DAD D
57BE EB              XCHG
57BF E1              POP H
57C0 19              DAD D
57C1 5E              MOV E,M
57C2 23              INX H
57C3 56              MOV D,M
57C4 2B              DCX H
57C5 C9              RET
57C6 7B             CMD MOV A,E
57C7 2F              CMA
57C8 C6 01           ADI 1
```

```
57CA 5F          2100  MOV E,A
57CB 7A          2110  MOV A,D
57CC 2F          2120  CMA
57CD CE 00       2130  ACI 0
57CF 57          2140  MOV D,A
57D0 C9          2150  RET
57D1 78          2160 BHCMP MOV A,B
57D2 BC          2170  CMP H
57D3 C0          2180  RNZ
57D4 79          2190  MOV A,C
57D5 95          2200  SUB L
57D6 C8          2210  RZ
57D7 1F          2220  RAR
57D8 B7          2230  ORA A
57D9 17          2240  RAL
57DA F8          2250  RM
57DB AF          2260  XRA A
57DC 3C          2270  INR A
57DD C9          2280  RET
57DE 21 3F 00    2290 READ LXI H,63
57E1 11 CE 50    2300  LXI D,LST
57E4 01 00 00    2310  LXI B,0
57E7 CD 20 0C    2320 RELP CALL WHO
57EA FE 18       2330  CPI 18H
57EC CA 1F 58    2340  JZ CAN
57EF FE 7F       2350  CPI 7FH
57F1 CA 0F 58    2360  JZ RUB
57F4 CD 24 0C    2370  CALL WH1
57F7 FE 0D       2380  CPI 0DH
57F9 CA 05 58    2390  JZ CRF
57FC 12          2400  STAX D
57FD 13          2410  INX D
57FE 03          2420  INX B
57FF 2B          2430  DCX H
5800 7C          2440  MOV A,H
5801 B5          2450  ORA L
5802 C2 E7 57    2460  JNZ RELP
5805 3E 20       2470 CRF MVI A,20H
5807 12          2480  STAX D
5808 03          2490  INX B
5809 69          2500  MOV L,C
580A 60          2510  MOV H,B
580B 22 24 54    2520  SHLD L00
580E C9          2530  RET
580F 78          2540 RUB MOV A,B
5810 B1          2550  ORA C
5811 CA E7 57    2560  JZ RELP
5814 1B          2570  DCX D
5815 0B          2580  DCX B
5816 23          2590  INX H
5817 3E 7F       2600  MVI A,7FH
5819 CD 24 0C    2610  CALL WH1
581C C3 E7 57    2620  JMP RELP
581F 78          2630 CAN MOV A,B
5820 B1          2640  ORA C
5821 CA E7 57    2650  JZ RELP
5824 3E 7F       2660  MVI A,7FH
5826 CD 24 0C    2670  CALL WH1
5829 1B          2680  DCX D
582A 0B          2690  DCX B
582B 23          2700  INX H
582C C3 1F 58    2710  JMP CAN
582F 06 00       2720 DCALC MVI B,0
5831 19          2730  DAD D
5832 04          2740  INR B
5833 7C          2750  MOV A,H
5834 B7          2760  ORA A
5835 F2 31 58    2770  JP $-7
5838 CD C6 57    2780  CALL CMD
583B 19          2790  DAD D
583C 05          2800  DCR B
583D 78          2810  MOV A,B
583E B9          2820  CMP C
583F C8          2830  RZ
5840 0D          2840  DCR C
5841 C6 30       2850  ADI 30H
5843 C9          2860  RET
5844 D5          2870 DECPR PUSH D
5845 E5          2880  PUSH H
5846 21 9E 52    2890  LXI H,OST
5849 7A          2900  MOV A,D
584A B7          2910  ORA A
584B F5          2920  PUSH P
584C F2 55 58    2930  JP CDEC
584F 36 2D       2940  MVI M,'-'
5851 23          2950  INX H
5852 CD C6 57    2960  CALL CMD
5855 E5          2970 CDEC PUSH H
5856 0E 00       2980  MVI C,0
5858 EB          2990  XCHG
5859 11 F0 D8    3000  LXI D,-10000
585C CD 2F 58    3010  CALL DCALC
585F CA 66 58    3020  JZ $+4
5862 E3          3030  XTHL
5863 77          3040  MOV M,A
5864 23          3050  INX H
5865 E3          3060  XTHL
5866 11 18 FC    3070  LXI D,-1000
5869 CD 2F 58    3080  CALL DCALC
586C CA 73 58    3090  JZ $+4
586F E3          3100  XTHL
5870 77          3110  MOV M,A
5871 23          3120  INX H
5872 E3          3130  XTHL
5873 11 9C FF    3140  LXI D,-100
5876 CD 2F 58    3150  CALL DCALC
5879 CA 80 58    3160  JZ $+4
587C E3          3170  XTHL
587D 77          3180  MOV M,A
587E 23          3190  INX H
587F E3          3200  XTHL
5880 11 F6 FF    3210  LXI D,-10
5883 CD 2F 58    3220  CALL DCALC
5886 CA 8D 58    3230  JZ $+4
5889 E3          3240  XTHL
588A 77          3250  MOV M,A
588B 23          3260  INX H
588C E3          3270  XTHL
588D 7D          3280  MOV A,L
588E E1          3290  POP H
588F C6 30       3300  ADI 30H
5891 77          3310  MOV M,A
5892 23          3320  INX H
5893 0D          3330  DCR C
5894 36 0D       3340  MVI M,0DH
5896 F1          3350  POP P
5897 F2 9B 58    3360  JP $+1
589A 0D          3370  DCR C
589B E1          3380  POP H
589C D1          3390  POP D
589D C9          3400  RET

589E CD 44 58    0010 DECOUT CALL DECPR
58A1 CD 02 0A    0020  CALL BLK1
58A4 C3 C8 58    0030  JMP OPUT
58A7 F5          0040 DECFMT PUSH P
58A8 CD 44 58    0050  CALL DECPR
58AB F1          0060  POP P
58AC 0D          0070  DCR C
58AD 81          0080  ADD C
58AE CA C8 58    0090  JZ OPUT
58B1 F2 C0 58    0100  JP FILL
58B4 91          0110  SUB C
58B5 4F          0120  MOV C,A
58B6 3E 2A       0130  MVI A,'*'
58B8 CD 24 0C    0140 FMLP CALL WH1
58BB 0C          0150  INR C
58BC C2 B8 58    0160  JNZ FMLP
58BF C9          0170  RET
58C0 2F          0180 FILL CMA
```

```
58C1 3C             INR A
58C2 4F             MOV C,A
58C3 3E 20          MVI A,' '
58C5 CD B8 58       CALL FMLP
58C8 E5       OPUT  PUSH H
58C9 21 9E 52       LXI H,OST
58CC CD AD 05       CALL OSEQ
58CF E1             POP H
58D0 C3 02 0A       JMP BLK1
58D3 2A 08 54 S1030 LHLD C0
58D6 4D             MOV C,L
58D7 44             MOV B,H
58D8 2A 24 54       LHLD L00
58DB CD D1 57       CALL BHCMP
58DE DA E7 58       JC $+6
58E1 CD F7 58       CALL S1090
58E4 C3 D3 58       JMP S1030
58E7 69             MOV L,C
58E8 60             MOV H,B
58E9 23             INX H
58EA 22 08 54       SHLD C0
58ED 2B             DCX H
58EE 11 CE 50       LXI D,LST
58F1 19             DAD D
58F2 7E             MOV A,M
58F3 32 D8 53       STA XST
58F6 C9             RET
58F7 2A 0E 54 S1090 LHLD C1
58FA EB             XCHG
58FB 3E 05          MVI A,5
58FD CD A7 58       CALL DECFMT
5900 3A 03 54       LDA F5+1
5903 B7             ORA A
5904 FA 20 59       JM L1160
5907 CD DE 57 L1110 CALL READ
590A 3A 24 54       LDA L00
590D 3D             DCR A
590E CA F7 58       JZ S1090
5911 3A CE 50       LDA LST
5914 FE 24          CPI '$'
5916 CA 60 59       JZ L1210
5919 21 00 00       LXI H,0
591C 22 08 54       SHLD C0
591F C9             RET
5920 2A F2 53 L1160 LHLD FPTR
5923 7E             MOV A,M
5924 FE 01          CPI 1
5926 C2 3A 59       JNZ L1190
5929 21 00 00       LXI H,0
592C 22 02 54       SHLD F5
592F 21 0D 0C       LXI H,KBUF+1
5932 36 24          MVI M,'$'
5934 2B             DCX H
5935 36 00          MVI M,FLAG
5937 C3 07 59       JMP L1110
593A 11 05 00 L1190 LXI D,5
593D 19             DAD D
593E 11 CE 50       LXI D,LST
5941 01 00 00       LXI B,0
5944 7E       IFLP  MOV A,M
5945 12             STAX D
5946 CD 24 0C       CALL WH1
5949 23             INX H
594A 13             INX D
594B 03             INX B
594C FE 0D          CPI 0DH
594E C2 44 59       JNZ IFLP
5951 1B             DCX D
5952 3E 20          MVI A,20H
5954 12             STAX D
5955 22 F2 53       SHLD FPTR
5958 69             MOV L,C
5959 60             MOV H,B
595A 22 24 54       SHLD L00
595D C3 0A 59       JMP L1110+3
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5960 21 FF FF      0940 L1210 LXI H,-1
5963 22 02 54      0950  SHLD F5
5966 21 CF 50      0960  LXI H,LST+1
5969 11 54 0C      0970  LXI D,0C54H
596C 01 FB FF      0980  LXI B,-5
596F CD 00 01      0990  CALL MOVE
5972 2A F4 53      1000  LHLD BOFP
5975 22 F2 53      1010  SHLD FPTR
5978 22 6A 0C      1020  SHLD 0C6AH
597B 21 89 59      1030  LXI H,$+11
597E 22 6C 0C      1040  SHLD 0C6CH
5981 3E 49         1050  MVI A,'I'
5983 32 73 0C      1060  STA 0C73H
5986 C3 9A 59      1070  JMP READO
5989 2A 7F 72      1080  LHLD 727FH
598C 22 0E 0C      1090  SHLD 0C0EH
598F 2A 6E 0C      1100  LHLD 0C6EH
5992 36 01         1110  MVI M,1
5994 22 F6 53      1120  SHLD EOFP
5997 C3 F7 58      1130  JMP S1090
599A               1140 MENTR EQU 7390H
599A 2A BC 73      1150 READO LHLD MENTR+2CH
599D 36 4C         1160  MVI M,'L'
599F 23            1170  INX H
59A0 36 4F         1180  MVI M,'O'
59A2 23            1190  INX H
59A3 36 20         1200  MVI M,' '
59A5 23            1210  INX H
59A6 EB            1220  XCHG
59A7 21 54 0C      1230  LXI H,0C54H
59AA 01 FB FF      1240  LXI B,-5
59AD CD 00 01      1250  CALL MOVE
59B0 EB            1260  XCHG
59B1 36 20         1270  MVI M,' '
59B3 23            1280  INX H
59B4 36 2E         1290  MVI M,'.'
59B6 23            1300  INX H
59B7 36 20         1310  MVI M,' '
59B9 23            1320  INX H
59BA EB            1330  XCHG
59BB 2A 6A 0C      1340  LHLD 0C6AH
59BE 4D            1350  MOV C,L
59BF 7C            1360  MOV A,H
59C0 CD F9 59      1370  CALL BINH
59C3 2B            1380  DCX H
59C4 7E            1390  MOV A,M
59C5 12            1400  STAX D
59C6 13            1410  INX D
59C7 23            1420  INX H
59C8 7E            1430  MOV A,M
59C9 12            1440  STAX D
59CA 13            1450  INX D
59CB 79            1460  MOV A,C
59CC CD F9 59      1470  CALL BINH
59CF 2B            1480  DCX H
59D0 7E            1490  MOV A,M
59D1 12            1500  STAX D
59D2 13            1510  INX D
59D3 23            1520  INX H
59D4 7E            1530  MOV A,M
59D5 12            1540  STAX D
59D6 13            1550  INX D
59D7 3E 0D         1560  MVI A,0DH
59D9 12            1570  STAX D
59DA 21 90 73      1580  LXI H,MENTR
59DD 22 BA 73      1590  SHLD MENTR+2AH
59E0 2A 0E 0C      1600  LHLD 0C0EH
59E3 22 7F 72      1610  SHLD 727FH
59E6 F3            1620  DI
59E7 2A BC 73      1630  LHLD MENTR+2CH
59EA CD C2 73      1640  CALL MENTR+32H
59ED 2A B0 73      1650  LHLD MENTR+20H
59F0 2B            1660  DCX H
59F1 22 6E 0C      1670  SHLD 0C6EH
59F4 2A 6C 0C      1680  LHLD 0C6CH
```

```
59F7 FB          1690       EI
59F8 E9          1700       PCHL
59F9 21 31 54    1710 BINH  LXI H,ADDS
59FC 47          1720       MOV B,A
59FD 1F          1730       RAR
59FE 1F          1740       RAR
59FF 1F          1750       RAR
5A00 1F          1760       RAR
5A01 CD 0C 5A    1770       CALL BIN1
5A04 77          1780       MOV M,A
5A05 23          1790       INX H
5A06 78          1800       MOV A,B
5A07 CD 0C 5A    1810       CALL BIN1
5A0A 77          1820       MOV M,A
5A0B C9          1830       RET
5A0C E6 0F       1840 BIN1  ANI 0FH
5A0E C6 30       1850       ADI 30H
5A10 FE 3A       1860       CPI '9'+1
5A12 D8          1870       RC
5A13 C6 07       1880       ADI 7
5A15 C9          1890       RET
5A16 2A A6 52    1900 S1960 LHLD T1
5A19 23          1910       INX H
5A1A 22 A6 52    1920       SHLD T1
5A1D 2B          1930       DCX H
5A1E 29          1940       DAD H
5A1F 29          1950       DAD H
5A20 29          1960       DAD H
5A21 11 0C 4F    1970       LXI D,TST
5A24 19          1980       DAD D
5A25 11 0E 51    1990       LXI D,AST
5A28 01 F8 FF    2000       LXI B,-8
5A2B EB          2010       XCHG
5A2C CD 00 01    2020       CALL MOVE
5A2F 2A A6 52    2030       LHLD T1
5A32 E5          2040       PUSH H
5A33 11 9C 50    2050       LXI D,TOST
5A36 19          2060       DAD D
5A37 2B          2070       DCX H
5A38 3A E8 53    2080       LDA KST
5A3B 77          2090       MOV M,A
5A3C E1          2100       POP H
5A3D FE 43       2110       CPI 'C'
5A3F C2 52 5A    2120       JNZ L2010
5A42 11 0C 53    2130       LXI D,T2
5A45 EB          2140       XCHG
5A46 CD BA 57    2150       CALL ARRAY
5A49 EB          2160       XCHG
5A4A 2A 18 54    2170       LHLD N3
5A4D EB          2180       XCHG
5A4E 73          2190       MOV M,E
5A4F 23          2200       INX H
5A50 72          2210       MOV M,D
5A51 C9          2220       RET
5A52 11 A6 52    2230 L2010 LXI D,T1
5A55 EB          2240       XCHG
5A56 CD BA 57    2250       CALL ARRAY
5A59 EB          2260       XCHG
5A5A 2A 20 54    2270       LHLD L1
5A5D EB          2280       XCHG
5A5E 73          2290       MOV M,E
5A5F 23          2300       INX H
5A60 72          2310       MOV M,D
5A61 3A E8 53    2320       LDA KST
5A64 FE 56       2330       CPI 'V'
5A66 C0          2340       RNZ
5A67 3A 22 54    2350       LDA F9
5A6A B7          2360       ORA A
5A6B C8          2370       RZ
5A6C 2A A6 52    2380       LHLD T1
5A6F 11 0C 53    2390       LXI D,T2
5A72 EB          2400       XCHG
5A73 CD BA 57    2410       CALL ARRAY
5A76 EB          2420       XCHG
5A77 2A 2C 54    2430       LHLD D0
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5A7A EB          2440       XCHG
5A7B 73          2450       MOV M,E
5A7C 23          2460       INX H
5A7D 72          2470       MOV M,D
5A7E EB          2480       XCHG
5A7F 23          2490       INX H
5A80 22 2C 54    2500       SHLD D0
5A83 C9          2510       RET
5A84 0E 05       2520 STCMP MVI C,5
5A86 C3 A1 5A    2530       JMP SEAR
5A89 2A 31 54    2540 COMS  LHLD ADDS
5A8C 3A 30 54    2550       LDA NCHR
5A8F 4F          2560       MOV C,A
5A90 D5          2570       PUSH D
5A91 CD A1 5A    2580       CALL SEAR
5A94 C2 99 5A    2590       JNZ $+2
5A97 D1          2600       POP D
5A98 C9          2610       RET
5A99 E3          2620       XTHL
5A9A E1          2630       POP H
5A9B 05          2640       DCR B
5A9C C2 89 5A    2650       JNZ COMS
5A9F 04          2660       INR B
5AA0 C9          2670       RET
5AA1 1A          2680 SEAR  LDAX D
5AA2 BE          2690       CMP M
5AA3 C2 B0 5A    2700       JNZ INCA
5AA6 FE 20       2710       CPI ' '
5AA8 C8          2720       RZ
5AA9 23          2730       INX H
5AAA 13          2740       INX D
5AAB 0D          2750       DCR C
5AAC C2 A1 5A    2760       JNZ SEAR
5AAF C9          2770       RET
5AB0 13          2780 INCA  INX D
5AB1 0D          2790       DCR C
5AB2 C2 B0 5A    2800       JNZ INCA
5AB5 0C          2810       INR C
5AB6 C9          2820       RET
5AB7 2A A6 52    2830 S2060 LHLD T1
5ABA 22 14 54    2840       SHLD I
5ABD 7C          2850       MOV A,H
5ABE B5          2860       ORA L
5ABF C2 C4 5A    2870       JNZ $+2
5AC2 3C          2880       INR A
5AC3 C9          2890       RET
5AC4 2B          2900       DCX H
5AC5 29          2910       DAD H
5AC6 29          2920       DAD H
5AC7 29          2930       DAD H
5AC8 11 0C 4F    2940       LXI D,TST
5ACB 19          2950       DAD D
5ACC 11 0E 51    2960       LXI D,AST
5ACF 0E 08       2970       MVI C,8
5AD1 CD A1 5A    2980       CALL SEAR
5AD4 2A 14 54    2990       LHLD I
5AD7 C8          3000       RZ
5AD8 2B          3010       DCX H
5AD9 C3 BA 5A    3020       JMP S2060+3
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5ADC 3A D8 53    0010 S1240 LDA XST
5ADF FE 20       0020       CPI 20H
5AE1 C2 EA 5A    0030       JNZ L1280
5AE4 CD D3 58    0040       CALL S1030
5AE7 C3 DC 5A    0050       JMP S1240
5AEA FE 41       0060 L1280 CPI 'A'
5AEC DA DE 5B    0070       JC L1460
5AEF FE 5B       0080       CPI 'Z'+1
5AF1 D2 DE 5B    0090       JNC L1460
5AF4 21 00 00    0100       LXI H,0
5AF7 22 10 54    0110       SHLD K
5AFA 21 AE 57    0120       LXI H,L1300
5AFD 11 0E 51    0130       LXI D,AST
5B00 01 F4 FF    0140       LXI B,-12
5B03 CD 00 01    0150       CALL MOVE
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5B06 2A 10 54    L1310 LHLD K
5B09 4D            MOV C,L
5B0A 44            MOV B,H
5B0B 21 08 00      LXI H,8
5B0E CD D1 57      CALL BHCMP
5B11 D2 23 5B      JNC L1330
5B14 60            MOV H,B
5B15 69            MOV L,C
5B16 23            INX H
5B17 22 10 54      SHLD K
5B1A 2B            DCX H
5B1B 11 0E 51      LXI D,AST
5B1E 19            DAD D
5B1F 3A D8 53      LDA XST
5B22 77            MOV M,A
5B23 CD D3 58    L1330 CALL S1030
5B26 6F            MOV L,A
5B27 26 00         MVI H,0
5B29 22 12 54      SHLD T
5B2C FE 30         CPI '0'
5B2E DA 40 5B      JC L1360
5B31 FE 3A         CPI '9'+1
5B33 DA 06 5B      JC L1310
5B36 FE 41         CPI 'A'
5B38 DA 40 5B      JC L1360
5B3B FE 5B         CPI 'Z'+1
5B3D DA 06 5B      JC L1310
5B40 21 01 00    L1360 LXI H,1
5B43 22 14 54      SHLD I
5B46 21 9C 00      LXI H,N0+N0+N0+N0+N0-4
5B49 22 16 54      SHLD J
5B4C 21 0E 51      LXI H,AST
5B4F 11 1A 51      LXI D,BST
5B52 01 F8 FF      LXI B,-8
5B55 CD 00 01      CALL MOVE
5B58 2A 14 54    L1390 LHLD I
5B5B EB            XCHG
5B5C 2A 16 54      LHLD J
5B5F 19            DAD D
5B60 11 F6 FF      LXI D,-10
5B63 01 FF FF      LXI B,-1
5B66 19          DIVL DAD D
5B67 03            INX B
5B68 7C            MOV A,H
5B69 B7            ORA A
5B6A F2 66 5B      JP DIVL
5B6D 69            MOV L,C
5B6E 60            MOV H,B
5B6F 29            DAD H
5B70 29            DAD H
5B71 09            DAD B
5B72 23            INX H
5B73 22 10 54      SHLD K
5B76 2B            DCX H
5B77 11 33 54      LXI D,WOST
5B7A 19            DAD D
5B7B 11 ED 53      LXI D,ZST
5B7E 01 FB FF      LXI B,-5
5B81 CD 00 01      CALL MOVE
5B84 21 FB FF      LXI H,-5
5B87 19            DAD D
5B88 11 1A 51      LXI D,BST
5B8B 0E 05         MVI C,5
5B8D 1A          L1400 LDAX D
5B8E BE            CMP M
5B8F C2 98 5B      JNZ L1410
5B92 23            INX H
5B93 13            INX D
5B94 0D            DCR C
5B95 C2 8D 5B      JNZ L1400
5B98 CC C8 5B    L1410 CZ JKM5
5B9B FC C8 5B      CM JKM5
5B9E F4 D3 5B      CP IKP5
5BA1 2A 16 54      LHLD J
5BA4 4D            MOV C,L
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5BA5 44          0910  MOV B,H
5BA6 2A 14 54    0920  LHLD I
5BA9 CD D1 57    0930  CALL BHCMP
5BAC F2 5B 5B    0940  JP L1390+3
5BAF 11 FB FF    0950  LXI D,-5
5BB2 19          0960  DAD D
5BB3 CD D1 57    0970  CALL BHCMP
5BB6 21 1A 51    0980  LXI H,BST
5BB9 FA BF 5B    0990  JM $+3
5BBC 21 D3 54    1000  LXI H,IDENT
5BBF 11 E3 53    1010  LXI D,SOST
5BC2 01 FB FF    1020  LXI B,-5
5BC5 C3 00 01    1030  JMP MOVE
5BC8 2A 10 54    1040 JKM5 LHLD K
5BCB 11 FB FF    1050  LXI D,-5
5BCE 19          1060  DAD D
5BCF 22 16 54    1070  SHLD J
5BD2 C9          1080  RET
5BD3 2A 10 54    1090 IKP5 LHLD K
5BD6 11 05 00    1100  LXI D,5
5BD9 19          1110  DAD D
5BDA 22 14 54    1120  SHLD I
5BDD C9          1130  RET
5BDE 21 ED 53    1140 L1460 LXI H,ZST
5BE1 3A D8 53    1150  LDA XST
5BE4 FE 30       1160  CPI '0'
5BE6 DA 42 5C    1170  JC L1580
5BE9 FE 3A       1180  CPI '9'+1
5BEB D2 42 5C    1190  JNC L1580
5BEE 77          1200 L1500 MOV M,A
5BEF 23          1210  INX H
5BF0 E5          1220  PUSH H
5BF1 CD D3 58    1230  CALL S1030
5BF4 E1          1240  POP H
5BF5 FE 30       1250  CPI '0'
5BF7 DA FF 5B    1260  JC $+5
5BFA FE 3A       1270  CPI '9'+1
5BFC DA EE 5B    1280  JC L1500
5BFF 11 ED 53    1290  LXI D,ZST
5C02 CD C6 57    1300  CALL CMD
5C05 19          1310  DAD D
5C06 4D          1320  MOV C,L
5C07 44          1330  MOV B,H
5C08 21 00 00    1340  LXI H,0
5C0B 11 ED 53    1350  LXI D,ZST
5C0E 1A          1360 L1530 LDAX D
5C0F 13          1370  INX D
5C10 D6 30       1380  SUI 30H
5C12 D5          1390  PUSH D
5C13 5D          1400  MOV E,L
5C14 54          1410  MOV D,H
5C15 29          1420  DAD H
5C16 29          1430  DAD H
5C17 19          1440  DAD D
5C18 29          1450  DAD H
5C19 5F          1460  MOV E,A
5C1A 16 00       1470  MVI D,0
5C1C 19          1480  DAD D
5C1D D1          1490  POP D
5C1E 0B          1500  DCX B
5C1F 79          1510  MOV A,C
5C20 B0          1520  ORA B
5C21 C2 0E 5C    1530  JNZ L1530
5C24 22 18 54    1540  SHLD N3
5C27 01 FF 7F    1550  LXI B,N1
5C2A CD D1 57    1560  CALL BHCMP
5C2D D2 36 5C    1570  JNC NOK
5C30 21 1E 00    1580  LXI H,30
5C33 C3 57 5D    1590  JMP FNE
5C36 21 D8 54    1600 NOK LXI H,NUM
5C39 11 E3 53    1610  LXI D,SOST
5C3C 01 FB FF    1620  LXI B,-5
5C3F C3 00 01    1630  JMP MOVE
5C42 21 E3 53    1640 L1580 LXI H,SOST
5C45 FE 3A       1650  CPI ':'
5C47 C2 61 5C    1660  JNZ L1640
5C4A E5          1670  PUSH H
5C4B CD D3 58    1680  CALL S1030
5C4E E1          1690  POP H
5C4F FE 3D       1700  CPI '='
5C51 36 3A       1710  MVI M,':'
5C53 23          1720  INX H
5C54 CA 5A 5C    1730  JZ L1620
5C57 36 20       1740  MVI M,' '
5C59 C9          1750  RET
5C5A 77          1760 L1620 MOV M,A
5C5B 23          1770  INX H
5C5C 36 20       1780  MVI M,' '
5C5E C3 D3 58    1790  JMP S1030
5C61 FE 3C       1800 L1640 CPI '<'
5C63 C2 81 5C    1810  JNZ L1710
5C66 77          1820  MOV M,A
5C67 23          1830  INX H
5C68 E5          1840  PUSH H
5C69 CD D3 58    1850  CALL S1030
5C6C E1          1860  POP H
5C6D FE 3E       1870  CPI '>'
5C6F CA 7A 5C    1880  JZ L1690
5C72 FE 3D       1890  CPI '='
5C74 CA 7A 5C    1900  JZ L1690
5C77 36 20       1910  MVI M,' '
5C79 C9          1920  RET
5C7A 77          1930 L1690 MOV M,A
5C7B 23          1940  INX H
5C7C 36 20       1950  MVI M,' '
5C7E C3 D3 58    1960  JMP S1030
5C81 FE 3E       1970 L1710 CPI '>'
5C83 C2 95 5C    1980  JNZ L1750
5C86 77          1990  MOV M,A
5C87 23          2000  INX H
5C88 E5          2010  PUSH H
5C89 CD D3 58    2020  CALL S1030
5C8C E1          2030  POP H
5C8D FE 3D       2040  CPI '='
5C8F CA 7A 5C    2050  JZ L1690
5C92 36 20       2060  MVI M,' '
5C94 C9          2070  RET
5C95 FE 27       2080 L1750 CPI ''''
5C97 C2 CA 5C    2090  JNZ L1790
5C9A 21 DD 54    2100  LXI H,STR
5C9D 11 E3 53    2110  LXI D,SOST
5CA0 01 FB FF    2120  LXI B,-5
5CA3 CD 00 01    2130  CALL MOVE
5CA6 21 4E 52    2140  LXI H,CST
5CA9 E5          2150 L1770 PUSH H
5CAA CD D3 58    2160  CALL S1030
5CAD E1          2170  POP H
5CAE FE 27       2180  CPI ''''
5CB0 CA B8 5C    2190  JZ QFND
5CB3 77          2200  MOV M,A
5CB4 23          2210  INX H
5CB5 C3 A9 5C    2220  JMP L1770
5CB8 E5          2230 QFND PUSH H
5CB9 CD D3 58    2240  CALL S1030
5CBC E1          2250  POP H
5CBD FE 27       2260  CPI ''''
5CBF C2 C7 5C    2270  JNZ L1780
5CC2 77          2280  MOV M,A
5CC3 23          2290  INX H
5CC4 C3 A9 5C    2300  JMP L1770
5CC7 36 20       2310 L1780 MVI M,' '
5CC9 C9          2320  RET
5CCA FE 7D       2330 L1790 CPI '}'
5CCC C2 DD 5C    2340  JNZ L1820
5CCF CD D3 58    2350 COM CALL S1030
5CD2 FE 7D       2360  CPI '}'
5CD4 C2 CF 5C    2370  JNZ COM
5CD7 CD D3 58    2380  CALL S1030
5CDA C3 DC 5A    2390  JMP S1240
5CDD FE 25       2400 L1820 CPI '%'
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5CDF C2 2E 5D     2410  JNZ L1930
5CE2 21 D8 54     2420  LXI H,NUM
5CE5 11 E3 53     2430  LXI D,SOST
5CE8 01 FB FF     2440  LXI B,-5
5CEB CD 00 01     2450  CALL MOVE
5CEE 21 00 00     2460  LXI H,0
5CF1 4D           2470  MOV C,L
5CF2 E5           2480 HXI PUSH H
5CF3 C5           2490  PUSH B
5CF4 CD D3 58     2500  CALL S1030
5CF7 C1           2510  POP B
5CF8 E1           2520  POP H
5CF9 D6 30        2530  SUI '0'
5CFB DA 19 5D     2540  JC L1910
5CFE FE 0A        2550  CPI 10
5D00 DA 0F 5D     2560  JC L1880
5D03 D6 07        2570  SUI 7
5D05 FE 0A        2580  CPI 10
5D07 DA 19 5D     2590  JC L1910
5D0A FE 10        2600  CPI 16
5D0C D2 19 5D     2610  JNC L1910
5D0F 29           2620 L1880 DAD H
5D10 29           2630  DAD H
5D11 29           2640  DAD H
5D12 29           2650  DAD H
5D13 85           2660  ADD L
5D14 6F           2670  MOV L,A
5D15 0C           2680  INR C
5D16 C3 F2 5C     2690  JMP HXI
5D19 22 18 54     2700 L1910 SHLD N3
5D1C 21 1B 00     2710  LXI H,27
5D1F 79           2720  MOV A,C
5D20 FE 05        2730  CPI 5
5D22 D2 57 5D     2740  JNC FNE
5D25 B7           2750  ORA A
5D26 C0           2760  RNZ
5D27 21 25 20     2770  LXI H,' %'
5D2A 22 E3 53     2780  SHLD SOST
5D2D C9           2790  RET
5D2E 21 E3 53     2800 L1930 LXI H,SOST
5D31 77           2810  MOV M,A
5D32 23           2820  INX H
5D33 36 20        2830  MVI M,' '
5D35 C3 D3 58     2840  JMP S1030
5D38 E5           2850 FNE2 PUSH H
5D39 CD DC 5A     2860  CALL S1240
5D3C E1           2870  POP H
5D3D E5           2880 FNE1 PUSH H
5D3E 11 E3 53     2890  LXI D,SOST
5D41 21 D9 53     2900  LXI H,FNE1ST
5D44 CD 84 5A     2910  CALL STCMP
5D47 E1           2920  POP H
5D48 C2 57 5D     2930  JNZ FNE
5D4B 21 AE 57     2940 BLST LXI H,L1300
5D4E 11 D9 53     2950  LXI D,FNE1ST
5D51 01 FB FF     2960  LXI B,-5
5D54 C3 00 01     2970  JMP MOVE
5D57 E5           2980 FNE PUSH H
5D58 2B           2990  DCX H
5D59 29           3000  DAD H
5D5A 11 66 57     3010  LXI D,ETAB
5D5D 19           3020  DAD D
5D5E 7E           3030  MOV A,M
5D5F 23           3040  INX H
5D60 66           3050  MOV H,M
5D61 6F           3060  MOV L,A
5D62 E3           3070  XTHL
5D63 E5           3080  PUSH H
5D64 2A 08 54     3090  LHLD C0
5D67 11 04 00     3100  LXI D,4
5D6A 19           3110  DAD D
5D6B CD 02 0A     3120 FL CALL BLK1
5D6E 2B           3130  DCX H
5D6F 7D           3140  MOV A,L
5D70 B4           3150  ORA H
5D71 C2 6B 5D     3160  JNZ FL
5D74 3E 5E        3170  MVI A,'↑'
5D76 CD 24 0C     3180  CALL WH1
5D79 CD 02 0A     3190  CALL BLK1
5D7C E1           3200  POP H
5D7D EB           3210  XCHG
5D7E CD 9E 58     3220  CALL DECOUT
5D81 CD F8 09     3230  CALL CRLF
5D84 E1           3240  POP H
5D85 CD AD 05     3250  CALL OSEQ
5D88 CD F8 09     3260  CALL CRLF
5D8B CD 20 0C     3270  CALL WH0
5D8E 2A 0E 0C     3280  LHLD 0C0EH
5D91 22 7F 72     3290  SHLD 727FH
5D94 C3 90 73     3300  JMP 7390H
5D97 3E 20        3310 FNG MVI A,'
5D99 32 1A 51     3320  STA BST
5D9C 2A FE 53     3330  LHLD Q9
5D9F D5           3340  PUSH D
5DA0 EB           3350  XCHG
5DA1 2A FC 53     3360  LHLD P9
5DA4 23           3370  INX H
5DA5 23           3380  INX H
5DA6 23           3390  INX H
5DA7 23           3400  INX H
5DA8 CD C6 57     3410  CALL CMD
5DAB 19           3420  DAD D
5DAC 7C           3430  MOV A,H
5DAD B7           3440  ORA A
5DAE 21 01 00     3450  LXI H,1
5DB1 F2 57 5D     3460  JP FNE
5DB4 2A FC 53     3470  LHLD P9
5DB7 D1           3480  POP D
5DB8 70           3490  MOV M,B
5DB9 23           3500  INX H
5DBA 71           3510  MOV M,C
5DBB 23           3520  INX H
5DBC 73           3530  MOV M,E
5DBD 23           3540  INX H
5DBE 72           3550  MOV M,D
5DBF 23           3560  INX H
5DC0 22 FC 53     3570  SHLD P9
5DC3 3A 04 54     3580  LDA Y9
5DC6 B7           3590  ORA A
5DC7 C2 14 5E     3600  JNZ L6400
5DCA 78           3610  MOV A,B
5DCB FE 10        3620  CPI 16
5DCD DA D8 5D     3630  JC L6390
5DD0 D6 10        3640  SUI 16
5DD2 47           3650  MOV B,A
5DD3 3E 58        3660  MVI A,'X'
5DD5 32 1A 51     3670  STA BST
5DD8 78           3680 L6390 MOV A,B
5DD9 87           3690  ADD A
5DDA 80           3700  ADD B
5DDB 47           3710  MOV B,A
5DDC 2A 0E 54     3720  LHLD C1
5DDF D5           3730  PUSH D
5DE0 C5           3740  PUSH B
5DE1 EB           3750  XCHG
5DE2 3E 10        3760  MVI A,16
5DE4 CD A7 58     3770  CALL DECFMT
5DE7 CD 02 0A     3780  CALL BLK1
5DEA C1           3790  POP B
5DEB 21 E2 54     3800  LXI H,MST
5DEE 58           3810  MOV E,B
5DEF 16 00        3820  MVI D,0
5DF1 19           3830  DAD D
5DF2 7E           3840  MOV A,M
5DF3 CD 24 0C     3850  CALL WH1
5DF6 23           3860  INX H
5DF7 7E           3870  MOV A,M
5DF8 CD 24 0C     3880  CALL WH1
5DFB 23           3890  INX H
5DFC 7E           3900  MOV A,M
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5DFD CD 24 0C     3910       CALL WH1
5E00 3A 1A 51     3920       LDA BST
5E03 CD 24 0C     3930       CALL WH1
5E06 CD 02 0A     3940       CALL BLK1
5E09 59           3950       MOV E,C
5E0A CD 9E 58     3960       CALL DECOUT
5E0D D1           3970       POP D
5E0E CD 9E 58     3980       CALL DECOUT
5E11 CD F8 09     3990       CALL CRLF
5E14 2A 0E 54     4000 L6400 LHLD C1
5E17 23           4010       INX H
5E18 22 0E 54     4020       SHLD C1
5E1B C9           4030       RET

5E1C CD 8F 5E     0010 S6520 CALL S6150
5E1F 2A 1A 54     0020 L6540 LHLD X
5E22 29           0030       DAD H
5E23 29           0040       DAD H
5E24 EB           0050       XCHG
5E25 2A F8 53     0060       LHLD P7
5E28 19           0070       DAD D
5E29 22 2E 54     0080       SHLD N
5E2C EB           0090       XCHG
5E2D 2A 0E 54     0100       LHLD C1
5E30 EB           0110       XCHG
5E31 23           0120       INX H
5E32 23           0130       INX H
5E33 73           0140       MOV M,E
5E34 23           0150       INX H
5E35 72           0160       MOV M,D
5E36 2A 04 54     0170       LHLD Y9
5E39 7C           0180       MOV A,H
5E3A B5           0190       ORA L
5E3B C0           0200       RNZ
5E3C 21 53 57     0210       LXI H,L6570
5E3F CD AD 05     0220       CALL OSEQ
5E42 23           0230       INX H
5E43 E5           0240       PUSH H
5E44 2A 1A 54     0250       LHLD X
5E47 EB           0260       XCHG
5E48 CD 9E 58     0270       CALL DECOUT
5E4B E1           0280       POP H
5E4C CD AD 05     0290       CALL OSEQ
5E4F 2A 0E 54     0300       LHLD C1
5E52 EB           0310       XCHG
5E53 CD 9E 58     0320       CALL DECOUT
5E56 C3 F8 09     0330       JMP CRLF
5E59 21 E3 53     0340 CKRES LXI H,SOST
5E5C 22 31 54     0350       SHLD ADDS
5E5F 3E 05        0360       MVI A,5
5E61 32 30 54     0370       STA NCHR
5E64 06 23        0380       MVI B,35
5E66 11 33 54     0390       LXI D,WOST
5E69 CD 89 5A     0400       CALL COMS
5E6C C0           0410       RNZ
5E6D 21 33 54     0420       LXI H,WOST
5E70 EB           0430       XCHG
5E71 CD C6 57     0440       CALL CMD
5E74 19           0450       DAD D
5E75 AF           0460       XRA A
5E76 C9           0470       RET
5E77 2A 00 54     0480 S6120 LHLD S9
5E7A 23           0490       INX H
5E7B 22 00 54     0500       SHLD S9
5E7E 2B           0510       DCX H
5E7F EB           0520       XCHG
5E80 21 22 51     0530       LXI H,S
5E83 CD BA 57     0540       CALL ARRAY
5E86 EB           0550       XCHG
5E87 2A 1A 54     0560       LHLD X
5E8A EB           0570       XCHG
5E8B 73           0580       MOV M,E
5E8C 23           0590       INX H
5E8D 72           0600       MOV M,D
5E8E C9           0610       RET
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5E8F 2A 00 54     0620 S6150 LHLD S9
5E92 2B           0630       DCX H
5E93 22 00 54     0640       SHLD S9
5E96 EB           0650       XCHG
5E97 21 22 51     0660       LXI H,S
5E9A CD BA 57     0670       CALL ARRAY
5E9D EB           0680       XCHG
5E9E 22 1A 54     0690       SHLD X
5EA1 C9           0700       RET
5EA2 2A FA 53     0710 S6180 LHLD P8
5EA5 22 1A 54     0720       SHLD X
5EA8 CD 77 5E     0730       CALL S6120
5EAB 21 DE 53     0740       LXI H,YST
5EAE 01 00 00     0750       LXI B,0
5EB1 7E           0760 L6190 MOV A,M
5EB2 FE 20        0770       CPI 20H
5EB4 CA C1 5E     0780       JZ L6200
5EB7 12           0790       STAX D
5EB8 23           0800       INX H
5EB9 13           0810       INX D
5EBA 0B           0820       DCX B
5EBB 79           0830       MOV A,C
5EBC FE FB        0840       CPI -5
5EBE C2 B1 5E     0850       JNZ L6190
5EC1 EB           0860 L6200 XCHG
5EC2 22 FA 53     0870       SHLD P8
5EC5 69           0880       MOV L,C
5EC6 60           0890       MOV H,B
5EC7 22 1A 54     0900       SHLD X
5ECA C3 77 5E     0910       JMP S6120
5ECD CD 8F 5E     0920 S6240 CALL S6150
5ED0 4D           0930       MOV C,L
5ED1 44           0940       MOV B,H
5ED2 CD 8F 5E     0950       CALL S6150
5ED5 22 FA 53     0960       SHLD P8
5ED8 11 DE 53     0970       LXI D,YST
5EDB C5           0980       PUSH B
5EDC 79           0990       MOV A,C
5EDD B0           1000       ORA B
5EDE C4 00 01     1010       CNZ MOVE
5EE1 C1           1020       POP B
5EE2 EB           1030       XCHG
5EE3 79           1040       MOV A,C
5EE4 FE FB        1050 L6270 CPI -5
5EE6 C8           1060       RZ
5EE7 36 20        1070       MVI M,' '
5EE9 23           1080       INX H
5EEA 3D           1090       DCR A
5EEB C3 E4 5E     1100       JMP L6270
5EEE 21 D3 54     1110 S2180 LXI H,IDENT
5EF1 11 D9 53     1120       LXI D,FNE1ST
5EF4 01 FB FF     1130       LXI B,-5
5EF7 CD 00 01     1140       CALL MOVE
5EFA 21 04 00     1150       LXI H,4
5EFD CD 3D 5D     1160       CALL FNE1
5F00 21 3D 20     1170       LXI H,' ='
5F03 22 D9 53     1180       SHLD FNE1ST
5F06 21 03 00     1190       LXI H,3
5F09 CD 38 5D     1200       CALL FNE2
5F0C CD DC 5A     1210       CALL S1240
5F0F 3A E3 53     1220       LDA SOST
5F12 FE 2D        1230       CPI '-'
5F14 F5           1240       PUSH P
5F15 CC DC 5A     1250       CZ S1240
5F18 CD 35 5F     1260       CALL S2240
5F1B F1           1270       POP P
5F1C C2 2A 5F     1280       JNZ $+11
5F1F 2A 18 54     1290       LHLD N3
5F22 EB           1300       XCHG
5F23 CD C6 57     1310       CALL CMD
5F26 EB           1320       XCHG
5F27 22 18 54     1330       SHLD N3
5F2A 3E 43        1340       MVI A,'C'
5F2C 32 E8 53     1350       STA KST
5F2F CD 16 5A     1360       CALL S1960
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5F32 C3 DC 5A    1370  JMP S1240
5F35 21 E3 53    1380 S2240 LXI H,SOST
5F38 11 D8 54    1390  LXI D,NUM
5F3B CD 84 5A    1400  CALL STCMP
5F3E C8          1410  RZ
5F3F 21 E3 53    1420  LXI H,SOST
5F42 11 D3 54    1430  LXI D,IDENT
5F45 CD 84 5A    1440  CALL STCMP
5F48 CA 67 5F    1450  JZ L2290
5F4B 21 DD 54    1460  LXI H,STR
5F4E 11 D9 53    1470  LXI D,FNE1ST
5F51 01 FB FF    1480  LXI B,-5
5F54 CD 00 01    1490  CALL MOVE
5F57 21 02 00    1500  LXI H,2
5F5A CD 3D 5D    1510  CALL FNE1
5F5D 3A 4E 52    1520  LDA CST
5F60 6F          1530  MOV L,A
5F61 26 00       1540  MVI H,0
5F63 22 18 54    1550  SHLD N3
5F66 C9          1560  RET
5F67 CD B7 5A    1570 L2290 CALL S2060
5F6A 2A 14 54    1580  LHLD I
5F6D EB          1590  XCHG
5F6E 21 02 00    1600  LXI H,2
5F71 7B          1610  MOV A,E
5F72 B2          1620  ORA D
5F73 CA 57 5D    1630  JZ FNE
5F76 E5          1640  PUSH H
5F77 21 9C 50    1650  LXI H,TOST
5F7A 19          1660  DAD D
5F7B 2B          1670  DCX H
5F7C 7E          1680  MOV A,M
5F7D E1          1690  POP H
5F7E FE 43       1700  CPI 'C'
5F80 C2 57 5D    1710  JNZ FNE
5F83 21 0C 53    1720  LXI H,T2
5F86 CD BA 57    1730  CALL ARRAY
5F89 EB          1740  XCHG
5F8A 22 18 54    1750  SHLD N3
5F8D C9          1760  RET
5F8E 21 D3 54    1770 S2340 LXI H,IDENT
5F91 11 D9 53    1780  LXI D,FNE1ST
5F94 01 FB FF    1790  LXI B,-5
5F97 CD 00 01    1800  CALL MOVE
5F9A 21 04 00    1810  LXI H,4
5F9D CD 3D 5D    1820  CALL FNE1
5FA0 3E 56       1830  MVI A,'V'
5FA2 32 E8 53    1840  STA KST
5FA5 CD 16 5A    1850  CALL S1960
5FA8 C3 DC 5A    1860  JMP S1240
5FAB 3A E3 53    1870 S2380 LDA SOST
5FAE FE 2B       1880  CPI '+'
5FB0 CA B8 5F    1890  JZ L2420
5FB3 FE 2D       1900  CPI '-'
5FB5 C2 2B 60    1910  JNZ L2590
5FB8 32 DE 53    1920 L2420 STA YST
5FBB 3E 20       1930  MVI A,' '
5FBD 32 DF 53    1940  STA YST+1
5FC0 CD A2 5E    1950  CALL S6180
5FC3 CD DC 5A    1960  CALL S1240
5FC6 CD 31 60    1970  CALL S2610
5FC9 CD CD 5E    1980  CALL S6240
5FCC 3A DE 53    1990  LDA YST
5FCF FE 2D       2000  CPI '-'
5FD1 C2 DD 5F    2010  JNZ L2460
5FD4 11 01 00    2020  LXI D,1
5FD7 01 00 01    2030  LXI B,100H
5FDA CD 97 5D    2040  CALL FNG
5FDD 3A E3 53    2050 L2460 LDA SOST
5FE0 FE 2B       2060  CPI '+'
5FE2 CA F7 5F    2070  JZ L2500
5FE5 FE 2D       2080  CPI '-'
5FE7 CA F7 5F    2090  JZ L2500
5FEA 21 92 54    2100  LXI H,WOST+95
5FED 11 E3 53    2110  LXI D,SOST
5FF0 CD 84 5A    2120  CALL STCMP
5FF3 CA F7 5F    2130  JZ L2500
5FF6 C9          2140  RET
5FF7 21 E3 53    2150 L2500 LXI H,SOST
5FFA 11 DE 53    2160  LXI D,YST
5FFD 01 FB FF    2170  LXI B,-5
6000 CD 00 01    2180  CALL MOVE
6003 CD A2 5E    2190  CALL S6180
6006 CD DC 5A    2200  CALL S1240
6009 CD 31 60    2210  CALL S2610
600C CD CD 5E    2220  CALL S6240
600F 01 00 01    2230  LXI B,100H
6012 11 03 00    2240  LXI D,3
6015 3A DE 53    2250  LDA YST
6018 FE 2D       2260  CPI '-'
601A CA 25 60    2270  JZ L2560
601D 1D          2280  DCR E
601E FE 2B       2290  CPI '+'
6020 CA 25 60    2300  JZ L2560
6023 1E 0E       2310  MVI E,14
6025 CD 97 5D    2320 L2560 CALL FNG
6028 C3 DD 5F    2330  JMP L2460
602B CD 31 60    2340 L2590 CALL S2610
602E C3 DD 5F    2350  JMP L2460
6031 CD B5 60    2360 S2610 CALL S2850
6034 3A E3 53    2370 L2630 LDA SOST
6037 FE 2A       2380  CPI '*'
6039 CA 57 60    2390  JZ L2700
603C CD 59 5E    2400  CALL CKRES
603F C0          2410  RNZ
6040 AF          2420  XRA A
6041 85          2430  ADD L
6042 CA 57 60    2440  JZ L2700
6045 D6 1E       2450  SUI 30
6047 CA 57 60    2460  JZ L2700
604A D6 32       2470  SUI 50
604C CA 57 60    2480  JZ L2700
604F D6 23       2490  SUI 35
6051 CA 57 60    2500  JZ L2700
6054 D6 05       2510  SUI 5
6056 C0          2520  RNZ
6057 21 E3 53    2530 L2700 LXI H,SOST
605A 11 DE 53    2540  LXI D,YST
605D 01 FB FF    2550  LXI B,-5
6060 CD 00 01    2560  CALL MOVE
6063 CD A2 5E    2570  CALL S6180
6066 CD DC 5A    2580  CALL S1240
6069 CD B5 60    2590  CALL S2850
606C CD CD 5E    2600  CALL S6240
606F 01 00 01    2610  LXI B,100H
6072 11 04 00    2620  LXI D,4
6075 3A DE 53    2630  LDA YST
6078 FE 2A       2640  CPI '*'
607A CA AF 60    2650  JZ L2830
607D C5          2660  PUSH B
607E D5          2670  PUSH D
607F 21 DE 53    2680  LXI H,YST
6082 CD 5C 5E    2690  CALL CKRES+3
6085 D1          2700  POP D
6086 C1          2710  POP B
6087 AF          2720  XRA A
6088 85          2730  ADD L
6089 C2 92 60    2740  JNZ L2730
608C 11 0F 00    2750  LXI D,15
608F C3 AF 60    2760  JMP L2830
6092 D6 1E       2770 L2730 SUI 30
6094 C2 9B 60    2780  JNZ L2740
6097 13          2790  INX D
6098 C3 AF 60    2800  JMP L2830
609B D6 32       2810 L2740 SUI 50
609D C2 A6 60    2820  JNZ L2760
60A0 11 07 00    2830  LXI D,7
60A3 C3 AF 60    2840  JMP L2830
60A6 11 11 00    2850 L2760 LXI D..
60A9 D6 23       2860  SUI 35
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60AB CA AF 60     JZ L2830
60AE 13           INX D
60AF CD 97 5D     L2830 CALL FNG
60B2 C3 34 60     JMP L2630
60B5 3A E3 53     S2850 LDA SOST

60B8 FE 28        CPI '('
60BA CA 73 61     JZ L3100
60BD CD 59 5E     CALL CKRES
60C0 C2 DD 60     JNZ L2920
60C3 3E AA        MVI A,170
60C5 95           SUB L
60C6 CA 6A 61     JZ L3080
60C9 D6 05        SUI 5
60CB CA 5D 61     JZ L3060
60CE D6 05        SUI 5
60D0 CA E3 60     JZ L2940
60D3 D6 4B        SUI 75
60D5 CA FF 61     JZ L3260
60D8 D6 0A        SUI 10
60DA CA 87 61     JZ L3140
60DD 21 17 00     L2920 LXI H,23
60E0 C3 57 5D     JMP FNE
60E3 CD B7 5A     L2940 CALL S2060
60E6 7C           MOV A,H
60E7 B5           ORA L
60E8 C2 F1 60     JNZ $+6
60EB 21 0B 00     LXI H,11
60EE C3 57 5D     JMP FNE
60F1 2B           DCX H
60F2 11 9C 50     LXI D,TOST
60F5 19           DAD D
60F6 7E           MOV A,M
60F7 FE 50        CPI 'P'
60F9 C2 02 61     JNZ L2970
60FC 21 15 00     LXI H,21
60FF C3 57 5D     JMP FNE
6102 FE 59        L2970 CPI 'Y'
6104 C2 1A 61     JNZ L3000
6107 01 00 05     LXI B,500H
610A 11 01 00     LXI D,1
610D CD 97 5D     CALL FNG
6110 2A 14 54     LHLD I
6113 2B           DCX H
6114 22 14 54     SHLD I
6117 C3 06 4F     JMP F4290
611A FE 41        L3000 CPI 'A'
611C CA B1 61     JZ L3190
611F FE 43        CPI 'C'
6121 C2 37 61     JNZ L3030
6124 2A 14 54     LHLD I
6127 EB           XCHG
6128 21 0C 53     LXI H,T2
612B CD BA 57     CALL ARRAY
612E 01 00 00     LXI B,0
6131 CD 97 5D     CALL FNG
6134 C3 DC 5A     JMP S1240
6137 2A 14 54     L3030 LHLD I
613A EB           XCHG
613B 21 0C 53     LXI H,T2
613E CD BA 57     CALL ARRAY
6141 D5           PUSH D
6142 2A 14 54     LHLD I
6145 EB           XCHG
6146 21 A6 52     LXI H,T1
6149 CD BA 57     CALL ARRAY
614C CD C6 57     CALL CMD
614F 2A 20 54     LHLD L1
6152 19           DAD D
6153 4D           MOV C,L
6154 06 02        MVI B,2
6156 D1           POP D
6157 CD 97 5D     CALL FNG
615A C3 DC 5A     JMP S1240
615D 2A 18 54     L3060 LHLD N3
6160 EB           XCHG
6161 01 00 00     LXI B,0
6164 CD 97 5D     CALL FNG
6167 C3 DC 5A     JMP S1240
616A 3A 4E 52     L3080 LDA CST
616D 5F           MOV E,A
616E 16 00        MVI D,0
6170 C3 61 61     JMP L3060+4
6173 CD DC 5A     L3100 CALL S1240
6176 CD 0E 62     CALL S3290
6179 3A E3 53     LDA SOST
617C FE 29        CPI ')'
617E CA DC 5A     JZ S1240
6181 21 16 00     LXI H,22
6184 C3 57 5D     JMP FNE
6187 21 5B 20     L3140 LXI H,' ['
618A 22 D9 53     SHLD FNE1ST
618D 21 21 00     LXI H,33
6190 CD 38 5D     CALL FNE2
6193 CD DC 5A     CALL S1240
6196 CD 0E 62     CALL S3290
6199 21 5D 20     LXI H,' ]'
619C 22 D9 53     SHLD FNE1ST
619F 21 22 00     LXI H,34
61A2 CD 3D 5D     CALL FNE1
61A5 01 FF 02     LXI B,2FFH
61A8 11 00 00     LXI D,0
61AB CD 97 5D     CALL FNG
61AE C3 DC 5A     JMP S1240
61B1 2A 14 54     L3190 LHLD I
61B4 22 1A 54     SHLD X
61B7 CD 77 5E     CALL S6120
61BA 21 5B 20     LXI H,' ['
61BD 22 D9 53     SHLD FNE1ST
61C0 21 21 00     LXI H,33
61C3 CD 38 5D     CALL FNE2
61C6 CD DC 5A     CALL S1240
61C9 CD 0E 62     CALL S3290
61CC 21 5D 20     LXI H,' ]'
61CF 22 D9 53     SHLD FNE1ST
61D2 21 22 00     LXI H,34
61D5 CD 3D 5D     CALL FNE1
61D8 CD 8F 5E     CALL S6150
61DB 2A 1A 54     LHLD X
61DE EB           XCHG
61DF 21 A6 52     LXI H,T1
61E2 CD BA 57     CALL ARRAY
61E5 CD C6 57     CALL CMD
61E8 2A 20 54     LHLD L1
61EB 19           DAD D
61EC 4D           MOV C,L
61ED 06 12        MVI B,18
61EF 2A 1A 54     LHLD X
61F2 EB           XCHG
61F3 21 0C 53     LXI H,T2
61F6 CD BA 57     CALL ARRAY
61F9 CD 97 5D     CALL FNG
61FC C3 DC 5A     JMP S1240
61FF CD DC 5A     L3260 CALL S1240
6202 CD B5 60     CALL S2850
6205 11 10 00     LXI D,16
6208 01 00 01     LXI B,100H
620B C3 97 5D     JMP FNG
620E CD AB 5F     S3290 CALL S2380
6211 2A E3 53     LHLD SOST
6214 11 08 00     LXI D,8
6217 44           MOV B,H
6218 4D           MOV C,L
6219 21 3D 20     LXI H,' ='
621C CD 43 62     CALL BHCMPJ
621F 13           INX D
6220 21 3C 3E     LXI H,'><'
6223 CD 43 62     CALL BHCMPJ
6226 13           INX D
6227 21 3C 20     LXI H,' <'
```

```
622A CD 43 62     1450  CALL BHCMPJ
622D 13           1460  INX D
622E 21 3E 3D     1470  LXI H,'=>'
6231 CD 43 62     1480  CALL BHCMPJ
6234 13           1490  INX D
6235 21 3E 20     1500  LXI H,' >'
6238 CD 43 62     1510  CALL BHCMPJ
623B 13           1520  INX D
623C 21 3C 3D     1530  LXI H,'=<'
623F CD 43 62     1540  CALL BHCMPJ
6242 C9           1550  RET
6243 CD D1 57     1560 BHCMPJ CALL BHCMP
6246 C0           1570  RNZ
6247 E1           1580  POP H
6248 D5           1590  PUSH D
6249 21 E3 53     1600  LXI H,SOST
624C 11 DE 53     1610  LXI D,YST
624F 01 FB FF     1620  LXI B,-5
6252 CD 00 01     1630  CALL MOVE
6255 CD A2 5E     1640  CALL S6180
6258 CD DC 5A     1650  CALL S1240
625B CD AB 5F     1660  CALL S2380
625E CD CD 5E     1670  CALL S6240
6261 D1           1680  POP D
6262 01 00 01     1690  LXI B,100H
6265 C3 97 5D     1700  JMP FNG
6268 CD B7 5A     1710 L3630 CALL S2060
626B CA 74 62     1720  JZ L3650
626E 21 0B 00     1730  LXI H,11
6271 C3 57 5D     1740  JMP FNE
6274 11 9C 50     1750 L3650 LXI D,TOST
6277 19           1760  DAD D
6278 2B           1770  DCX H
6279 7E           1780  MOV A,M
627A FE 41        1790  CPI 'A'
627C CA 94 62     1800  JZ L3700
627F FE 56        1810  CPI 'V'
6281 CA C7 62     1820  JZ L3760
6284 FE 59        1830  CPI 'Y'
6286 CA C7 62     1840  JZ L3760
6289 FE 50        1850  CPI 'P'
628B CA 06 4F     1860  JZ F4290
628E 21 0C 00     1870  LXI H,12
6291 C3 57 5D     1880  JMP FNE
6294 2A 14 54     1890 L3700 LHLD I
6297 22 1A 54     1900  SHLD X
629A CD 77 5E     1910  CALL S6120
629D 21 10 00     1920  LXI H,16
62A0 22 1A 54     1930  SHLD X
62A3 CD 77 5E     1940  CALL S6120
62A6 21 5B 20     1950  LXI H,' ['
62A9 22 D9 53     1960  SHLD FNE1ST
62AC 21 21 00     1970  LXI H,33
62AF CD 38 5D     1980  CALL FNE2
62B2 CD DC 5A     1990  CALL S1240
62B5 CD 0E 62     2000  CALL S3290
62B8 21 5D 20     2010  LXI H,' ]'
62BB 22 D9 53     2020  SHLD FNE1ST
62BE 21 22 00     2030  LXI H,34
62C1 CD 3D 5D     2040  CALL FNE1
62C4 C3 D9 62     2050  JMP L3780
62C7 2A 14 54     2060 L3760 LHLD I
62CA 22 1A 54     2070  SHLD X
62CD CD 77 5E     2080  CALL S6120
62D0 21 00 00     2090  LXI H,0
62D3 22 1A 54     2100  SHLD X
62D6 CD 77 5E     2110  CALL S6120
62D9 CD DC 5A     2120 L3780 CALL S1240
62DC 2A E3 53     2130  LHLD SOST
62DF 01 3A 3D     2140  LXI B,'=:'
62E2 CD D1 57     2150  CALL BHCMP
62E5 CA EE 62     2160  JZ L3810
62E8 21 0D 00     2170  LXI H,13
62EB C3 57 5D     2180  JMP FNE
62EE CD DC 5A     2190 L3810 CALL S1240
62F1 CD 0E 62     2200  CALL S3290
62F4 CD 8F 5E     2210  CALL S6150
62F7 2A 1A 54     2220  LHLD X
62FA 22 10 54     2230  SHLD K
62FD CD 8F 5E     2240  CALL S6150
6300 3A 10 54     2250  LDA K
6303 C6 03        2260  ADI 3
6305 47           2270  MOV B,A
6306 2A 1A 54     2280  LHLD X
6309 EB           2290  XCHG
630A 21 A6 52     2300  LXI H,T1
630D CD BA 57     2310  CALL ARRAY
6310 CD C6 57     2320  CALL CMD
6313 2A 20 54     2330  LHLD L1
6316 19           2340  DAD D
6317 4D           2350  MOV C,L
6318 2A 1A 54     2360  LHLD X
631B EB           2370  XCHG
631C 21 0C 53     2380  LXI H,T2
631F CD BA 57     2390  CALL ARRAY
6322 C3 97 5D     2400  JMP FNG
6325 21 28 20     2410 L3870 LXI H,' ('
6328 22 D9 53     2420  SHLD FNE1ST
632B 21 1F 00     2430  LXI H,31
632E CD 38 5D     2440  CALL FNE2
6331 CD DC 5A     2450 L3880 CALL S1240
6334 E5           2460  PUSH H
6335 21 DD 54     2470  LXI H,STR
6338 11 E3 53     2480  LXI D,SOST
633B CD 84 5A     2490  CALL STCMP
633E E1           2500  POP H
633F C2 99 63     2510  JNZ L3950
6342 11 4E 52     2520  LXI D,CST
6345 CD C6 57     2530  CALL CMD
6348 19           2540  DAD D
6349 7D           2550  MOV A,L
634A FE 01        2560  CPI 1
634C C2 66 63     2570  JNZ L3910
634F 01 00 00     2580  LXI B,0
6352 3A 4E 52     2590  LDA CST
6355 5F           2600  MOV E,A
6356 51           2610  MOV D,C
6357 CD 97 5D     2620  CALL FNG
635A 01 00 08     2630  LXI B,800H
635D 11 01 00     2640  LXI D,1
6360 CD 97 5D     2650  CALL FNG
6363 C3 93 63     2660  JMP L3940
6366 21 4E 52     2670 L3910 LXI H,CST
6369 5F           2680  MOV E,A
636A 16 00        2690  MVI D,0
636C D5           2700  PUSH D
636D E5           2710 L3920 PUSH H
636E F5           2720  PUSH P
636F 7E           2730  MOV A,M
6370 01 00 00     2740  LXI B,0
6373 51           2750  MOV D,C
6374 5F           2760  MOV E,A
6375 CD 97 5D     2770  CALL FNG
6378 F1           2780  POP P
6379 3D           2790  DCR A
637A CA 82 63     2800  JZ L3930
637D E1           2810  POP H
637E 23           2820  INX H
637F C3 6D 63     2830  JMP L3920
6382 D1           2840 L3930 POP D
6383 D1           2850  POP D
6384 01 00 00     2860  LXI B,0
6387 CD 97 5D     2870  CALL FNG
638A 01 00 08     2880  LXI B,800H
638D 11 08 00     2890  LXI D,8
6390 CD 97 5D     2900  CALL FNG
6393 CD DC 5A     2910 L3940 CALL S1240
6396 C3 C3 63     2920  JMP L4000
6399 CD 0E 62     2930 L3950 CALL S3290
639C 21 01 00     2940  LXI H,1
```

```
639F 3A E3 53
63A2 FE 23
63A4 CA AE 63
63A7 FE 25
63A9 C2 B0 63
63AC 23
63AD 23
63AE 23
63AF 23
63B0 22 10 54
63B3 7D
63B4 FE 02
63B6 F4 DC 5A
63B9 2A 10 54
63BC EB
63BD 01 00 08
63C0 CD 97 5D
63C3 3A E3 53
63C6 FE 2C
63C8 CA 31 63
63CB 21 29 20
63CE 22 D9 53
63D1 21 16 00
63D4 CD 3D 5D
63D7 C3 DC 5A
63DA 21 28 20
63DD 22 D9 53
63E0 21 1F 00
63E3 CD 38 5D
63E6 21 D3 54
63E9 11 D9 53
63EC 01 FB FF
63EF CD 00 01
63F2 21 04 00
63F5 CD 38 5D
63F8 CD B7 5A
63FB 7C
63FC B5
63FD C2 06 64
6400 21 0B 00
6403 C3 57 5D
6406 22 1A 54
6409 CD 77 5E
640C 2A 14 54
640F 11 9C 50
6412 19
6413 2B
6414 7E
6415 FE 41
6417 CA 94 64
641A FE 56
641C CA 25 64
641F 21 04 00
6422 C3 57 5D
6425 21 00 00
6428 22 0C 54
642B CD DC 5A
642E 21 00 00
6431 3A E3 53
6434 FE 23
6436 CA 40 64
6439 FE 25
643B C2 42 64
643E 23
643F 23
6440 23
6441 23
6442 22 10 54
6445 01 00 08
6448 EB
6449 CD 97 5D
644C 2A 10 54
644F 7D
6450 B4
6451 C4 DC 5A
```

```
 LDA SOST
 CPI '#'
 JZ L3980-2
 CPI '%'
 JNZ L3980
 INX H
 INX H
 INX H
 INX H
L3980 SHLD K
 MOV A,L
 CPI 2
 CP S1240
L3990 LHLD K
 XCHG
 LXI B,800H
 CALL FNG
L4000 LDA SOST
 CPI ','
 JZ L3880
 LXI H,' )'
 SHLD FNE1ST
 LXI H,22
 CALL FNE1
 JMP S1240
L4040 LXI H,' ('
 SHLD FNE1ST
 LXI H,31
 CALL FNE2
L4050 LXI H,IDENT
 LXI D,FNE1ST
 LXI B,-5
 CALL MOVE
 LXI H,4
 CALL FNE2
 CALL S2060
 MOV A,H
 ORA L
 JNZ L4070
 LXI H,11
 JMP FNE
L4070 SHLD X
 CALL S6120
 LHLD I
 LXI D,TOST
 DAD D
 DCX H
 MOV A,M
 CPI 'A'
 JZ L4190
 CPI 'V'
 JZ L4090
 LXI H,4
 JMP FNE
L4090 LXI H,0
 SHLD L0
L4100 CALL S1240
 LXI H,0
 LDA SOST
 CPI '#'
 JZ L4130-2
 CPI '%'
 JNZ L4130
 INX H
 INX H
 INX H
 INX H
L4130 SHLD K
 LXI B,800H
 XCHG
 CALL FNG
 LHLD K
 MOV A,L
 ORA H
 CNZ S1240
```

```
6454 CD 8F 5E
6457 2A 0C 54
645A 23
645B 23
645C 23
645D 45
645E 2A 1A 54
6461 EB
6462 21 A6 52
6465 CD BA 57
6468 CD C6 57
646B 2A 20 54
646E 19
646F 4D
6470 2A 1A 54
6473 EB
6474 21 0C 53
6477 CD BA 57
647A CD 97 5D
647D 3A E3 53
6480 FE 2C
6482 CA E6 63
6485 21 29 20
6488 22 D9 53
648B 21 1F 00
648E CD 3D 5D
6491 C3 DC 5A
6494 21 5B 20
6497 22 D9 53
649A 21 21 00
649D CD 38 5D
64A0 CD DC 5A
64A3 CD 0E 62
64A6 21 5D 20
64A9 22 D9 53
64AC 21 22 00
64AF CD 3D 5D
64B2 21 10 00
64B5 22 0C 54
64B8 C3 2B 64
64BB
>

64BB 21 28 20
64BE 22 D9 53
64C1 21 1F 00
64C4 CD 38 5D
64C7 CD DC 5A
64CA CD 0E 62
64CD 21 29 20
64D0 22 D9 53
64D3 21 16 00
64D6 CD 3D 5D
64D9 01 FF 04
64DC 11 00 00
64DF CD 97 5D
64E2 C3 DC 5A
64E5 21 00 00
64E8 22 28 54
64EB 2A 14 54
64EE 22 2A 54
64F1 EB
64F2 21 72 53
64F5 CD BA 57
64F8 7B
64F9 B2
64FA CA 5E 65
64FD 21 28 20
6500 22 D9 53
6503 21 1F 00
6506 CD 38 5D
6509 2A 28 54
650C 22 1A 54
650F CD 77 5E
6512 2A 2A 54
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```
 CALL S6150
 LHLD L0
 INX H
 INX H
 INX H
 MOV B,L
 LHLD X
 XCHG
 LXI H,T1
 CALL ARRAY
 CALL CMD
 LHLD L1
 DAD D
 MOV C,L
 LHLD X
 XCHG
 LXI H,T2
 CALL ARRAY
 CALL FNG
 LDA SOST
 CPI ','
 JZ L4050
 LXI H,' )'
 SHLD FNE1ST
 LXI H,31
 CALL FNE1
 JMP S1240
L4190 LXI H,' ['
 SHLD FNE1ST
 LXI H,33
 CALL FNE2
 CALL S1240
 CALL S3290
 LXI H,' ]'
 SHLD FNE1ST
 LXI H,34
 CALL FNE1
 LXI H,16
 SHLD L0
 JMP L4100
ASPC EQU $

L4240 LXI H,' ('
 SHLD FNE1ST
 LXI H,31
 CALL FNE2
 CALL S1240
 CALL S3290
 LXI H,' )'
 SHLD FNE1ST
 LXI H,22
 CALL FNE1
 LXI B,4FFH
 LXI D,0
 CALL FNG
 JMP S1240
L4290 LXI H,0
 SHLD K2
 LHLD I
 SHLD K3
 XCHG
 LXI H,T3
 CALL ARRAY
 MOV A,E
 ORA D
 JZ L4400
 LXI H,' ('
 SHLD FNE1ST
 LXI H,31
 CALL FNE2
L4320 LHLD K2
 SHLD X
 CALL S6120
 LHLD K3
```

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6515 22 1A 54    SHLD X
6518 CD 77 5E    CALL S6120
651B CD DC 5A    CALL S1240
651E CD 0E 62    CALL S3290
6521 CD 8F 5E    CALL S6150
6524 22 2A 54    SHLD K3
6527 CD 8F 5E    CALL S6150
652A 23          INX H
652B 22 28 54    SHLD K2
652E 3A E3 53    LDA SOST
6531 FE 2C       CPI ','
6533 CA 09 65    JZ L4320
6536 2A 2A 54    LHLD K3
6539 11 72 53    LXI D,T3
653C EB          XCHG
653D CD BA 57    CALL ARRAY
6540 CD C6 57    CALL CMD
6543 2A 2A 54    LHLD K3
6546 19          DAD D
6547 7D          MOV A,L
6548 B7          ORA A
6549 C2 52 65    JNZ L4390
654C 21 23 00    LXI H,35
654F C3 57 5D    JMP FNE
6552 21 29 20   L4390 LXI H,' )'
6555 22 D9 53    SHLD FNE1ST
6558 21 16 00    LXI H,22
655B CD 3D 5D    CALL FNE1
655E 06 04      L4400 MVI B,4
6560 2A 2A 54    LHLD K3
6563 11 A6 52    LXI D,T1
6566 EB          XCHG
6567 CD BA 57    CALL ARRAY
656A CD C6 57    CALL CMD
656D 2A 20 54    LHLD L1
6570 19          DAD D
6571 4D          MOV C,L
6572 2A 2A 54    LHLD K3
6575 11 0C 53    LXI D,T2
6578 EB          XCHG
6579 CD BA 57    CALL ARRAY
657C CD 97 5D    CALL FNG
657F 2A 28 54    LHLD K2
6582 7C          MOV A,H
6583 B5          ORA L
6584 CA DC 5A    JZ S1240
6587 EB          XCHG
6588 CD C6 57    CALL CMD
658B 01 00 05    LXI B,500H
658E CD 97 5D    CALL FNG
6591 C3 DC 5A    JMP S1240
6594 CD DC 5A   L4440 CALL S1240
6597 CD 0E 62    CALL S3290
659A 21 B0 54    LXI H,WOST+125
659D 11 D9 53    LXI D,FNE1ST
65A0 01 FB FF    LXI B,-5
65A3 CD 00 01    CALL MOVE
65A6 21 10 00    LXI H,16
65A9 CD 3D 5D    CALL FNE1
65AC CD DC 5A    CALL S1240
65AF 2A 0E 54    LHLD C1
65B2 22 1A 54    SHLD X
65B5 CD 77 5E    CALL S6120
65B8 01 00 07    LXI B,700H
65BB 11 00 00    LXI D,0
65BE CD 97 5D    CALL FNG
65C1 CD 03 4F    CALL F3490
65C4 21 60 54    LXI H,WOST+45
65C7 11 E3 53    LXI D,SOST
65CA CD 84 5A    CALL STCMP
65CD C2 1C 5E    JNZ S6520
65D0 CD 8F 5E    CALL S6150
65D3 22 10 54    SHLD K
65D6 2A 0E 54    LHLD C1
65D9 22 1A 54    SHLD X
65DC CD 77 5E    CALL S6120
65DF 01 00 06    LXI B,600H
65E2 11 00 00    LXI D,0
65E5 CD 97 5D    CALL FNG
65E8 2A 10 54    LHLD K
65EB 22 1A 54    SHLD X
65EE CD 1F 5E    CALL L6540
65F1 CD DC 5A    CALL S1240
65F4 CD 03 4F    CALL F3490
65F7 C3 1C 5E    JMP S6520
65FA CD DC 5A   L4590 CALL S1240
65FD CD 03 4F    CALL F3490
6600 3A E3 53    LDA SOST
6603 FE 3B       CPI ';'
6605 CA FA 65    JZ L4590
6608 21 65 54    LXI H,WOST+50
660B 11 E3 53    LXI D,SOST
660E CD 84 5A    CALL STCMP
6611 CA DC 5A    JZ S1240
6614 21 11 00    LXI H,17
6617 C3 57 5D    JMP FNE
661A 21 5B 20   L4650 LXI H,' ['
661D 22 D9 53    SHLD FNE1ST
6620 21 21 00    LXI H,33
6623 CD 38 5D    CALL FNE2
6626 CD DC 5A    CALL S1240
6629 CD 0E 62    CALL S3290
662C 3A E3 53    LDA SOST
662F FE 5D       CPI ']'
6631 CA 3A 66    JZ L4680
6634 21 22 00    LXI H,34
6637 C3 57 5D    JMP FNE
663A 21 3A 3D   L4680 LXI H,'=:'
663D 22 D9 53    SHLD FNE1ST
6640 21 0D 00    LXI H,13
6643 CD 38 5D    CALL FNE2
6646 CD DC 5A    CALL S1240
6649 CD 0E 62    CALL S3290
664C 01 FF 03    LXI B,3FFH
664F 11 00 00    LXI D,0
6652 C3 97 5D    JMP FNG
6655 2A 0E 54   L4730 LHLD C1
6658 22 1A 54    SHLD X
665B CD 77 5E    CALL S6120
665E CD DC 5A   L4740 CALL S1240
6661 CD 03 4F    CALL F3490
6664 3A E3 53    LDA SOST
6667 FE 3B       CPI ';'
6669 CA 5E 66    JZ L4740
666C 21 BF 54    LXI H,WOST+140
666F 11 D9 53    LXI D,FNE1ST
6672 01 FB FF    LXI B,-5
6675 CD 00 01    CALL MOVE
6678 21 0A 00    LXI H,10
667B CD 3D 5D    CALL FNE1
667E CD DC 5A    CALL S1240
6681 CD 0E 62    CALL S3290
6684 CD 8F 5E    CALL S6150
6687 EB          XCHG
6688 01 00 07    LXI B,700H
668B C3 97 5D    JMP FNG
668E CD DC 5A   L4800 CALL S1240
6691 2A 0E 54    LHLD C1
6694 22 1A 54    SHLD X
6697 CD 77 5E    CALL S6120
669A CD 0E 62    CALL S3290
669D 2A 0E 54    LHLD C1
66A0 22 1A 54    SHLD X
66A3 CD 77 5E    CALL S6120
66A6 01 00 07    LXI B,700H
66A9 11 00 00    LXI D,0
66AC CD 97 5D    CALL FNG
66AF 21 44 4F    LXI H,'OD'
66B2 22 D9 53    SHLD FNE1ST
66B5 21 12 00    LXI H,18
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66B8 CD 3D 5D    1830  CALL FNE1
66BB CD DC 5A    1840  CALL S1240
66BE CD 03 4F    1850  CALL F3490
66C1 CD 8F 5E    1860  CALL S6150
66C4 22 10 54    1870  SHLD K
66C7 CD 8F 5E    1880  CALL S6150
66CA EB          1890  XCHG
66CB 01 00 06    1900  LXI B,600H
66CE CD 97 5D    1910  CALL FNG
66D1 2A 10 54    1920  LHLD K
66D4 22 1A 54    1930  SHLD X
66D7 C3 1F 5E    1940  JMP L6540
66DA CD DC 5A    1950 L4890 CALL S1240
66DD CD 0E 62    1960  CALL S3290
66E0 21 4F 46    1970  LXI H,'FO'
66E3 22 D9 53    1980  SHLD FNE1ST
66E6 21 19 00    1990  LXI H,25
66E9 CD 3D 5D    2000  CALL FNE1
66EC 21 01 00    2010  LXI H,1
66EF 22 1E 54    2020  SHLD I2
66F2 21 00 00    2030 L4920 LXI H,0
66F5 22 1C 54    2040  SHLD I1
66F8 CD DC 5A    2050 L4930 CALL S1240
66FB CD 35 5F    2060  CALL S2240
66FE 01 00 01    2070  LXI B,100H
6701 11 15 00    2080  LXI D,21
6704 CD 97 5D    2090  CALL FNG
6707 01 00 00    2100  LXI B,0
670A 2A 18 54    2110  LHLD N3
670D EB          2120  XCHG
670E CD 97 5D    2130  CALL FNG
6711 01 00 01    2140  LXI B,100H
6714 11 08 00    2150  LXI D,8
6717 CD 97 5D    2160  CALL FNG
671A CD DC 5A    2170  CALL S1240
671D 3A E3 53    2180  LDA SOST
6720 FE 3A       2190  CPI ':'
6722 CA 4A 67    2200  JZ L4990
6725 21 2C 20    2210  LXI H,' ,'
6728 22 D9 53    2220  SHLD FNE1ST
672B 21 05 00    2230  LXI H,5
672E CD 3D 5D    2240  CALL FNE1
6731 2A 0E 54    2250  LHLD C1
6734 22 1A 54    2260  SHLD X
6737 CD 77 5E    2270  CALL S6120
673A 01 01 07    2280  LXI B,701H
673D 11 00 00    2290  LXI D,0
6740 CD 97 5D    2300  CALL FNG
6743 2A 1C 54    2310  LHLD I1
6746 23          2320  INX H
6747 C3 F5 66    2330  JMP L4930-3
674A 2A 0E 54    2340 L4990 LHLD C1
674D 22 10 54    2350  SHLD K
6750 01 00 07    2360  LXI B,700H
6753 11 00 00    2370  LXI D,0
6756 CD 97 5D    2380  CALL FNG
6759 21 01 00    2390  LXI H,1
675C 22 14 54    2400  SHLD I
675F EB          2410 L5000 XCHG
6760 2A 1C 54    2420  LHLD I1
6763 CD C6 57    2430  CALL CMD
6766 19          2440  DAD D
6767 7C          2450  MOV A,H
6768 B7          2460  ORA A
6769 FA 79 67    2470  JM $+13
676C CD 1C 5E    2480  CALL S6520
676F 2A 14 54    2490  LHLD I
6772 23          2500  INX H
6773 22 14 54    2510  SHLD I
6776 C3 5F 67    2520  JMP L5000
6779 2A 10 54    2530  LHLD K
677C 22 1A 54    2540  SHLD X
677F CD 77 5E    2550  CALL S6120
6782 CD DC 5A    2560  CALL S1240
6785 2A 1E 54    2570  LHLD I2
6788 22 1A 54    2580  SHLD X
678B CD 77 5E    2590  CALL S6120
678E CD 03 4F    2600  CALL F3490
6791 CD 8F 5E    2610  CALL S6150
6794 22 1E 54    2620  SHLD I2
6797 21 60 54    2630  LXI H,WOST+45
679A 11 E3 53    2640  LXI D,SOST
679D CD 84 5A    2650  CALL STCMP
67A0 CA D0 67    2660  JZ L5090
67A3 3A E3 53    2670  LDA SOST
67A6 FE 3B       2680  CPI ';'
67A8 C2 00 68    2690  JNZ L5130
67AB 2A 0E 54    2700  LHLD C1
67AE 22 10 54    2710  SHLD K
67B1 01 00 06    2720  LXI B,600H
67B4 11 00 00    2730  LXI D,0
67B7 CD 97 5D    2740  CALL FNG
67BA CD 1C 5E    2750  CALL S6520
67BD 2A 10 54    2760  LHLD K
67C0 22 1A 54    2770  SHLD X
67C3 CD 77 5E    2780  CALL S6120
67C6 2A 1E 54    2790  LHLD I2
67C9 23          2800  INX H
67CA 22 1E 54    2810  SHLD I2
67CD C3 F2 66    2820  JMP L4920
67D0 2A 0E 54    2830 L5090 LHLD C1
67D3 22 10 54    2840  SHLD K
67D6 01 00 06    2850  LXI B,600H
67D9 11 00 00    2860  LXI D,0
67DC CD 97 5D    2870  CALL FNG
67DF CD 1C 5E    2880  CALL S6520
67E2 2A 10 54    2890  LHLD K
67E5 22 1A 54    2900  SHLD X
67E8 CD 77 5E    2910  CALL S6120
67EB CD DC 5A    2920  CALL S1240
67EE 2A 1E 54    2930  LHLD I2
67F1 22 1A 54    2940  SHLD X
67F4 CD 77 5E    2950  CALL S6120
67F7 CD 03 4F    2960  CALL F3490
67FA CD 8F 5E    2970  CALL S6150
67FD 22 1E 54    2980  SHLD I2
6800 21 65 54    2990 L5130 LXI H,WOST+50
6803 11 D9 53    3000  LXI D,FNE1ST
6806 01 FB FF    3010  LXI B,-5
6809 CD 00 01    3020  CALL MOVE
680C 21 11 00    3030  LXI H,17
680F CD 3D 5D    3040  CALL FNE1
6812 21 01 00    3050  LXI H,1
6815 22 14 54    3060  SHLD I
6818 CD 1C 5E    3070 L5140 CALL S6520
681B 2A 14 54    3080  LHLD I
681E 23          3090  INX H
681F 22 14 54    3100  SHLD I
6822 EB          3110  XCHG
6823 2A 1E 54    3120  LHLD I2
6826 CD C6 57    3130  CALL CMD
6829 19          3140  DAD D
682A 7C          3150  MOV A,H
682B B7          3160  ORA A
682C F2 18 68    3170  JP L5140
682F 01 00 05    3180  LXI B,500H
6832 11 FF FF    3190  LXI D,-1
6835 CD 97 5D    3200  CALL FNG
6838 C3 DC 5A    3210  JMP S1240
683B 21 D3 54    3220 L5170 LXI H,IDENT
683E 11 D9 53    3230  LXI D,FNE1ST
6841 01 FB FF    3240  LXI B,-5
6844 CD 00 01    3250  CALL MOVE
6847 21 04 00    3260  LXI H,4
684A CD 38 5D    3270  CALL FNE2
684D CD 68 62    3280  CALL L3630
6850 CD 77 5E    3290  CALL S6120
6853 21 01 00    3300  LXI H,1
6856 22 22 54    3310  SHLD F9
6859 21 B5 54    3320  LXI H,WOST+130
685C 11 E3 53    3330  LXI D,SOST
685F CD 84 5A    3340  CALL STCMP
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6862 CA 7D 68    JZ L5210
6865 21 5B 54    LXI H,WOST+40
6868 11 D9 53    LXI D,FNE1ST
686B 01 FB FF    LXI B,-5
686E CD 00 01    CALL MOVE
6871 21 1C 00    LXI H,28
6874 CD 3D 5D    CALL FNE1
6877 21 00 00    LXI H,0
687A 22 22 54    SHLD F9
687D CD DC 5A   L5210 CALL S1240
6880 CD 0E 62    CALL S3290
6883 CD 8F 5E    CALL S6150
6886 22 10 54    SHLD K
6889 2A 0E 54    LHLD C1
688C 22 1A 54    SHLD X
688F CD 77 5E    CALL S6120
6892 01 00 01    LXI B,100H
6895 11 15 00    LXI D,21
6898 CD 97 5D    CALL FNG
689B 06 02       MVI B,2
689D 2A 10 54    LHLD K
68A0 11 A6 52    LXI D,T1
68A3 EB          XCHG
68A4 CD BA 57    CALL ARRAY
68A7 CD C6 57    CALL CMD

68AA 2A 20 54    LHLD L1
68AD 19          DAD D
68AE 4D          MOV C,L
68AF 2A 10 54    LHLD K
68B2 11 0C 53    LXI D,T2
68B5 EB          XCHG
68B6 CD BA 57    CALL ARRAY
68B9 CD 97 5D    CALL FNC
68BC 2A 22 54    LHLD F9
68BF 11 0D 00    LXI D,13
68C2 EB          XCHG
68C3 CD C6 57    CALL CMD
68C6 19          DAD D
68C7 19          DAD D
68C8 EB          XCHG
68C9 01 00 01    LXI B,100H
68CC CD 97 5D    CALL FNG
68CF 2A 0E 54    LHLD C1
68D2 22 1A 54    SHLD X
68D5 CD 77 5E    CALL S6120
68D8 01 00 07    LXI B,700H
68DB 11 00 00    LXI D,0
68DE CD 97 5D    CALL FNG
68E1 2A 22 54    LHLD F9
68E4 22 1A 54    SHLD X
68E7 CD 77 5E    CALL S6120
68EA 2A 10 54    LHLD K
68ED 22 1A 54    SHLD X
68F0 CD 77 5E    CALL S6120
68F3 21 44 4F    LXI H,'OD'
68F6 22 D9 53    SHLD FNE1ST
68F9 21 12 00    LXI H,18
68FC CD 3D 5D    CALL FNE1
68FF CD DC 5A    CALL S1240
6902 CD 68 69    CALL S3490
6905 CD 8F 5E    CALL S6150
6908 06 02       MVI B,2
690A 11 A6 52    LXI D,T1
690D EB          XCHG
690E CD BA 57    CALL ARRAY
6911 CD C6 57    CALL CMD
6914 2A 20 54    LHLD L1
6917 19          DAD D
6918 4D          MOV C,L
6919 C5          PUSH B
691A 2A 1A 54    LHLD X
691D EB          XCHG
691E 21 0C 53    LXI H,T2
6921 CD BA 57    CALL ARRAY
6924 D5          PUSH D
6925 CD 97 5D    CALL FNG
6928 2A 1A 54    LHLD X
692B 22 10 54    SHLD K
692E CD 8F 5E    CALL S6150
6931 EB          XCHG
6932 CD C6 57    CALL CMD
6935 21 14 00    LXI H,20
6938 19          DAD D
6939 EB          XCHG
693A 01 00 01    LXI B,100H
693D CD 97 5D    CALL FNG
6940 D1          POP D
6941 C1          POP B
6942 04          INR B
6943 CD 97 5D    CALL FNC
6946 CD 8F 5E    CALL S6150
6949 22 10 54    SHLD K
694C CD 8F 5E    CALL S6150
694F EB          XCHG
6950 01 00 06    LXI B,600H
6953 CD 97 5D    CALL FNG
6956 2A 10 54    LHLD K
6959 22 1A 54    SHLD X
695C CD 1F 5E    CALL L6540
695F 11 FF FF    LXI D,-1
6962 01 00 05    LXI B,500H
6965 C3 97 5D    JMP FNG
6968 CD 59 5E   S3490 CALL CKRES
696B C0          RNZ
696C 3E A0       MVI A,160
696E 95          SUB L
696F CA 68 62    JZ L3630
6972 D6 05       SUI 5
6974 CA 25 63    JZ L3870
6977 D6 05       SUI 5
6979 CA 8E 66    JZ L4800
697C D6 28       SUI 40
697E CA 55 66    JZ L4730
6981 D6 05       SUI 5
6983 CA DA 63    JZ L4040
6986 D6 1E       SUI 30
6988 CA 1A 66    JZ L4650
698B D6 0A       SUI 10
698D CA 94 65    JZ L4440
6990 D6 0A       SUI 10
6992 CA 3B 68    JZ L5170
6995 D6 23       SUI 35
6997 CA DA 66    JZ L4890
699A D6 05       SUI 5
699C CA BB 64    JZ L4240
699F D6 05       SUI 5
69A1 CA FA 65    JZ L4590
69A4 C9          RET
69A5 21 D3 54   L5730 LXI H,IDENT
69A8 11 D9 53    LXI D,FNE1ST
69AB 01 FB FF    LXI B,-5
69AE CD 00 01    CALL MOVE
69B1 21 04 00    LXI H,4
69B4 CD 38 5D    CALL FNE2
69B7 21 00 00    LXI H,0
69BA 22 26 54    SHLD K1
69BD 3E 50       MVI A,'P'
69BF 32 E8 53    STA KST
69C2 CD 16 5A    CALL S1960
69C5 2A 20 54    LHLD L1
69C8 23          INX H
69C9 22 20 54    SHLD L1
69CC C3 FE 69    JMP L5810
69CF 21 D3 54   L5770 LXI H,IDENT
69D2 11 D9 53    LXI D,FNE1ST
69D5 01 FB FF    LXI B,-5
69D8 CD 00 01    CALL MOVE
69DB 21 04 00    LXI H,4
69DE CD 38 5D    CALL FNE2
69E1 3E 46       MVI A,'F'
69E3 32 E8 53    STA KST
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69E6 CD 16 5A    1270       CALL S1960
69E9 2A 20 54    1280       LHLD L1
69EC 23          1290       INX H
69ED 22 20 54    1300       SHLD L1
69F0 21 01 00    1310       LXI H,1
69F3 22 26 54    1320       SHLD K1
69F6 3E 59       1330       MVI A,'Y'
69F8 32 E8 53    1340       STA KST
69FB CD 16 5A    1350       CALL S1960
69FE 2A 26 54    1360 L5810 LHLD K1
6A01 22 28 54    1370       SHLD K2
6A04 CD DC 5A    1380       CALL S1240
6A07 2A A6 52    1390       LHLD T1
6A0A 22 1A 54    1400       SHLD X
6A0D CD 77 5E    1410       CALL S6120
6A10 2A 2C 54    1420       LHLD D0
6A13 22 1A 54    1430       SHLD X
6A16 CD 77 5E    1440       CALL S6120
6A19 3A E3 53    1450       LDA SOST
6A1C FE 28       1460       CPI '('
6A1E C2 6E 6A    1470       JNZ L5890
6A21 CD DC 5A    1480 L5850 CALL S1240
6A24 21 00 00    1490       LXI H,0
6A27 22 22 54    1500       SHLD F9
6A2A CD 8E 5F    1510       CALL S2340
6A2D 2A 26 54    1520       LHLD K1
6A30 23          1530       INX H
6A31 22 26 54    1540       SHLD K1
6A34 3A E3 53    1550       LDA SOST
6A37 FE 2C       1560       CPI ','
6A39 CA 21 6A    1570       JZ L5850
6A3C 21 29 20    1580       LXI H,' )'
6A3F 22 D9 53    1590       SHLD FNE1ST
6A42 21 16 00    1600       LXI H,22
6A45 CD 3D 5D    1610       CALL FNE1
6A48 CD DC 5A    1620       CALL S1240
6A4B 2A 26 54    1630       LHLD K1
6A4E EB          1640       XCHG
6A4F CD C6 57    1650       CALL CMD
6A52 2A A6 52    1660       LHLD T1
6A55 19          1670       DAD D
6A56 EB          1680       XCHG
6A57 21 72 53    1690       LXI H,T3
6A5A CD BA 57    1700       CALL ARRAY
6A5D E5          1710       PUSH H
6A5E 2A 28 54    1720       LHLD K2
6A61 EB          1730       XCHG
6A62 CD C6 57    1740       CALL CMD
6A65 2A 26 54    1750       LHLD K1
6A68 19          1760       DAD D
6A69 EB          1770       XCHG
6A6A E1          1780       POP H
6A6B 73          1790       MOV M,E
6A6C 23          1800       INX H
6A6D 72          1810       MOV M,D
6A6E 21 3B 20    1820 L5890 LXI H,' ;'
6A71 22 D9 53    1830       SHLD FNE1ST
6A74 21 05 00    1840       LXI H,5
6A77 CD 3D 5D    1850       CALL FNE1
6A7A 2A 26 54    1860       LHLD K1
6A7D 4D          1870       MOV C,L
6A7E 44          1880       MOV B,H
6A7F 21 01 00    1890       LXI H,1
6A82 22 14 54    1900       SHLD I
6A85 2A A6 52    1910       LHLD T1
6A88 EB          1920       XCHG
6A89 21 0C 53    1930       LXI H,T2
6A8C CD BA 57    1940       CALL ARRAY
6A8F EB          1950       XCHG
6A90 2A 14 54    1960       LHLD I
6A93 EB          1970 L5910 XCHG
6A94 CD C6 57    1980       CALL CMD
6A97 1B          1990       DCX D
6A98 1B          2000       DCX D
6A99 1B          2010       DCX D
6A9A 73          2020       MOV M,E
6A9B 23          2030       INX H
6A9C 72          2040       MOV M,D
6A9D 2B          2050       DCX H
6A9E 2B          2060       DCX H
6A9F 2B          2070       DCX H
6AA0 EB          2080       XCHG
6AA1 2A 14 54    2090       LHLD I
6AA4 23          2100       INX H
6AA5 22 14 54    2110       SHLD I
6AA8 CD D1 57    2120       CALL BHCMP
6AAB D2 93 6A    2130       JNC L5910
6AAE CD DC 5A    2140       CALL S1240
6AB1 CD 09 4F    2150       CALL F5340
6AB4 2A 20 54    2160       LHLD L1
6AB7 2B          2170       DCX H
6AB8 22 20 54    2180       SHLD L1
6ABB CD 8F 5E    2190       CALL S6150
6ABE 22 2C 54    2200       SHLD D0
6AC1 CD 8F 5E    2210       CALL S6150
6AC4 22 A6 52    2220       SHLD T1
6AC7 21 3B 20    2230       LXI H,' ;'
6ACA 22 D9 53    2240       SHLD FNE1ST
6ACD 21 05 00    2250       LXI H,5
6AD0 CD 3D 5D    2260       CALL FNE1
6AD3 CD DC 5A    2270       CALL S1240
6AD6 CD 59 5E    2280       CALL CKRES
6AD9 3E 64       2290       MVI A,100
6ADB 95          2300       SUB L
6ADC CA A5 69    2310       JZ L5730
6ADF D6 28       2320       SUI 40
6AE1 CA CF 69    2330       JZ L5770
6AE4 D6 32       2340       SUI 50
6AE6 CA EF 6A    2350       JZ L5980
6AE9 21 19 00    2360       LXI H,25
6AEC C3 57 5D    2370       JMP FNE
6AEF CD DC 5A    2380 L5980 CALL S1240
6AF2 CD 8F 5E    2390       CALL S6150
6AF5 22 10 54    2400       SHLD K
6AF8 EB          2410       XCHG
6AF9 21 0C 53    2420       LXI H,T2
6AFC CD BA 57    2430       CALL ARRAY
6AFF EB          2440       XCHG
6B00 22 1A 54    2450       SHLD X
6B03 D5          2460       PUSH D
6B04 CD 1F 5E    2470       CALL L6540
6B07 2A 0E 54    2480       LHLD C1
6B0A EB          2490       XCHG
6B0B E1          2500       POP H
6B0C 73          2510       MOV M,E
6B0D 23          2520       INX H
6B0E 72          2530       MOV M,D
6B0F 2A 2C 54    2540       LHLD D0
6B12 EB          2550       XCHG
6B13 01 00 05    2560       LXI B,500H
6B16 CD 97 5D    2570       CALL FNG
6B19 CD 68 69    2580 L6020 CALL S3490
6B1C 3A E3 53    2590       LDA SOST
6B1F FE 3B       2600       CPI ';'
6B21 C2 2A 6B    2610       JNZ L6050
6B24 CD DC 5A    2620       CALL S1240
6B27 C3 19 6B    2630       JMP L6020
6B2A 21 65 54    2640 L6050 LXI H,WOST+50
6B2D 11 E3 53    2650       LXI D,SOST
6B30 CD 84 5A    2660       CALL STCMP
6B33 CA 3C 6B    2670       JZ L6060
6B36 21 11 00    2680       LXI H,17
6B39 C3 57 5D    2690       JMP FNE
6B3C CD DC 5A    2700 L6060 CALL S1240
6B3F 01 00 01    2710       LXI B,100H
6B42 11 00 00    2720       LXI D,0
6B45 C3 97 5D    2730       JMP FNG

6B48 21 00 00    0010 S5340 LXI H,0
6B4B 22 2C 54    0020       SHLD D0
6B4E 2A 26 54    0030       LHLD K1
6B51 EB          0040       XCHG
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6B52 2A A6 52    LHLD T1
6B55 CD C6 57    CALL CMD
6B58 19          DAD D
6B59 22 1A 54    SHLD X
6B5C EB          XCHG
6B5D 21 0C 53    LXI H,T2
6B60 CD BA 57    CALL ARRAY
6B63 EB          XCHG
6B64 2A 0E 54    LHLD C1
6B67 EB          XCHG
6B68 73          MOV M,E
6B69 23          INX H
6B6A 72          MOV M,D
6B6B 01 00 06    LXI B,600H
6B6E 11 00 00    LXI D,0
6B71 CD 97 5D    CALL FNG
6B74 CD 77 5E    CALL S6120
6B77 CD 59 5E    CALL CKRES
6B7A C2 97 6B    JNZ L5440
6B7D 3E 91       MVI A,145
6B7F 95          SUB L
6B80 CA CD 6B    JZ L5550
6B83 D6 2D       SUI 45
6B85 CA A5 69    JZ L5730
6B88 D6 28       SUI 40
6B8A CA CF 69    JZ L5770
6B8D D6 23       SUI 35
6B8F CA 9D 6B    JZ L5460
6B92 D6 0F       SUI 15
6B94 CA EF 6A    JZ L5980
6B97 21 19 00   L5440 LXI H,25
6B9A C3 57 5D    JMP FNE
6B9D CD DC 5A   L5460 CALL S1240
6BA0 CD EE 5E    CALL S2180
6BA3 21 3B 20    LXI H,' ;'
6BA6 22 D9 53    SHLD FNE1ST
6BA9 21 05 00    LXI H,5
6BAC CD 3D 5D    CALL FNE1
6BAF CD DC 5A    CALL S1240
6BB2 CD 59 5E    CALL CKRES
6BB5 3E 91       MVI A,145
6BB7 95          SUB L
6BB8 CA CD 6B    JZ L5550
6BBB D6 2D       SUI 45
6BBD CA A5 69    JZ L5730
6BC0 D6 28       SUI 40
6BC2 CA CF 69    JZ L5770
6BC5 D6 32       SUI 50
6BC7 CA EF 6A    JZ L5980
6BCA C3 A0 6B    JMP L5460+3
6BCD 21 00 00   L5550 LXI H,0
6BD0 22 0C 54    SHLD L0
6BD3 2C          INR L
6BD4 22 22 54    SHLD F9
6BD7 CD DC 5A   L5560 CALL S1240
6BDA CD 8E 5F    CALL S2340
6BDD 2A 0C 54   L5570 LHLD L0
6BE0 23          INX H
6BE1 22 0C 54    SHLD L0
6BE4 3A E3 53    LDA SOST
6BE7 FE 2C       CPI ','
6BE9 CA D7 6B    JZ L5560
6BEC 21 3A 20    LXI H,' :'
6BEF 22 D9 53    SHLD FNE1ST
6BF2 21 05 00    LXI H,5
6BF5 CD 3D 5D    CALL FNE1
6BF8 CD DC 5A    CALL S1240
6BFB 21 38 54    LXI H,WOST+5
6BFE 11 E3 53    LXI D,SOST
6C01 CD 84 5A    CALL STCMP
6C04 CA 1C 6C    JZ L5610
6C07 21 79 54    LXI H,WOST+70
6C0A 11 D9 53    LXI D,FNE1ST
6C0D 01 FB FF    LXI B,-5
6C10 CD 00 01    CALL MOVE
6C13 21 24 00    LXI H,36
6C16 CD 3D 5D    CALL FNE1
6C19 C3 AE 6C    JMP L5670
6C1C 21 5B 20   L5610 LXI H,' ['
6C1F 22 D9 53    SHLD FNE1ST
6C22 21 21 00    LXI H,33
6C25 CD 38 5D    CALL FNE2
6C28 CD DC 5A    CALL S1240
6C2B CD 35 5F    CALL S2240
6C2E 21 5D 20    LXI H,' ]'
6C31 22 D9 53    SHLD FNE1ST
6C34 21 22 00    LXI H,34
6C37 CD 38 5D    CALL FNE2
6C3A 21 4F 46    LXI H,'FO'
6C3D 22 D9 53    SHLD FNE1ST
6C40 21 1A 00    LXI H,26
6C43 CD 38 5D    CALL FNE2
6C46 21 79 54    LXI H,WOST+70
6C49 11 D9 53    LXI D,FNE1ST
6C4C 01 FB FF    LXI B,-5
6C4F CD 00 01    CALL MOVE
6C52 21 24 00    LXI H,36
6C55 CD 38 5D    CALL FNE2
6C58 2A 0C 54    LHLD L0
6C5B EB          XCHG
6C5C 2A 2C 54    LHLD D0
6C5F CD C6 57    CALL CMD
6C62 19          DAD D
6C63 22 2C 54    SHLD D0
6C66 2A A6 52    LHLD T1
6C69 E5          PUSH H
6C6A 19          DAD D
6C6B 23          INX H
6C6C 22 14 54    SHLD I
6C6F C1          POP B
6C70 11 9C 50   L5650 LXI D,TOST
6C73 19          DAD D
6C74 2B          DCX H
6C75 36 41       MVI M,'A'
6C77 2A 14 54    LHLD I
6C7A EB          XCHG
6C7B 21 72 53    LXI H,T3
6C7E CD BA 57    CALL ARRAY
6C81 EB          XCHG
6C82 2A 18 54    LHLD N3
6C85 23          INX H
6C86 EB          XCHG
6C87 73          MOV M,E
6C88 23          INX H
6C89 72          MOV M,D
6C8A 2A 2C 54    LHLD D0
6C8D EB          XCHG
6C8E 19          DAD D
6C8F 22 2C 54    SHLD D0
6C92 D5          PUSH D
6C93 2A 14 54    LHLD I
6C96 EB          XCHG
6C97 21 0C 53    LXI H,T2
6C9A CD BA 57    CALL ARRAY
6C9D D1          POP D
6C9E 73          MOV M,E
6C9F 23          INX H
6CA0 72          MOV M,D
6CA1 2A 14 54    LHLD I
6CA4 23          INX H
6CA5 22 14 54    SHLD I
6CA8 CD D1 57    CALL BHCMP
6CAB D2 70 6C    JNC L5650
6CAE 21 3B 20   L5670 LXI H,' ;'
6CB1 22 D9 53    SHLD FNE1ST
6CB4 21 05 00    LXI H,5
6CB7 CD 38 5D    CALL FNE2
6CBA CD DC 5A    CALL S1240
6CBD CD 59 5E    CALL CKRES
6CC0 3E 64       MVI A,100
6CC2 95          SUB L
6CC3 CA A5 69    JZ L5730
```

```
6CC6 D6 28        SUI 40
6CC8 CA CF 69     JZ L5770
6CCB D6 32        SUI 50
6CCD CA EF 6A     JZ L5980
6CD0 21 00 00     LXI H,0
6CD3 22 0C 54     SHLD L0
6CD6 2C           INR L
6CD7 22 22 54     SHLD F9
6CDA CD 8E 5F     CALL S2340
6CDD C3 DD 6B     JMP L5570
6CE0 AF          RUN XRA A
6CE1 D3 04        OUT 4
6CE3 31 00 10     LXI P,1000H
6CE6 CDFD 09     CALL CLEAR
6CE9 21 33 54     LXI H,WOST
6CEC 11 F4 B0     LXI D,-TST
6CEF 19           DAD D
6CF0 11 0C 4F     LXI D,TST
6CF3 EB           XCHG
6CF4 36 00       ZER MVI M,0
6CF6 23           INX H
6CF7 1B           DCX D
6CF8 7B           MOV A,E
6CF9 B2           ORA D
6CFA C2 F4 6C     JNZ ZER
6CFD CD 4B 5D     CALL BLST
6D00 21 00 10     LXI H,SRCFIL
6D03 22 F4 53     SHLD BOFP
6D06 22 F6 53     SHLD EOFP
6D09 22 F2 53     SHLD FPTR
6D0C 36 01        MVI M,1
6D0E 21 EA 51     LXI H,SST
6D11 22 FA 53     SHLD P8
6D14 21 00 2C     LXI H,PCODES
6D17 22 FC 53     SHLD P9
6D1A 22 F8 53     SHLD P7
6D1D 21 FD 54     LXI H,L250
6D20 CD AD 05     CALL OSEQ
6D23 CD F8 09     CALL CRLF
6D26 21 FF 4E     LXI H,MEMLIM
6D29 22 FE 53     SHLD Q9
6D2C 21 14 55     LXI H,L280
6D2F CD AD 05     CALL OSEQ
6D32 CD 20 0C     CALL WH0
6D35 CD 24 0C     CALL WH1
6D38 47           MOV B,A
6D39 CD F8 09     CALL CRLF
6D3C 78           MOV A,B
6D3D FE 59        CPI 'Y'
6D3F 21 00 00     LXI H,0
6D42 CA 46 6D     JZ $+1
6D45 2C           INR L
6D46 22 04 54     SHLD Y9
6D49 3E 20        MVI A,' '
6D4B 32 D8 53     STA XST
6D4E CD DC 5A     CALL S1240
6D51 CD 48 6B     CALL S5340
6D54 21 2E 20     LXI H,' .'
6D57 22 D9 53     SHLD FNE1ST
6D5A 21 09 00     LXI H,9
6D5D CD 3D 5D     CALL FNE1
6D60 2A FC 53     LHLD P9
6D63 36 FF        MVI M,0FFH
6D65 23           INX H
6D66 36 FF        MVI M,0FFH
6D68 11 28 55     LXI D,L339
6D6B EB           XCHG
6D6C CD AD 05     CALL OSEQ
6D6F CD 0C 0A     CALL DEOUT
6D72 3E 04        MVI A,H
6D74 CD 24 0C     CALL WH1
6D77 CD F8 09     CALL CRLF
6D7A 21 36 55     LXI H,L340
6D7D CD AD 05     CALL OSEQ
6D80 CD 20 0C     CALL WH0
6D83 CD 24 0C     CALL WH1
6D86 47           MOV B,A
6D87 CD F8 09     CALL CRLF
6D8A 78           MOV A,B
6D8B FE 49        CPI 'I'
6D8D CA 9E 6D     JZ INTRP
6D90 FE 54        CPI 'T'
6D92 CA A4 6D     JZ TRANS
6D95 2A 0E 0C     LHLD 0C0EH
6D98 22 7F 72     SHLD 727FH
6D9B C3 90 73     JMP 7390H
6D9E 11 56 55    INTRP LXI D,L360
6DA1 C3 A7 6D     JMP $+3
6DA4 11 63 55    TRANS LXI D,L370
6DA7 2A BC 73     LHLD MENTR+2CH
6DAA EB           XCHG
6DAB 01 F3 FF     LXI B,-13
6DAE CD 00 01     CALL MOVE
6DB1 3E 0D        MVI A,0DH
6DB3 12           STAX D
6DB4 21 90 73     LXI H,MENTR
6DB7 22 BA 73     SHLD MENTR+2AH
6DBA 2A 0E 0C     LHLD 0C0EH
6DBD 22 7F 72     SHLD 727FH
6DC0 2A BC 73     LHLD MENTR+2CH
6DC3 C3 C2 73     JMP MENTR+32H
6DC6             LSTBYT EQU $-1
```

*Symbol Table for listing 5.*

| | |
|---|---|
| F3490 | 4F03 |
| F4290 | 4F06 |
| F5340 | 4F09 |
| PCODES | 2C00 |
| MEMLIM | 4EFF |
| SRCFIL | 1000 |
| N0 | 0020 |
| T0 | 0032 |
| N1 | 7FFF |
| N2 | 0008 |
| TST | 4F0C |
| T0ST | 509C |
| LST | 50CE |
| AST | 510E |
| BST | 511A |
| S | 5122 |
| SST | 51EA |
| CST | 524E |
| OST | 529E |
| T1 | 52A6 |
| T2 | 530C |
| T3 | 5372 |
| XST | 53D8 |
| FNE1ST | 53D9 |
| YST | 53DE |
| S0ST | 53E3 |
| KST | 53E8 |
| ZST | 53ED |
| FPTR | 53F2 |
| BOFP | 53F4 |
| EOFP | 53F6 |
| P7 | 53F8 |
| P8 | 53FA |
| P9 | 53FC |
| Q9 | 53FE |
| S9 | 5400 |
| F5 | 5402 |
| Y9 | 5404 |
| Z | 5406 |
| C0 | 5408 |
| E9 | 540A |
| L0 | 540C |
| C1 | 540E |
| K | 5410 |
| T | 5412 |
| I | 5414 |
| J | 5416 |
| N3 | 5418 |
| X | 541A |
| I1 | 541C |
| I2 | 541E |
| L1 | 5420 |
| F9 | 5422 |
| L00 | 5424 |
| K1 | 5426 |
| K2 | 5428 |
| K3 | 542A |
| D0 | 542C |
| N | 542E |
| NCHR | 5430 |
| ADDS | 5431 |
| WOST | 5433 |
| IDENT | 54D3 |
| NUM | 54D8 |

| | |
|---|---|
| STR | 54DD |
| MST | 54E2 |
| L250 | 54FD |
| L280 | 5514 |
| L339 | 5528 |
| L340 | 5536 |
| L360 | 5556 |
| L370 | 5563 |
| L6570 | 5753 |
| L1300 | 57AE |
| WH0 | 0C20 |
| WH1 | 0C24 |
| MOVE | 0100 |
| OSEQ | 05AD |
| CROUT | 09F8 |
| CRLF | 09F8 |
| CLEAR | 09FD |
| BLK1 | 0A02 |
| DEOUT | 0A0C |
| ARRAY | 57BA |
| CMD | 57C6 |
| BHCMP | 57D1 |
| READ | 57DE |
| DECOUT | 589E |
| DECFMT | 58A7 |
| S1030 | 58D3 |
| S1090 | 58F7 |
| MENTR | 7390 |
| READ0 | 599A |
| S1960 | 5A16 |
| STCMP | 5A84 |
| COMS | 5A89 |
| SEAR | 5AA1 |
| S2060 | 5AB7 |
| S1240 | 5ADC |
| FNE2 | 5D38 |
| FNE1 | 5D3D |
| BLST | 5D4B |
| FNE | 5D57 |
| FNG | 5D97 |
| S6520 | 5E1C |
| L6540 | 5E1F |
| CKRES | 5E59 |
| S6120 | 5E77 |
| S6150 | 5E8F |
| S6180 | 5EA2 |
| S6240 | 5ECD |
| S2180 | 5EEE |
| S2240 | 5F35 |
| S2340 | 5F8E |
| S2380 | 5FAB |
| S2610 | 6031 |
| S2850 | 60B5 |
| S3290 | 620E |
| BHCMPJ | 6243 |
| L3630 | 6268 |
| L3650 | 6274 |
| L3700 | 6294 |
| L3760 | 62C7 |
| L3780 | 62D9 |
| L3810 | 62EE |
| L3870 | 6325 |
| L3880 | 6331 |

| | |
|---|---|
| L3910 | 6366 |
| L3920 | 636D |
| L3930 | 6382 |
| L3940 | 6393 |
| L3950 | 6399 |
| L3980 | 63B0 |
| L3990 | 63B9 |
| L4000 | 63C3 |
| L4040 | 63DA |
| L4050 | 63E6 |
| L4070 | 6406 |
| L4090 | 6425 |
| L4100 | 642B |
| L4130 | 6442 |
| L4190 | 6494 |
| ASPC | 64BB |
| L4240 | 64BB |
| L4290 | 64E5 |
| L4320 | 6509 |
| L4390 | 6552 |
| L4400 | 655E |
| L4440 | 6594 |
| L4590 | 65FA |
| L4650 | 661A |
| L4680 | 663A |
| L4730 | 6655 |
| L4740 | 665E |
| L4800 | 668E |
| L4890 | 66DA |
| L4920 | 66F2 |
| L4930 | 66F8 |
| L4990 | 674A |
| L5000 | 675F |
| L5090 | 67D0 |
| L5130 | 6800 |
| L5140 | 6818 |
| L5170 | 683B |
| L5210 | 687D |
| S3490 | 6968 |
| L5730 | 69A5 |
| L5770 | 69CF |
| L5810 | 69FE |
| L5850 | 6A21 |
| L5890 | 6A6E |
| L5910 | 6A93 |
| L5980 | 6AEF |
| L6020 | 6B19 |
| L6050 | 6B2A |
| L6060 | 6B3C |
| S5340 | 6B48 |
| L5440 | 6B97 |
| L5460 | 6B9D |
| L5550 | 6BCD |
| L5560 | 6BD7 |
| L5570 | 6BDD |
| L5610 | 6C1C |
| L5650 | 6C70 |
| L5670 | 6CAE |
| RUN | 6CE0 |
| ZER | 6CF4 |
| INTRP | 6D9E |
| TRANS | 6DA4 |
| LSTBYT | 6DC5 |

# Listing 6: Sample Code for DEOUT, OSEQ and MOVE Routines

```
* SAMPLE SOURCE CODE FOR UTILITIES DEOUT, OSEQ AND
*  MOVE REQUIRED BY THE TINY PASCAL PACKAGE
DEOUT MOV A,D
 CALL BYTEO
 MOV A,E
BYTEO PUSH P
 ANI 0F0H
 RAR
 RAR
 RAR
 RAR
 CALL NYBO
 POP P
 ANI 0FH
NYBO ADI 30H
 CPI 3AH
 JC $+2
 ADI 7
 JMP WH1
OSEQ MOV A,M
 CPI 13
 RZ
 INX H
 CALL WH1
 JMP OSEQ
MOVE MOV A,M
 STAX D
 INX H
 INX D
 INX B
 MOV A,B
 ORA C
 JNZ MOVE
 RZ
* WH1 IS THE ROUTINE THAT PUTS OUT THE ACCUMULATOR
*        CONTENTS TO THE CONSOLE DEVICE.
```

# Appendix C:

## An APL Interpreter in Pascal

# APL in CDC Pascal

```
PASCAL COMPILER - E.T.H. ZURICH, SWITZERLAND  PASCAL CYBER V2.0    78/10/06. 11.48.26.
                                              UNIVERSITY OF MINNESOTA        (77/03/14)

PROGRAM SCANNER(INPUT+, OUTPUT, APLFILE);

   LABEL 100;
CONST
PREFIX1 = 60; PREFIX2 = 62; (* PREFIX FOR CDC ASCII 12-BIT CODES *)
MAXVARNAMELENGTH = 10;
MAXINPUTLINE = 132;
INPUTARRAYSIZE = 134;
NUMBEROFMESSAGES = 100; MESSAGELENGTH = 80;

TYPE
    PACKEDSTRING = PACKED ARRAY[1..MAXVARNAMELENGTH] OF 0..8191;

    TOKENNOUN = (FORMRES,FORMARG,GLOBVAR,MONADOPER,
            REDUCTOPER,DYADOPER,SPECOPER,CONSTANT,
            STATEND);

  VALUES = RECORD
       REALVAL: REAL;
       NEXTVALUE: ↑VALUES;
  END;
  VARTAB = RECORD
       VARNAME: PACKEDSTRING;                              (* V1 *)
       FUNCTABPTR: ↑FUNCTAB;                              (* V2 - FTAB *)
       VALTABPTR: ↑VALTAB;                                (* V3 - VTAB *)
       DEFEREDVALTABPTR:↑FPARMTAB;
       NEXTVARTABPTR: ↑VARTAB;
  END;

  VALTAB = RECORD
       INTERMEDRESULT: BOOLEAN;
       DIMENSIONS: INTEGER;
```

```
      FIRSTDIMEN: ↑DIMENINFO;
      FORWARDORDER: BOOLEAN;
      FIRSTVALUE: ↑VALUES;
      NEXTVALTABLINK:↑VALTAB
 END;

 TDKENTABLE = RECORD
      NEXTOKEN: ↑TOKENTABLE;
      CASE NOUN     :  TOKENNOUN OF                              (* P *)
             FORMRES,FORMARG,GLDBVAR:                            (* VTAB *)
                             (VARTABPTR: ↑VARTAB);
             MONADOPER: (MONINDX:INTEGER);
             REDUCTDPER: (REDINDX:INTEGER);
             DYADOPER: (DOPINDX:INTEGER);
             SPECDPER: (CHARINDX:INTEGER);
             CDNSTANT: (VALTABPTR: ↑VALTAB);
             STATEND: (ENDADJ:INTEGER);
 END;
 VFUNC = RECORD
      NEXTSTMNT:↑TOKENTABLE;
      NEXTVFUNCPTR:↑VFUNC;
      STATLABEL:PACKEDSTRING
 END;

 FUNCTAB = RECDRD
      FUNCNAME: PACKEDSTRING;                                    (* FI *)
      ARITY: (NILADIC,MDNADIC,DYADIC);                           (* F2 *)
      RESULT : BOOLEAN; (* TRUE = EXPLICIT *)                    (* F3 *)
      RESULTNAME: PACKEDSTRING;                                  (* F4 *)
      LEFTARG: PACKEDSTRING;                                     (* F5 *)
      RIGHTARG: PACKEDSTRING;                                    (* F6 *)
      FIRSTATEMENT:↑VFUNC;
      NEXTFUNCTABPTR : ↑FUNCTAB;
      NUMOFSTATEMENTS: INTEGER;
 END;

 FPARMTAB=RECORD
            PTRVAL:↑VALTAB;                        (* SDI AND SD2 *)
            LASTPARM:↑FPARMTAB;                    (* LINK TD LAST *)
                                                        (* SD1 OR SD2 *)
                   END;

 DIMENINFO = RECORD
      NEXTDIMEN: ↑DIMENINFD;
      DIMENLENGTH: INTEGER;
 END;

 OPRECORD = RECORD
      OPINDEX: INTEGER;
      DPSYMBOL: INTEGER;
 END;

 OPERANDTAB=RECDRD
              OPERPTR:↑VALTAB;                           (* SVAL *)
              LASTOPER:↑OPERANDTAB;        (* LINK TO LAST SVAL *)
            END;
 SUBRTAB=RECORD                                          (* SF *)
            CALLEDSUBR:↑FUNCTAB;                         (* S1 *)
            TDKENCALLINGSUBR:↑TOKENTABLE;                (* S2 *)
            STATEMCALLINGSUBR:↑VFUNC;                     (* S3 *)
            LASTSUBRPTR:↑SUBRTAB;          (* LINK 'D LAST SF *)
         END;
 OPTABLE = ARRAY[1..16] OF OPRECORD;

 VARTABPTRTYPE = ↑VARTAB;
 TYPEVALTABPTR = ↑VALTAB;
 TDKENPTR=↑TOKENTABLE;
 PTRFUNCTAB=↑FUNCTAB;
 TYPEVALUESPTR=↑VALUES;
```

```
APLCHARSET=(ASYMBOL, BSYMBOL, CSYMBOL, OSYMBOL, ESYMBOL, FSYMBOL, GSYMBOL,
            HSYMBOL, ISYMBOL, JSYMBOL, KSYMBOL, LSYMBOL, MSYMBOL, NSYMBOL,
            OSYMBOL, PSYMBOL, QSYMBOL, RSYMBOL, SSYMBOL, TSYMBOL, USYMBOL,
            VSYMBOL, WSYMBOL, XSYMBOL, YSYMBOL, ZSYMBOL,

            ONESYMBOL, TWOSYMBOL, THREESYMBOL, FOURSYMBOL, FIVESYMBOL,
            SIXSYMBOL, SEVENSYMBOL, EIGHTSYMBOL, NINESYMBOL, ZEROSYMBOL,

            COLON, RIGHTARROW, LEFTARROW, SMALLCIRCLE, PERIOD, LEFTPAREN,
            RIGHTPAREN, LEFTBRACKET, RIGHTBRACKET, SEMICOLON, QUADRANGLE,
            SPACE,

            PLUS, MINUS, TIMES, OIVIDE, ASTERISK, IOTA, RHO, COMMA, TILDE,
            EQUALS, NOTEQUAL, LESSTHAN, LESSOREQUAL, GREATEROREQUAL,
            GREATERTHAN, ANDSYMBOL, ORSYMBOL,

            CEILING, FLOOR, LARGECIRCLE, FORWAROSLASH,

            DOUBLEQUOTE, NEGATIVE, QUESTIONMARK, OMEGA, EPSILON,
            UPARROW, OOWNARROW, ALPHA, UNDERSCORE, DEL, DELTA,
            SINGLEQUOTE, EASTCAP, WESTCAP, SOUTHCAP, NORTHCAP,
            IBEAM, TBEAM, VERTICALSTROKE, BACKWARDSLASH);

VAR
XCOLONSYM,XRIGHTARROW,XLEFTARROW,XLITTLECIRCLE,XPERIOD,
XLEFTPAR,XRIGHTPAR,XLEFTBRACKET,XRIGHTBRACKET,XSEMICOLSYM,XQUADSYM:INTEGER;
CHARACTER:ARRAY[APLCHARSET] OF INTEGER;
APLSTATEMENT:ARRAY[1..INPUTARRAYSIZE] OF INTEGER;
OIGITS:ARRAY[ONESYMBOL..ZEROSYMBOL] OF INTEGER;
ERRORMSGS:PACKED ARRAY[1..NUMBEROFMESSAGES,1..MESSAGELENGTH] OF CHAR;

APLFILE:TEXT;
MOPTAB, DOPTAB, REOTAB, CHARTAB, SPECTAB:OPTABLE;
SAVELABEL:PACKEOSTRING;
NAME: PACKEOSTRING;

NEWTOKENPTR, OLOTOKENPTR, HOLOTOKENPTR, SAVETOKENPTR: ↑TOKENTABLE;
TESTFUNCPTR, NEWFUNCTABPTR, OLOFUNCTABPTR: ↑FUNCTAB;
NEWVARTABPTR, OLOVARTABPTR: ↑VARTAB;
LEFTVALPTR,RIGHTVALPTR,VALPTR:↑VALUES;
NEWVALUES, NEWVALPTR: ↑VALUES;
NEWDIM: ↑OIMENINFO;
DIMPTR,NEWPTR,LEFTOIMPTR,RIGHTDIMPTR:↑OIMENINFO;
VARPOINTER:↑VARTAB;
OLDVFUNCPTR, NEWVFUNCPTR:↑VFUNC;
NEWVALTABLINK, OLDVALTABLINK: ↑VALTAB;

POSITION:INTEGER;
LINELENGTH:INTEGER;
COOE,COLCNT:INTEGER;
FUNCSTATEMENTS:INTEGER;

TOKENERROR, FIRSTFUNCTION:BOOLEAN;
LINETOOLONG,HASLABEL:BOOLEAN;
SWITCH, FUNCTIONMOOE, TOKENSWITCH, ITSANIDENTIFIER:BOOLEAN;

OPERTABPTR:↑OPERANDTAB;                          (* SV *)
PTRLASTOPER:↑OPERANOTAB;
SUBRTABPTR:↑SUBRTAB;
RPARMPTR:↑FPARMTAB;                           (* P1 *)
LPARMPTR:↑FPARMTAB;                            (* P2 *)
VFUNCPTR:↑VFUNC;                                  (* NL *)
HOLO:↑TOKENTABLE;                        (* HOLDS LAST SYMBOL *)


PROCEOURE INITPARSER;
BEGIN
  OPERTABPTR:=NIL;
```

```
   SUBRTABPTR:=NIL;
   LPARMPTR:=NIL;
   RPARMPTR:=NIL;
   VFUNCPTR:=NIL;
   HOLD:=NIL;
   XCOLONSYM:=1;
   XRIGHTARROW:=2;
   XLEFTARROW:=3;
   XLITTLECIRCLE:=4;
   XPERIOD:=5;
   XLEFTPAR:=6;
   XRIGHTPAR:=7;
   XLEFTBRACKET:=8;
   XRIGHTBRACKET:=9;
   XSEMICOLSYM:=10;
   XQUADSYM:=11;
   NEW(OPERTABPTR);
   OPERTABPTR↑.LASTOPER:=NIL;
   PTRLASTOPER:=OPERTABPTR;
END;


PROCEDURE INITIALIZECHARACTERSET; (*READ INSTALLATION CHARACTER SET FROM FILE*)
VAR
TESTFORPREFIX:INTEGER;
FILECHARACTER:CHAR;
SYMBOLINDEX:APLCHARSET;
BEGIN
RESET(APLFILE);
FOR SYMBOLINDEX:=ASYMBOL TO BACKWARDSLASH DO
 BEGIN
   READ(APLFILE,FILECHARACTER);

   (* THE FOLLOWING CODE WOULD BE REMOVED FOR NON-CDC INSTALLATIONS *)
   TESTFORPREFIX:=ORD(FILECHARACTER);
   IF (TESTFORPREFIX = PREFIX1) OR (TESTFORPREFIX = PREFIX2)
     THEN
       BEGIN
         READ(APLFILE,FILECHARACTER);
         CHARACTER[SYMBOLINDEX]:=100*TESTFORPREFIX + ORD(FILECHARACTER);
         END
     ELSE
   (*                                                              *)

       CHARACTER[SYMBOLINDEX]:=ORD(FILECHARACTER)
 END
END; (* INITIALIZECHARACTERSET *)


PROCEDURE READINERRORMSGS;
VAR
MSGROW,MSGCOL:INTEGER;
BEGIN
READLN(APLFILE);
FOR MSGROW:=1 TO NUMBEROFMESSAGES DO
  FOR MSGCOL:=1 TO MESSAGELENGTH DO
    ERRORMSGS[MSGROW,MSGCOL]:=' '; (* BLANK OUT ERROR MESSAGES *)
FOR MSGROW:=1 TO NUMBEROFMESSAGES DO
  BEGIN (* READ IN ERROR MESSAGES FROM FILE *)
    MSGCOL:=0;
    WHILE NOT EOLN(APLFILE) DO
      BEGIN
        MSGCOL:=MSGCOL + 1;
        READ(APLFILE,ERRORMSGS[MSGROW,MSGCOL]);
      END;
    READLN(APLFILE);
  END
END; (* READINERRORMSGS *)

```

```
PROCEDURE FILLUPTABLES;
BEGIN

(*          MONADIC OPERATORS              *)
MOPTAB[1].OPSYMBOL := CHARACTER[PLUS];   MOPTAB[1].OPINDEX := 2;
MOPTAB[2].OPSYMBOL := CHARACTER[MINUS];  MOPTAB[2].OPINDEX := 3;
MOPTAB[3].OPSYMBOL := CHARACTER[TIMES];  MOPTAB[3].OPINDEX := 4;
MOPTAB[4].OPSYMBOL := CHARACTER[DIVIDE];  MOPTAB[4].OPINDEX := 5;
MOPTAB[5].OPSYMBOL := CHARACTER[ASTERISK];  MOPTAB[5].OPINDEX := 6;
MOPTAB[6].OPSYMBOL := CHARACTER[IOTA];  MOPTAB[6].OPINDEX := 21;
MOPTAB[7].OPSYMBOL := CHARACTER[RHO];  MOPTAB[7].OPINDEX := 22;
MOPTAB[8].OPSYMBOL := CHARACTER[COMMA];  MOPTAB[8].OPINDEX := 23;
MOPTAB[9].OPSYMBOL := CHARACTER[TILDE];  MOPTAB[9].OPINDEX := 1;

(*          DYADIC OPERATORS               *)
DOPTAB[1].OPSYMBOL := CHARACTER[PLUS];  DOPTAB[1].OPINDEX := 52;
DOPTAB[2].OPSYMBOL := CHARACTER[MINUS];  DOPTAB[2].OPINDEX := 53;
DOPTAB[3].OPSYMBOL := CHARACTER[TIMES];  DOPTAB[3].OPINDEX := 54;
DOPTAB[4].OPSYMBOL := CHARACTER[DIVIDE];  DOPTAB[4].OPINDEX := 55;
DOPTAB[5].OPSYMBOL := CHARACTER[ASTERISK];  DOPTAB[5].OPINDEX := 56;
DOPTAB[6].OPSYMBOL := CHARACTER[IOTA];  DOPTAB[6].OPINDEX := 87;
DOPTAB[7].OPSYMBOL := CHARACTER[RHO];  DOPTAB[7].OPINDEX := 88;
DOPTAB[8].OPSYMBOL := CHARACTER[COMMA];  DOPTAB[8].OPINDEX := 89;
DOPTAB[9].OPSYMBOL := CHARACTER[EQUALS];  DOPTAB[9].OPINDEX := 71;
DOPTAB[10].OPSYMBOL := CHARACTER[NOTEQUAL];  DOPTAB[10].OPINDEX := 72;
DOPTAB[11].OPSYMBOL := CHARACTER[LESSTHAN];  DOPTAB[11].OPINDEX := 73;
DOPTAB[12].OPSYMBOL := CHARACTER[LESSOREQUAL];  DOPTAB[12].OPINDEX := 74;
DOPTAB[13].OPSYMBOL := CHARACTER[GREATEROREQUAL];  DOPTAB[13].OPINDEX := 75;
DOPTAB[14].OPSYMBOL := CHARACTER[GREATERTHAN];  DOPTAB[14].OPINDEX := 76;
DOPTAB[15].OPSYMBOL := CHARACTER[ANDSYMBOL];  DOPTAB[15].OPINDEX := 77;
DOPTAB[16].OPSYMBOL := CHARACTER[ORSYMBOL];  DOPTAB[16].OPINDEX := 78;

(*          SPECIAL CHARACTER              *)
CHARTAB[1].OPSYMBOL := CHARACTER[COLON];
CHARTAB[2].OPSYMBOL := CHARACTER[RIGHTARROW];
CHARTAB[3].OPSYMBOL := CHARACTER[LEFTARROW];
CHARTAB[4].OPSYMBOL := CHARACTER[SMALLCIRCLE];
CHARTAB[5].OPSYMBOL := CHARACTER[PERIOD];
CHARTAB[6].OPSYMBOL := CHARACTER[LEFTPAREN];
CHARTAB[7].OPSYMBOL := CHARACTER[RIGHTPAREN];
CHARTAB[8].OPSYMBOL := CHARACTER[LEFTBRACKET];
CHARTAB[9].OPSYMBOL := CHARACTER[RIGHTBRACKET];
CHARTAB[10].OPSYMBOL := CHARACTER[SEMICOLON];
CHARTAB[11].OPSYMBOL := CHARACTER[QUADRANGLE];
CHARTAB[12].OPSYMBOL := CHARACTER[SPACE];

SPECTAB[1].OPSYMBOL:=CHARACTER[COLON];
SPECTAB[2].OPSYMBOL:=CHARACTER[RIGHTARROW];
SPECTAB[3].OPSYMBOL:=CHARACTER[LEFTARROW];
SPECTAB[4].OPSYMBOL:=CHARACTER[LEFTPAREN];
SPECTAB[5].OPSYMBOL:=CHARACTER[SEMICOLON];
SPECTAB[6].OPSYMBOL:=CHARACTER[LEFTBRACKET];

(*          REDUCTION OPERATOR             *)
REDTAB[1].OPSYMBOL := CHARACTER[PLUS];  REDTAB[1].OPINDEX := 2;
REDTAB[2].OPSYMBOL := CHARACTER[MINUS];     REDTAB[2].OPINDEX := 3;
REDTAB[3].OPSYMBOL := CHARACTER[TIMES];  REDTAB[3].OPINDEX := 4;
REDTAB[4].OPSYMBOL := CHARACTER[DIVIDE];  REDTAB[4].OPINDEX := 5;
REDTAB[5].OPSYMBOL := CHARACTER[ASTERISK];  REDTAB[5].OPINDEX := 6;
REDTAB[6].OPSYMBOL := CHARACTER[EQUALS];  REDTAB[6].OPINDEX := 21;
REDTAB[7].OPSYMBOL := CHARACTER[NOTEQUAL];  REDTAB[7].OPINDEX := 22;
REDTAB[8].OPSYMBOL := CHARACTER[LESSTHAN];     REDTAB[8].OPINDEX := 23;
REDTAB[9].OPSYMBOL := CHARACTER[LESSOREQUAL];  REDTAB[9].OPINDEX := 24;
REDTAB[10].OPSYMBOL := CHARACTER[GREATEROREQUAL];  REDTAB[10].OPINDEX := 25;
REDTAB[11].OPSYMBOL := CHARACTER[GREATERTHAN];  REDTAB[11].OPINDEX := 26;
REDTAB[12].OPSYMBOL := CHARACTER[ANDSYMBOL];  REDTAB[12].OPINDEX := 27;
REDTAB[13].OPSYMBOL := CHARACTER[ORSYMBOL];  REDTAB[13].OPINDEX := 28;
REDTAB[14].OPSYMBOL := CHARACTER[CEILING];  REDTAB[14].OPINDEX := 29;
```

```
REDTAB[15].OPSYMBOL := CHARACTER[FLOOR];  REDTAB[15].OPINDEX := 30;
REDTAB[16].OPSYMBOL := CHARACTER[LARGECIRCLE];  REDTAB[16].OPINDEX := 31;

   DIGITS[ONESYMBOL]:=1; DIGITS[TWOSYMBOL]:=2; DIGITS[THREESYMBOL]:=3;
   DIGITS[FOURSYMBOL]:=4; DIGITS[FIVESYMBOL]:=5; DIGITS[SIXSYMBOL]:=6;
   DIGITS[SEVENSYMBOL]:=7; DIGITS[EIGHTSYMBOL]:=8;
   DIGITS[NINESYMBOL]:=9; DIGITS[ZEROSYMBOL]:=0;

END; (* FILLUPTABLES *)


PROCEDURE PRINTAPLSTATEMENT;
VAR
PREFIX,NUM:INTEGER;
INDEX:INTEGER;
BEGIN
FOR INDEX:=1 TO LINELENGTH DO
 BEGIN
   IF APLSTATEMENT[INDEX] > 6000
     THEN
       BEGIN
         PREFIX:=APLSTATEMENT[INDEX] DIV 100;
         WRITE(CHR(PREFIX));
         NUM:=APLSTATEMENT[INDEX] - 100*PREFIX;
         WRITE(CHR(NUM))
       END
     ELSE
       WRITE(CHR(APLSTATEMENT[INDEX]))
 END;
WRITELN
END; (* PRINTAPLSTATEMENT *)


PROCEDURE SERROR(ERRORINDEX:INTEGER);
VAR
MSGCOL:INTEGER;
BEGIN
TOKENERROR:=TRUE;
FOR MSGCOL:=1 TO MESSAGELENGTH DO
  WRITE(ERRORMSGS[ERRORINDEX,MSGCOL]);
WRITELN;
PRINTAPLSTATEMENT; (* ECHO STATEMENT TO USER *)
FOR MSGCOL:=1 TO (POSITION - 1) DO
 WRITE(' ');
WRITELN(CHR(CHARACTER[UPARROW])); (* PRINT POINTER TO USER ERROR *)
END; (* ERROR *)


PROCEDURE SKIPSPACES;
BEGIN
WHILE (APLSTATEMENT[POSITION] = CHARACTER[SPACE])
 AND (POSITION <= LINELENGTH) DO
 POSITION:=POSITION + 1
END; (* SKIPSPACES *)


PROCEDURE GETAPLSTATEMENT;
VAR
INPUTCHAR:CHAR;
TESTFORPREFIX:INTEGER;
FIRSTTRY:BOOLEAN;
BEGIN
FOR LINELENGTH:=1 TO MAXINPUTLINE DO
APLSTATEMENT[LINELENGTH]:=CHARACTER[SPACE]; (* BLANK OUT LINE *)
LINELENGTH:=0;
FIRSTTRY:=TRUE;
POSITION:=1;
LINETOOLONG:=FALSE;
APLSTATEMENT[INPUTARRAYSIZE]:=CHARACTER[OMEGA];
```

```
APLSTATEMENT[INPUTARRAYSIZE - 1]:=CHARACTER[SPACE];  (* SET END-OF-LINE *)
REPEAT
 BEGIN
  IF NOT FIRSTTRY THEN GETSEG(INPUT); (* TEST FOR *CR* ONLY *)
  FIRSTTRY:=FALSE;
WHILE (NOT EOLN) AND (NOT LINETOOLONG) DO
   IF LINELENGTH < MAXINPUTLINE
     THEN
       BEGIN
         LINELENGTH:=LINELENGTH + 1;
         READ(INPUTCHAR);

         (* THE FOLLOWING CODE WOULD BE REMOVED FOR NON-CDC INSTALLATIONS *)
         TESTFORPREFIX:=ORD(INPUTCHAR);
         IF (TESTFORPREFIX = PREFIX1) OR (TESTFORPREFIX = PREFIX2)
           THEN
             BEGIN
               READ(INPUTCHAR);
               APLSTATEMENT[LINELENGTH]:=100*TESTFORPREFIX + ORD(INPUTCHAR);
               END
           ELSE
         (*
                                                                         *)
               APLSTATEMENT[LINELENGTH]:=ORD(INPUTCHAR)
       END
     ELSE LINETOOLONG:=TRUE
 END
UNTIL LINELENGTH <> 0; (* REJECT NULL LINES *)
IF LINETOOLONG THEN SERROR(71)
END; (* GETAPLSTATEMENT *)


FUNCTION ITSADIGIT(TESTCHAR:INTEGER):BOOLEAN;
VAR
DIGITINDEX:APLCHARSET;
BEGIN (* TEST TO SEE IF INPUT CHARACTER IS A DIGIT *)
ITSADIGIT:=FALSE;
FOR DIGITINDEX:=ONESYMBOL TO ZEROSYMBOL DO
 IF TESTCHAR = CHARACTER[DIGITINDEX] THEN ITSADIGIT:=TRUE
END; (* ITSADIGIT *)


FUNCTION ITSALETTER(TESTCHAR:INTEGER):BOOLEAN;
VAR
LETTERINDEX:APLCHARSET;
BEGIN (* TEST TO SEE IF INPUT CHARACTER IS A LETTER *)
ITSALETTER:=FALSE;
FOR LETTERINDEX:=ASYMBOL TO ZSYMBOL DO
 IF TESTCHAR = CHARACTER[LETTERINDEX] THEN ITSALETTER:=TRUE
END; (* ITSALETTER *)


FUNCTION CHARTONUM(TESTCHAR:INTEGER):INTEGER;
VAR
DIGITINDEX:APLCHARSET;
BEGIN (* CHAGE A CHARACTER TO A NUMBER *)
FOR DIGITINDEX:=ONESYMBOL TO ZEROSYMBOL DO
 IF TESTCHAR = CHARACTER[DIGITINDEX] THEN CHARTONUM:=DIGITS[DIGITINDEX]
END; (* CHARTONUM *)


FUNCTION NAMESMATCH(NAMEONE, NAMETWO:PACKEDSTRING):BOOLEAN;
VAR
INDEX:INTEGER;
BEGIN (* SEE IF TWO NAMES (IDENTIFIERS) ARE THE SAME *)
NAMESMATCH:=TRUE;
FOR INDEX:=1 TO MAXVARNAMELENGTH DO
 IF NAMEONE[INDEX] <> NAMETWO[INDEX]
   THEN NAMESMATCH:=FALSE
```

```
END; (* NAMESMATCH *)
PROCEDURE TABLELOOKUP(TESTCHAR,TABLELENGTH:INTEGER;TABLE:OPTABLE;
                     VAR TABLEINDEX:INTEGER);
VAR
INDEX:INTEGER;
BEGIN (* CHECK FOR MEMBERSHIP IN A GIVEN TABLE *)
TABLEINDEX:=0;
FOR INDEX:=1 TO TABLELENGTH DO
 IF TESTCHAR = TABLE[INDEX].OPSYMBOL
   THEN TABLEINDEX:=INDEX
END; (* TABLELOOKUP *)
PROCEDURE IDENTIFIER(VAR NAME:PACKEDSTRING; VAR ITSANIDENTIFIER:BOOLEAN);
VAR
NAMELENGTH:INTEGER;
NAMETOOLONG:BOOLEAN;
BEGIN
ITSANIDENTIFIER:=FALSE;
SKIPSPACES;
IF ITSALETTER(APLSTATEMENT[POSITION])
 THEN
   BEGIN
     NAMETOOLONG:=FALSE;
     ITSANIDENTIFIER:=TRUE;
     FOR NAMELENGTH:=1 TO MAXVARNAMELENGTH DO (* BLANK OUT NAME *)
       NAME[NAMELENGTH]:=CHARACTER[SPACE];
     NAMELENGTH:=0;
     WHILE (ITSALETTER(APLSTATEMENT[POSITION])) OR
           (ITSADIGIT(APLSTATEMENT[POSITION])) DO
       BEGIN (* BUILD IDENTIFIER *)
         NAMELENGTH:=NAMELENGTH + 1;
         IF NAMELENGTH <= MAXVARNAMELENGTH
           THEN
             NAME[NAMELENGTH]:=APLSTATEMENT[POSITION]
           ELSE
             NAMETOOLONG:=TRUE;
         POSITION:=POSITION + 1
       END;
     IF NAMETOOLONG
       THEN
           SERROR(70)  (* NAME GREATER THAN MAXLENGTH *)
   END
END; (* IDENTIFIER *)
PROCEDURE MAKEANUMBER(VAR REALNUMBER:REAL; VAR ITSANUMBER:BOOLEAN);
VAR
SIGN,DIGITCOUNT:INTEGER;
BEGIN (* CONVERT CHARACTER INPUT STRING TO NUMERICAL REPRESENTATION *)
ITSANUMBER:=FALSE;
SKIPSPACES;
SIGN:=1;
DIGITCOUNT:=0;
REALNUMBER:=0.0;
IF(APLSTATEMENT[POSITION] = CHARACTER[NEGATIVE]) OR
  (ITSADIGIT(APLSTATEMENT[POSITION]))
 THEN
   BEGIN
     ITSANUMBER:=TRUE;
     IF APLSTATEMENT[POSITION] = CHARACTER[NEGATIVE]
       THEN
         BEGIN
           SIGN:=-1;
           POSITION:=POSITION + 1
         END;
     IF NOT ITSADIGIT(APLSTATEMENT[POSITION])
```

```
      THEN
       BEGIN
        SERROR(1); (* DIGIT MUST FOLLOW A MINUS SIGN *)
        ITSANUMBER:=FALSE;
       END
        ELSE
          BEGIN (* FORM WHOLE NUMBER PORTION *)
            WHILE ITSADIGIT(APLSTATEMENT[POSITION]) DO
              BEGIN
                REALNUMBER:=10.0*REALNUMBER+CHARTONUM(APLSTATEMENT[POSITION]);
                POSITION:=POSITION + 1
              END;
            IF APLSTATEMENT[POSITION] = CHARACTER[PERIOD]
              THEN
                BEGIN
                  POSITION:=POSITION + 1;
                  WHILE ITSADIGIT(APLSTATEMENT[POSITION]) DO
                    BEGIN (* FORM FRACTIONAL PORTION *)
                      REALNUMBER:=REALNUMBER +
                                  CHARTONUM(APLSTATEMENT[POSITION]) *
                                  EXP( (-1.0 - DIGITCOUNT) * 2.302585I);
                      DIGITCOUNT:=DIGITCOUNT + 1;
                      POSITION:=POSITION + 1;
                    END;
                  IF DIGITCOUNT = 0
                    THEN BEGIN
                         SERROR(2); (* DIGITS MUST FOLLOW A DECIMAL POINT *)
                         ITSANUMBER:=FALSE;
                         END
                END;
            REALNUMBER:=REALNUMBER*SIGN
          END
    END
END; (* MAKEANUMBER *)


FUNCTION MONADICREFERENCE:BOOLEAN;
VAR
SUBPOSITION, TABLEINDEX:INTEGER;
BEGIN (* SEE IF OPERATOR IS MONADIC WITHIN CONTEXT OF INPUT LINE *)
MONADICREFERENCE:=FALSE;
IF NEWTOKENPTR↑.NEXTOKEN↑.NOUN = STATEND
 THEN MONADICREFERENCE:= TRUE
 ELSE
   BEGIN
     SUBPOSITION:=POSITION - 1;
     WHILE (SUBPOSITION > 0) AND
           (APLSTATEMENT[SUBPOSITION]=CHARACTER[SPACE]) DO
           SUBPOSITION:=SUBPOSITION - 1; (* GET LAST NON-BLANK *)
     IF SUBPOSITION  <> 0 THEN
       TABLELOOKUP(APLSTATEMENT[SUBPOSITION],6,SPECTAB,TABLEINDEX);
     IF (TABLEINDEX <> 0) OR (SUBPOSITION = 0)
       THEN MONADICREFERENCE:=TRUE
       ELSE
         IF (NEWTOKENPTR↑.NEXTOKEN↑.NOUN <> FORMRES) AND
            (NEWTOKENPTR↑.NEXTOKEN↑.NOUN <> FORMARG) AND
            (NEWTOKENPTR↑.NEXTOKEN↑.NOUN <> GLOBVAR) AND
            (NEWTOKENPTR↑.NEXTOKEN↑.NOUN <> CONSTANT) AND
            (APLSTATEMENT[SUBPOSITION] <> CHARACTER[PERIOD]) AND
            (APLSTATEMENT[SUBPOSITION] <> CHARACTER[RIGHTPAREN]) AND
            (APLSTATEMENT[SUBPOSITION] <> CHARACTER[RIGHTBRACKET])
           THEN MONADICREFERENCE:=TRUE
   END
END; (* MONADICREFERENCE *)


PROCEDURE DYADICOPCHECK;
VAR
TABLEINDEX:INTEGER;
```

```
BEGIN
TABLELOOKUP(APLSTATEMENT[POSITION],16,DOPTAB,TABLEINDEX);
IF TABLEINDEX = 0
 THEN
   BEGIN
     TABLELOOKUP(APLSTATEMENT[POSITION],12,CHARTAB,TABLEINDEX);
     IF TABLEINDEX = 0
       THEN
        IF APLSTATEMENT[POSITION] = CHARACTER[SOUTHCAP]
          THEN
            BEGIN
              OLDTOKENPTR:=SAVETOKENPTR;
              DISPOSE(NEWTOKENPTR);
              NEWTOKENPTR:=SAVETOKENPTR;
              POSITION:=LINELENGTH + 1;
            END (* THIS WAS A COMMENT - IGNORE REMAINDER OF LINE *)
          ELSE SERROR(4) (* INVALID CHARACTER ENCOUNTERED *)
       ELSE
         BEGIN (* SPECIAL CHARACTER ENCOUNTERED *)
           NEWTOKENPTR↑.NOUN:=SPECOPER;
           NEWTOKENPTR↑.CHARINDX:=TABLEINDEX
         END
   END
 ELSE
   IF MONADICREFERENCE
     THEN SERROR(74) (*MONADIC REFERENCE TO DYADIC OPERATOR*)
     ELSE
         BEGIN (* OPERATOR IS DYADIC *)
           NEWTOKENPTR↑.NOUN:=DYADOPER;
           NEWTOKENPTR↑.DOPINDX:=TABLEINDEX
         END
END;(*DYADICOPCHECK*)


PROCEDURE CHECKOTHERTABLES;
VAR
TABLEINDEX:INTEGER;
CHKINDEX:INTEGER;
FUNCTION NEXTNONBLANK:INTEGER;
BEGIN
  CHKINDEX:=POSITION + 1;
  WHILE (CHKINDEX < LINELENGTH) AND
        (APLSTATEMENT[CHKINDEX] = CHARACTER[SPACE]) DO
          CHKINDEX:=CHKINDEX + 1;
  NEXTNONBLANK:=APLSTATEMENT[CHKINDEX];
END; (* NEXTNONBLANK *)
BEGIN
IF NEXTNONBLANK = CHARACTER[FORWARDSLASH]
THEN
  BEGIN
    TABLELOOKUP(APLSTATEMENT[POSITION],16,REDTAB,TABLEINDEX);
    IF TABLEINDEX = 0
      THEN SERROR(72) (* INVALID REDUCTION OPERATOR *)
      ELSE
        IF NOT MONADICREFERENCE
          THEN SERROR(73) (* DYADIC REDUCTION REFERENCE *)
          ELSE
            BEGIN (* OPERATOR IS VALID REDUCTION OPERATOR *)
              NEWTOKENPTR↑.NOUN:=REDUCTOPER;
              NEWTOKENPTR↑.REDINDX:=TABLEINDEX;
            END;
    POSITION:=CHKINDEX + 1;
  END
ELSE
  BEGIN
    TABLELOOKUP(APLSTATEMENT[POSITION],9,MOPTAB,TABLEINDEX);
    IF TABLEINDEX = 0
      THEN DYADICOPCHECK
      ELSE
```

```
            IF NOT MONADICREFERENCE
               THEN DYADICOPCHECK
               ELSE
                  BEGIN (* OPERATOR IS MONADIC *)
                     NEWTOKENPTR↑.NOUN:=MONADOPER;
                     NEWTOKENPTR↑.MONINDX:=TABLEINDEX;
                  END;
         POSITION:=POSITION + 1;
      END
   END; (* CHECKOTHERTABLES *)


PROCEDURE TRYTOGETANUMBER;
VAR
NUMBERCOUNT:INTEGER;
REALNUMBER:REAL;
ITSANUMBER:BOOLEAN;
BEGIN
NUMBERCOUNT:=0;
MAKEANUMBER(REALNUMBER,ITSANUMBER);
IF NOT ITSANUMBER
 THEN CHECKOTHERTABLES
 ELSE
    BEGIN (* STORE VALUES IN VALUE TABLE *)
       NEW(NEWVALTABLINK);
       NEWVALTABLINK↑.NEXTVALTABLINK:=OLDVALTABLINK;
       OLDVALTABLINK:=NEWVALTABLINK;
       NEWVALTABLINK↑.FORWARDORDER:=TRUE;
       IF FUNCTIONMODE
          THEN NEWVALTABLINK↑.INTERMEDRESULT:=FALSE
          ELSE NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
       SWITCH:=TRUE;
       WHILE ITSANUMBER DO
          BEGIN
             NUMBERCOUNT:=NUMBERCOUNT + 1;
             NEW(NEWVALUES);
             IF SWITCH = TRUE
                THEN
                   BEGIN
                      SWITCH:=FALSE;
                      NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                   END
                ELSE
                   NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
             NEWVALUES↑.REALVAL:=REALNUMBER;
             NEWVALPTR:=NEWVALUES;
             MAKEANUMBER(REALNUMBER,ITSANUMBER)
          END;
       NEWVALUES↑.NEXTVALUE:=NIL;
       IF NUMBERCOUNT > I
          THEN
             BEGIN
                NEWVALTABLINK↑.DIMENSIONS:=1; (* NUMBER IS A VECTOR *)
                NEW(NEWDIM);
                NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM;
                NEWDIM↑.DIMENLENGTH:=NUMBERCOUNT;
                NEWDIM↑.NEXTDIMEN:=NIL
             END
          ELSE
             BEGIN
                NEWVALTABLINK↑.DIMENSIONS:=0; (* NUMBER IS A SCALAR *)
                NEWVALTABLINK↑.FIRSTDIMEN:=NIL
             END;
       NEWTOKENPTR↑.NOUN:=CONSTANT;
       NEWTOKENPTR↑.VALTABPTR:=NEWVALTABLINK;
    END
END; (* TRYTOGETANUMBER *)
```

```
FUNCTION NAMEINVARTABLE(NAME:PACKEDSTRING;VAR VARPOINTER:VARTABPTRTYPE;
                          TESTFUNCPTR:PTRFUNCTAB):BOOLEAN;
VAR
FOUND:BOOLEAN;
BEGIN
FOUND:=FALSE;
VARPOINTER:=OLDVARTABPTR;
WHILE (VARPOINTER <> NIL) AND (FOUND = FALSE) DO
 BEGIN
   IF (NAMESMATCH(NAME,VARPOINTER↑.VARNAME)) AND
      (VARPOINTER↑.FUNCTABPTR = TESTFUNCPTR) (* TEST FOR GLOBAL VAR *)
     THEN FOUND:=TRUE
     ELSE VARPOINTER:=VARPOINTER↑.NEXTVARTABPTR
 END;
NAMEINVARTABLE:=FOUND;
END; (*NAMEINVARTABLE*)

PROCEDURE ADDNAMETOVARTABLE(NAME:PACKEDSTRING);
BEGIN (* NEW VARIABLE NAME ENCOUNTERED *)
NEW(NEWVARTABPTR);
NEWVARTABPTR↑.NEXTVARTABPTR:=OLDVARTABPTR;
OLDVARTABPTR:=NEWVARTABPTR;
NEWVARTABPTR↑.VARNAME:=NAME;
NEWVARTABPTR↑.VALTABPTR:=NIL;
IF NEWTOKENPTR <> NIL THEN
IF (NEWTOKENPTR↑.NOUN = FORMRES) OR (NEWTOKENPTR↑.NOUN = FORMARG)
 THEN NEWVARTABPTR↑.FUNCTABPTR:=NEWFUNCTABPTR
 ELSE NEWVARTABPTR↑.FUNCTABPTR:=NIL
END; (* ADDNAMETOVARTABLE *)

FUNCTION FUNCTIONALREADYDEFINED(VAR NEWFUNAME:PACKEDSTRING;VAR FUNCINDEX:
PTRFUNCTAB):BOOLEAN;
VAR
FOUND:BOOLEAN;
BEGIN
FOUND:=FALSE;
FUNCINDEX:=OLDFUNCTABPTR;
WHILE (FUNCINDEX <> NIL) AND (FOUND = FALSE) AND
      (NEWFUNCTABPTR <> NIL) DO
 IF NAMESMATCH(FUNCINDEX↑.FUNCNAME,NEWFUNAME)
   THEN FOUND:=TRUE
   ELSE FUNCINDEX:=FUNCINDEX↑.NEXTFUNCTABPTR;
FUNCTIONALREADYDEFINED:=FOUND
END; (* FUNCTIONALREEADYDEFINED *)

PROCEDURE MAKETOKENLINK;
BEGIN
NEW(NEWTOKENPTR);
NEWTOKENPTR↑.NEXTOKEN:=OLDTOKENPTR;
SAVETOKENPTR:=OLDTOKENPTR;
OLDTOKENPTR:=NEWTOKENPTR
END; (* MAKETOKENLINK *)

PROCEDURE PROCESSFUNCTIONHEADER;
VAR
DUMMYPTR:↑FUNCTAB;
NAME1,NAME2,NAME3:PACKEDSTRING;
ITSANIDENTIFIER,FUNCHEADERROR:BOOLEAN;
ARITYINDEX:INTEGER;
BEGIN
FUNCHEADERROR:=FALSE;
FUNCTIONMODE:=TRUE;
FUNCSTATEMENTS:=-1;
IF FIRSTFUNCTION THEN BEGIN
                          FUNCSTATEMENTS:=0;
```

```
                                      FIRSTFUNCTION:=FALSE;
                                   END;
ARITYINDEX:=1;
POSITION:=POSITION + 1;
IDENTIFIER(NAME1,ITSANIDENTIFIER);
IF NOT ITSANIDENTIFIER
 THEN
   BEGIN
     SERROR(7); (* UNRECOGNIZABLE FUNCTION/ARGUMENT NAME *)
     FUNCTIONMODE:=FALSE; (* EXIT FUNCTION MODE *)
     FUNCHEADERROR:=TRUE
   END
 ELSE
   BEGIN
     NEW(NEWFUNCTABPTR);
     SKIPSPACES;
     IF APLSTATEMENT[POSITION] = CHARACTER[LEFTARROW]
       THEN
         BEGIN
           NEWFUNCTABPTR↑.RESULT:=TRUE; (* EXPLICIT RESULT *)
           NEWFUNCTABPTR↑.RESULTNAME:=NAME1;
           POSITION:=POSITION + 1;
           IDENTIFIER(NAME1,ITSANIDENTIFIER);
           IF NOT ITSANIDENTIFIER
             THEN
               BEGIN
                 SERROR(6);(*UNRECOGNIZABLE NAME TO RIGHT OF EXPLICIT RES*)
                 FUNCHEADERROR:=TRUE
               END
         END
       ELSE
         NEWFUNCTABPTR↑.RESULT:=FALSE; (* NO EXPLICIT RESULT *)
     SKIPSPACES;
     IF (POSITION <= LINELENGTH) AND (NOT FUNCHEADERROR)
       THEN
         BEGIN
           IDENTIFIER(NAME2,ITSANIDENTIFIER);
           IF NOT ITSANIDENTIFIER
             THEN
               BEGIN
                 SERROR(7);(* INVALID FUNCTION/ARGUMENT NAME *)
                 FUNCHEADERROR:=TRUE
               END
             ELSE
               ARITYINDEX:=2
         END;
     SKIPSPACES;
     IF (POSITION <= LINELENGTH) AND (NOT FUNCHEADERROR)
       THEN
         BEGIN
           IDENTIFIER(NAME3,ITSANIDENTIFIER);
           IF NOT ITSANIDENTIFIER
             THEN
               BEGIN
                 SERROR(9); (* INVALID FUNCTION RIGHT ARGUMENT NAME *)
                 FUNCHEADERROR:=TRUE
               END
             ELSE
               ARITYINDEX:=3
         END;
     SKIPSPACES;
     IF (POSITION <= LINELENGTH) AND (NOT FUNCHEADERROR)
       THEN
         BEGIN
           SERROR(3); (* EXTRANEOUS CHARACTERS TO RIGHT OF FUNCTION HEADER *)
           FUNCHEADERROR:=TRUE
         END;
     CASE ARITYINDEX OF
       1: BEGIN
```

```
                NEWFUNCTABPTR↑.ARITY:=NILADIC;
                NEWFUNCTABPTR↑.FUNCNAME:=NAME1;
             END;
          2: BEGIN
                NEWFUNCTABPTR↑.ARITY:=MONADIC;
                NEWFUNCTABPTR↑.FUNCNAME:=NAME1;
                NEWFUNCTABPTR↑.RIGHTARG:=NAME2;
                ADDNAMETOVARTABLE(NAME2);
                NEWVARTABPTR↑.FUNCTABPTR:=NEWFUNCTABPTR;
             END;
          3: BEGIN
                NEWFUNCTABPTR↑.ARITY:=DYADIC;
                NEWFUNCTABPTR↑.LEFTARG:=NAME1;
                NEWFUNCTABPTR↑.FUNCNAME:=NAME2;
                NEWFUNCTABPTR↑.RIGHTARG:=NAME3;
                ADDNAMETOVARTABLE(NAME1);
                NEWVARTABPTR↑.FUNCTABPTR:=NEWFUNCTABPTR;
                ADDNAMETOVARTABLE(NAME3);
                NEWVARTABPTR↑.FUNCTABPTR:=NEWFUNCTABPTR;
             END
      END; (* CASE *)
      IF FUNCTIONALREADYDEFINED(NEWFUNCTABPTR↑.FUNCNAME,DUMMYPTR)
        THEN
          BEGIN
            SERROR(5); (* FUNCTION ALREADY DEFINED *)
            FUNCHEADERROR:=TRUE;
          END;
      IF FUNCHEADERROR
        THEN BEGIN
               DISPOSE(NEWFUNCTABPTR); (* HEADER NO GOOD *)
               FUNCTIONMODE:=FALSE; (* EXIT FUNCTION MODE *)
               NEWFUNCTABPTR:=OLDFUNCTABPTR;
               END
    END
END; (* PROCESSFUNCHEADER *)


PROCEDURE DESTROYSTATEMENT;
VAR
DUMTOKENPTR:↑TOKENTABLE;
AUXSUBRTABPTR:↑SUBRTAB;
BEGIN
  IF SUBRTABPTR <> NIL THEN
    BEGIN
      WHILE SUBRTABPTR↑.LASTSUBRPTR <> NIL DO
        BEGIN
          AUXSUBRTABPTR:=SUBRTABPTR;
          SUBRTABPTR:=SUBRTABPTR↑.LASTSUBRPTR;
          DISPOSE(AUXSUBRTABPTR);
        END;
      DISPOSE(SUBRTABPTR);
    END;
DUMTOKENPTR:=OLDTOKENPTR;
WHILE DUMTOKENPTR <> HOLDTOKENPTR DO
 BEGIN
   OLDTOKENPTR:=OLDTOKENPTR↑.NEXTOKEN;
   DISPOSE(DUMTOKENPTR);
   DUMTOKENPTR:=OLDTOKENPTR
 END;
NEWTOKENPTR:=HOLDTOKENPTR;
OLDTOKENPTR:=HOLDTOKENPTR  (* RETURN POINTER TO END OF LAST GOOD LINE *)
END; (* DESTROYSTATEMENT *)


PROCEDURE REVERSELINKLIST(VAR ARGPTR:TYPEVALTABPTR);
VAR
HOLD,TEMPTR:↑VALUES;
BEGIN (* REVERSELINKLIST *)
VALPTR:=ARGPTR↑.FIRSTVALUE;
```

```
TEMPTR:=VALPTR↑.NEXTVALUE;
WHILE TEMPTR <> NIL DO
 BEGIN
   HOLD:=TEMPTR↑.NEXTVALUE;
   TEMPTR↑.NEXTVALUE:=VALPTR;
   VALPTR:=TEMPTR;
   TEMPTR:=HOLD
 END;
ARGPTR↑.FIRSTVALUE↑.NEXTVALUE:=NIL;
ARGPTR↑.FIRSTVALUE:=VALPTR;
IF ARGPTR↑.FORWARDORDER = TRUE
 THEN ARGPTR↑.FORWARDORDER:=FALSE
 ELSE ARGPTR↑.FORWARDORDER:=TRUE (* TOGGLE LIST ORDER SWITCH *)
END; (* REVERSELINKLIST *)


   PROCEDURE PARSER(VAR TOKENTABPTR:TOKENPTR;VAR PTRTODA:TYPEVALTABPTR);
     VAR
       VFUNCHOLD:↑VFUNC;                                    (* HOLD WHILE SEARCHING *)
       AUXOPERTABPTR:↑OPERANDTAB;
       AUXSUBRTABPTR:↑SUBRTAB;
       AUXRPARMPTR:↑FPARMTAB;
       AUXLPARMPTR:↑FPARMTAB;
       VALIDEXP:BOOLEAN;    (* TRUE IF VALID EXPRESSION *)
       CNT:INTEGER;
       NPV:INTEGER;    (* NUMBER OF INDICES *)
       ASSIGN,ASSIGN1:BOOLEAN;   (* ASSIGN.IN PROGRESS *)
       DONESUCCESSOR:BOOLEAN;
       DONEPARSE:BOOLEAN;


PROCEDURE ERROR(ERRORINDEX:INTEGER);
VAR
MSGCOL:INTEGER;
BEGIN
WRITE(≡ ≡,ERRORINDEX,≡  ≡);
FOR MSGCOL:=1 TO MESSAGELENGTH DO
  WRITE(ERRORMSGS[ERRORINDEX,MSGCOL]);
WRITELN;
GOTO 100; (* RETURN TO SCANNER *)
END; (* ERROR *)


         PROCEDURE RELEASE;
           BEGIN (* RELEASEOPERTAB *)
             OPERTABPTR:=PTRLASTOPER;
             WHILE OPERTABPTR↑.LASTOPER<>NIL DO
               BEGIN
                 AUXOPERTABPTR:=OPERTABPTR;
                 OPERTABPTR:=OPERTABPTR↑.LASTOPER;
                 DISPOSE(AUXOPERTABPTR);
               END;
           END; (* RELEASEOPERTAB *)


       PROCEDURE EXPRESSION(VAR VALIDEXP:BOOLEAN);FORWARD;


     PROCEDURE RETURNTOCALLINGSUBR;
       VAR
         NAMEPTR:↑VARTAB;
       BEGIN (* RETURNTOCALLINGSUBR *)
         IF SUBRTABPTR↑.CALLEDSUBR↑.RESULT THEN
           BEGIN (* PLACE EXPLICIT RESULT IN OPERTAB *)
             IF NOT NAMEINVARTABLE(SUBRTABPTR↑.CALLEDSUBR↑.RESULTNAME,NAMEPTR,
                                  SUBRTABPTR↑.CALLEDSUBR)
               THEN ERROR(11) (* ↑SYMBOL NOT FOUND↑ *)
             ELSE
               BEGIN
```

```
                  AUXOPERTABPTR:=OPERTABPTR;
                  NEW(OPERTABPTR);
                  OPERTABPTR↑.LASTOPER:=AUXOPERTABPTR;
                  PTRLASTOPER:=OPERTABPTR;
                  OPERTABPTR↑.OPERPTR:=NAMEPTR↑.VALTABPTR;
                END;
            END;
      (* RETURN TO CALLING FUNCTION *)
          VFUNCPTR:=SUBRTABPTR↑.STATEMCALLINGSUBR;
          TOKENTABPTR:=SUBRTABPTR↑.TOKENCALLINGSUBR↑.NEXTOKEN;
          IF SUBRTABPTR↑.CALLEDSUBR↑.ARITY<>NILADIC THEN
            BEGIN (* MONADIC OR DYADIC *)
              AUXRPARMPTR:=RPARMPTR;
              RPARMPTR:=RPARMPTR↑.LASTPARM;
              DISPOSE(AUXRPARMPTR);
              IF SUBRTABPTR↑.CALLEDSUBR↑.ARITY=DYADIC THEN
                BEGIN (* DYADIC ONLY *)
                  AUXLPARMPTR:=LPARMPTR;
                  LPARMPTR:=LPARMPTR↑.LASTPARM;
                  DISPOSE(AUXLPARMPTR);
                END;
            END;
          AUXSUBRTABPTR:=SUBRTABPTR;
          SUBRTABPTR:=SUBRTABPTR↑.LASTSUBRPTR;
          DISPOSE (AUXSUBRTABPTR);
        END; (* RETURNTOCALLINGSUBR *)


      FUNCTION SPECSYMBOL(SYM:INTEGER):BOOLEAN;
        VAR
          VALIDSYM:BOOLEAN;
        BEGIN (* SPECSYMBOL *)
          VALIDSYM:=FALSE;
          IF TOKENTABPTR↑.NOUN=SPECOPER THEN
            IF TOKENTABPTR↑.CHARINDX=SYM THEN
              BEGIN
                HOLD:=TOKENTABPTR;
                TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
                VALIDSYM:=TRUE;
              END;
          SPECSYMBOL:=VALIDSYM;
        END; (* SPECSYMBOL *)


          PROCEDURE CALLSUBR;
            VAR
              PTRTOVARTAB:↑VARTAB;
            BEGIN (* CALLSUBR *)
              IF SUBRTABPTR↑.CALLEDSUBR↑.ARITY<>NILADIC THEN
                BEGIN
            IF NOT NAMEINVARTABLE(SUBRTABPTR↑.CALLEDSUBR↑.RIGHTARG,PTRTOVARTAB,
                                  SUBRTABPTR↑.CALLEDSUBR)
                 THEN ERROR(32);
                  IF PTRTOVARTAB↑.FUNCTABPTR<>SUBRTABPTR↑.CALLEDSUBR THEN
                    ERROR(32);(* PROGRAM LOGIC ERROR, VARIABLE NAME OF *)
                              (* FUNCTION ARGUMENT NOT FOUND IN SYMBOL TABLE *)
                  AUXRPARMPTR:=RPARMPTR;
                  NEW(RPARMPTR);
                  RPARMPTR↑.LASTPARM:=AUXRPARMPTR;
                  PTRTOVARTAB↑.DEFEREDVALTABPTR:=RPARMPTR;
                  IF SUBRTABPTR↑.CALLEDSUBR↑.ARITY=DYADIC THEN
                    BEGIN (* IF DYADIC *)
                      IF NOT NAMEINVARTABLE(SUBRTABPTR↑.CALLEDSUBR↑.LEFTARG,
                      PTRTOVARTAB,SUBRTABPTR↑.CALLEDSUBR) THEN ERROR(33);
                      IF PTRTOVARTAB↑.FUNCTABPTR<>SUBRTABPTR↑.CALLEDSUBR THEN
                        ERROR(33); (* SAME AS ERROR(32) *)
                      AUXLPARMPTR:=LPARMPTR;
                      NEW(LPARMPTR);
                      LPARMPTR↑.LASTPARM:=AUXLPARMPTR;
```

```
                    PTRTOVARTAB↑.DEFEREDVALTABPTR:=LPARMPTR;
                    LPARMPTR↑.PTRVAL:=OPERTABPTR↑.OPERPTR;
                    AUXOPERTABPTR:=OPERTABPTR;
                    OPERTABPTR:=OPERTABPTR↑.LASTOPER;
                    DISPOSE(AUXOPERTABPTR);
                    PTRLASTOPER:=OPERTABPTR;
                  END;
                RPARMPTR↑.PTRVAL:=OPERTABPTR↑.OPERPTR;
                AUXOPERTABPTR:=OPERTABPTR;
                OPERTABPTR:=OPERTABPTR↑.LASTOPER;
                DISPOSE(AUXOPERTABPTR);
                PTRLASTOPER:=OPERTABPTR;
              END;
            TOKENTABPTR:=SUBRTABPTR↑.CALLEDSUBR↑.FIRSTATEMENT↑.NEXTSTMNT;
            VFUNCPTR:=SUBRTABPTR↑.CALLEDSUBR↑.FIRSTATEMENT;
          END; (* CALLSUBR *)


        FUNCTION FUNCTCALL:BOOLEAN;
          VAR
            PTRTOFUNCTAB:↑FUNCTAB;
            NAMEOFFUNC:PACKEDSTRING;
            VALIDFN:BOOLEAN;
          BEGIN (* FUNCTCALL *)
            VALIDFN:=FALSE;
            IF TOKENTABPTR↑.NOUN=GLOBVAR THEN
              BEGIN
                NAMEOFFUNC:=TOKENTABPTR↑.VARTABPTR↑.VARNAME;
                IF FUNCTIONALREADYDEFINED(NAMEOFFUNC,PTRTOFUNCTAB) THEN
                  BEGIN
                    AUXSUBRTABPTR:=SUBRTABPTR;
                    NEW(SUBRTABPTR);
                    SUBRTABPTR↑.LASTSUBRPTR:=AUXSUBRTABPTR;
                    SUBRTABPTR↑.CALLEDSUBR:=PTRTOFUNCTAB;
                    SUBRTABPTR↑.TOKENCALLINGSUBR:=TOKENTABPTR;
                    SUBRTABPTR↑.STATEMCALLINGSUBR:=VFUNCPTR;
                    HOLD:=TOKENTABPTR;
                    TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
                    VALIDFN:=TRUE;
                  END;
              END;
            FUNCTCALL:=VALIDFN;
          END; (* FUNCTCALL *)


PROCEDURE NUMWRITE(REALNO:REAL);
VAR
  PREFIX,ROOT:INTEGER;
SIGDIG,COLCNT:INTEGER;
BEGIN (* OUTPUT A NUMBER *)
IF REALNO >= 0.0
  THEN WRITE(≡ ≡, REALNO:12:2) (* OUTPUT POSITIVE NUMBER *)
  ELSE
    BEGIN (* OUTPUT NEGATIVE NUMBER *)
    REALNO:=-1.0*REALNO;
      SIGDIG:=TRUNC((LN(REALNO))/(LN(10.0)));
      FOR COLCNT:=1 TO (7 - SIGDIG) DO
        WRITE(≡ ≡);
      IF CHARACTER[NEGATIVE] < 6000
        THEN WRITE(CHR(CHARACTER[NEGATIVE]))
        ELSE
          BEGIN
            PREFIX:=CHARACTER[NEGATIVE] DIV 100;
            ROOT:=CHARACTER[NEGATIVE] - (100*PREFIX);
            WRITE(CHR(PREFIX), CHR(ROOT));
          END;
      SIGDIG:=SIGDIG + 5;
      WRITE(REALNO:SIGDIG:2);
    END
```

```
END; (* NUMWRITE *)


          PROCEDURE OUTPUTVAL;
            VAR
              CNT:INTEGER;
              AUXVALUESPTR:↑VALUES;
             DIMHOLD, DIMEN1,DIMEN2, DIMEN3:INTEGER;
              OUTCNT1,OUTCNT2,OUTCNT3:INTEGER;
              IDIMENS:INTEGER;
            BEGIN (* OUTPUTVAL *)
              CNT:=0;
              WRITELN;WRITELN;
               IF NOT OPERTABPTR↑.OPERPTR↑.FORWARDORDER THEN
                 REVERSELINKLIST(OPERTABPTR↑.OPERPTR);
              AUXVALUESPTR:=OPERTABPTR↑.OPERPTR↑.FIRSTVALUE;
              IDIMENS:=OPERTABPTR↑.OPERPTR↑.DIMENSIONS;
              IF NOT(IDIMENS IN [0..3] ) THEN
                BEGIN
                  FOR COLCNT:=1 TO MESSAGELENGTH DO
                    WRITE(ERRORMSGS[60,COLCNT]);
                  WRITELN;
                END
              ELSE
                IF AUXVALUESPTR=NIL THEN
                BEGIN
                  FOR COLCNT:=1 TO MESSAGELENGTH DO
                    WRITE(ERRORMSGS[61,COLCNT]);
                  WRITELN;
                END
                ELSE
                  IF IDIMENS=0 THEN
                         BEGIN
                    NUMWRITE(AUXVALUESPTR↑.REALVAL);
                    WRITELN;
                    END
                  ELSE
                    BEGIN
                      DIMEN1:=OPERTABPTR↑.OPERPTR↑.FIRSTDIMEN↑.DIMENLENGTH;
                      IF IDIMENS>=2 THEN DIMEN2 :=
                      OPERTABPTR↑.OPERPTR↑.FIRSTDIMEN↑.NEXTDIMEN↑.DIMENLENGTH
                       ELSE DIMEN2:=1;
                      IF IDIMENS=3 THEN DIMEN3:=
                       OPERTABPTR↑.OPERPTR↑.FIRSTDIMEN↑.NEXTDIMEN↑.
                         NEXTDIMEN↑.DIMENLENGTH
                       ELSE DIMEN3:=1;
                      IF IDIMENS=3 THEN BEGIN (* ROTATE DIMENSIONS *)
                                         DIMHOLD:=DIMEN1; DIMEN1:=DIMEN2;
                                         DIMEN2:=DIMEN3; DIMEN3:=DIMHOLD;
                                         END;
                      FOR OUTCNT3:=1 TO DIMEN3 DO
                       BEGIN
                      FOR OUTCNT2:=1 TO DIMEN1 DO
                        BEGIN
                          FOR OUTCNT1:=1 TO DIMEN2 DO
                            BEGIN
                                CNT:=CNT + 1;
                              IF(((CNT-1)MOD 5)=0) AND
                                (CNT<>1) THEN
                                BEGIN
                                  WRITELN;
                                  WRITE('  ');
                                END;
                              NUMWRITE(AUXVALUESPTR↑.REALVAL);
                              AUXVALUESPTR:=AUXVALUESPTR↑.NEXTVALUE;
                            END;
                          IF IDIMENS>=2 THEN
                              BEGIN
                                WRITELN;
```

```
                                          CNT:=0;
                                        END;
                                END;
                               WRITELN; WRITELN;
                               END;
                            (*WRITELN;*)
                            END;
                END; (* OUTPUTVAL *)


        FUNCTION VARIABLE:BOOLEAN;
          VAR
            GLOBORDUMMY:BOOLEAN;                        (* GORD *)
            PASSEDADJ:↑VARTAB;                          (* K *)
            RARG:BOOLEAN;                               (* RD *)
            PARMPTR:↑VALTAB;                            (* PT *)
            VALIDVAR:BOOLEAN;
            VALIDINDEX:BOOLEAN;


          PROCEDURE INPUTVAL;
            VAR
              AUXPTRTODA:↑VALTAB;
              AUXVALUESPTR:↑VALUES;
              AUX2VALUESPTR:↑VALUES;
              REALV:REAL;
              BOOLV:BOOLEAN;
              CCNTR,CNT:INTEGER;
              AUXDIMENINFOPTR:↑DIMENINFO;
            BEGIN (* INPUTVAL *)
              CNT:=0;
              POSITION:=1;
              AUXPTRTODA:=PTRTODA;
              NEW(PTRTODA);
              AUXPTRTODA↑.NEXTVALTABLINK:=PTRTODA;
              AUXOPERTABPTR:=OPERTABPTR;
              NEW(OPERTABPTR);
              PTRLASTOPER:=OPERTABPTR;
              OPERTABPTR↑.LASTOPER:=AUXOPERTABPTR;
              OPERTABPTR↑.OPERPTR:=PTRTODA;
              NEW(AUX2VALUESPTR);
              PTRTODA↑.FIRSTVALUE:=AUX2VALUESPTR;
              FOR CCNTR:=1 TO MESSAGELENGTH DO
                WRITE(ERRORMSGS[63,CCNTR]);WRITELN;
              READLN;
              GETAPLSTATEMENT;
              REPEAT
                MAKEANUMBER(REALV,BOOLV);
                SKIPSPACES;
                IF NOT BOOLV THEN
                  BEGIN
                    FOR COLCNT:=1 TO MESSAGELENGTH DO
                      WRITE(ERRORMSGS[62,COLCNT]);
                      WRITELN;
                    POSITION:=1;
                    CNT:=0;
                    AUX2VALUESPTR:=OPERTABPTR↑.OPERPTR↑.FIRSTVALUE;
                    FOR CCNTR:=1 TO MESSAGELENGTH DO
                      WRITE(ERRORMSGS[63,CCNTR]);WRITELN;
                    READLN;
                    GETAPLSTATEMENT
                  END
                ELSE
                  BEGIN
                    CNT:=CNT+1;
                    AUXVALUESPTR:=AUX2VALUESPTR;
                    NEW(AUX2VALUESPTR);
                    AUXVALUESPTR↑.REALVAL:=REALV;
                    AUXVALUESPTR↑.NEXTVALUE:=AUX2VALUESPTR;
```

```
                  END;
                UNTIL POSITION>LINELENGTH;
                DISPOSE(AUX2VALUESPTR);
                AUXVALUESPTR↑.NEXTVALUE:=NIL;
                PTRTODA↑.INTERMEDRESULT:=FALSE;
                PTRTODA↑.DIMENSIONS:=1;
                PTRTODA↑.FORWARDORDER:=TRUE;
                PTRTODA↑.NEXTVALTABLINK:=NIL;
                NEW(AUXDIMENINFOPTR);
                PTRTODA↑.FIRSTDIMEN:=AUXDIMENINFOPTR;
                AUXDIMENINFOPTR↑.DIMENLENGTH:=CNT;
                AUXDIMENINFOPTR↑.NEXTDIMEN:=NIL;
              END; (* INPUTVAL *)


          PROCEDURE GETARRAYPOSITION(VAR VALUESPTR:TYPEVALUESPTR);
            VAR
              INDICE:REAL;
              KCNT:INTEGER;
              SL:INTEGER;
              AUXDIMENINFOPTR:↑DIMENINFO;
            BEGIN (* GETARRAYPOSITION *)
              IF NPV<>PARMPTR↑.DIMENSIONS THEN ERROR(35);
                                (* ↑WRONG NUM. OF SUBSCRIPTS↑ *)
              SL:=0;
              AUXOPERTABPTR:=OPERTABPTR;
              AUXDIMENINFOPTR:=PARMPTR↑.FIRSTDIMEN;
              FOR KCNT:=1 TO NPV DO
                BEGIN
                  IF AUXOPERTABPTR↑.OPERPTR↑.DIMENSIONS<>0 THEN
                    ERROR(35); (* ↑NON-SCALER INDICES↑ *)
                  INDICE:=AUXOPERTABPTR↑.OPERPTR↑.FIRSTVALUE↑.REALVAL;
                  IF INDICE-1.0*TRUNC(INDICE)<>0.0 THEN
                    ERROR(37); (* ↑NON-INTEGER INDICES↑ *)
                  IF NOT(TRUNC(INDICE)
                  IN [1..AUXDIMENINFOPTR↑.DIMENLENGTH]) THEN
                    ERROR(38); (* ↑OUT OF RANGE INDEX↑ *)
                  SL:=(SL*AUXDIMENINFOPTR↑.DIMENLENGTH)+TRUNC(INDICE)-1;
                  AUXOPERTABPTR:=AUXOPERTABPTR↑.LASTOPER;
                  DISPOSE(OPERTABPTR);
                  OPERTABPTR:=AUXOPERTABPTR;
                  AUXDIMENINFOPTR:=AUXDIMENINFOPTR↑.NEXTDIMEN;
                END;
              VALUESPTR:=PARMPTR↑.FIRSTVALUE;
              WHILE SL<>0 DO(* DETERMINE WHICH VALUE IN  *)
                        (* PT[SVAL(SV)][SVAL(SV-1)]...[SVAL(SV-NPV+1)]*)
                        (*          := SVAL(SV-NPV)                  *)
                BEGIN
                  VALUESPTR:=VALUESPTR↑.NEXTVALUE;
                  SL:=SL-1;
                END;
            END; (* GETARRAYPOSITION *)


          PROCEDURE LINKRESULTS;
            VAR
              PTRTOVALUES:↑VALUES;
            BEGIN (* LINKRESULTS *)
              IF NPV=0 THEN
                BEGIN
                  IF NOT GLOBORDUMMY THEN
                    IF RARG THEN
                      RPARMPTR↑.PTRVAL:=OPERTABPTR↑.OPERPTR
                    ELSE
                      LPARMPTR↑.PTRVAL:=OPERTABPTR↑.OPERPTR
                  ELSE
                    PASSEDADJ↑.VALTABPTR:=OPERTABPTR↑.OPERPTR
                END
              ELSE
```

```
          BEGIN
            IF GLOBORDUMMY THEN PARMPTR:=PASSEDADJ↑.VALTABPTR
            ELSE PARMPTR:=PASSEDADJ↑.DEFEREDVALTABPTR↑.PTRVAL;
            GETARRAYPOSITION(PTRTOVALUES);
            IF OPERTABPTR↑.OPERPTR↑.DIMENSIONS<>0 THEN
              ERROR(36); (* ↑ASSIGNED EXPRESSION NOT A SCALAR↑ *)
            PTRTOVALUES↑.REALVAL:=
            OPERTABPTR↑.OPERPTR↑.FIRSTVALUE↑.REALVAL;
          END;
        AUXOPERTABPTR:=OPERTABPTR;
        OPERTABPTR:=OPERTABPTR↑.LASTOPER;
        DISPOSE(AUXOPERTABPTR);
        PTRLASTOPER:=OPERTABPTR;
      END; (* LINKRESULTS *)


    PROCEDURE STACKPOINTERS;
      VAR
        AUXPTRTODA:↑VALTAB;
        PTRTOVALUES,AUXVALUESPTR:↑VALUES;
      BEGIN (* STACKPOINTERS *);
        IF NPV=0 THEN
          BEGIN
            AUXOPERTABPTR:=OPERTABPTR;
            NEW(OPERTABPTR);
            OPERTABPTR↑.LASTOPER:=AUXOPERTABPTR;
            OPERTABPTR↑.OPERPTR:=PARMPTR;
            PTRLASTOPER:=OPERTABPTR
          END
        ELSE
          BEGIN
            AUXPTRTODA:=PTRTODA;
            NEW(PTRTODA);
            PTRTODA↑.NEXTVALTABLINK:=AUXPTRTODA;
            PTRTODA↑.INTERMEDRESULT:=TRUE;
            PTRTODA↑.DIMENSIONS:=0;
            PTRTODA↑.FIRSTDIMEN:=NIL;
            PTRTODA↑.FORWARDORDER:=TRUE;
            NEW(AUXVALUESPTR);
            PTRTODA↑.FIRSTVALUE:=AUXVALUESPTR;
            GETARRAYPOSITION(PTRTOVALUES);
            PTRTODA↑.FIRSTVALUE↑.REALVAL:=PTRTOVALUES↑.REALVAL;
            PTRTODA↑.FIRSTVALUE↑.NEXTVALUE:=NIL;
            AUXOPERTABPTR:=OPERTABPTR;
            NEW(OPERTABPTR);
            OPERTABPTR↑.LASTOPER:=AUXOPERTABPTR;
            OPERTABPTR↑.OPERPTR:=PTRTODA;
            PTRLASTOPER:=OPERTABPTR;
          END;
      END; (* STACKPOINTERS *)


    FUNCTION SIMPLEVARIABLE:BOOLEAN;
      VAR
        VALIDSV:BOOLEAN;
      BEGIN (* SIMPLEVARIABLE *)
        VALIDSV:=FALSE;
        RARG:=FALSE;
        GLOBORDUMMY:=FALSE;
        IF ASSIGN THEN
          BEGIN
            IF (TOKENTABPTR↑.NOUN=FORMRES) OR
                (TOKENTABPTR↑.NOUN=GLOBVAR) THEN
              BEGIN
                GLOBORDUMMY:=TRUE;
                PASSEDADJ:=TOKENTABPTR↑.VARTABPTR;
                HOLD:=TOKENTABPTR;
                TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
                VALIDSV:=TRUE
```

```
                    END
                  ELSE
                    IF TOKENTABPTR↑.NOUN=FORMARG THEN
                      BEGIN
                        IF NAMESMATCH
                        (TOKENTABPTR↑.VARTABPTR↑.FUNCTABPTR↑.LEFTARG,
                        TOKENTABPTR↑.VARTABPTR↑.VARNAME ) THEN RARG:=TRUE;
                        PASSEDADJ:=TOKENTABPTR↑.VARTABPTR
                      END
              END
              ELSE
                BEGIN
                  IF (TOKENTABPTR↑.NOUN=FORMRES) OR
                     (TOKENTABPTR↑.NOUN=GLOBVAR) THEN
                    BEGIN
                      PARMPTR:=TOKENTABPTR↑.VARTABPTR↑.VALTABPTR;
                      IF PARMPTR<>NIL THEN
                        BEGIN
                          HOLD:=TOKENTABPTR;
                          TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
                          VALIDSV:=TRUE
                        END
                    END
                  ELSE
                    BEGIN
                      IF TOKENTABPTR↑.NOUN=FORMARG THEN
                        BEGIN
                          IF NAMESMATCH
                          (TOKENTABPTR↑.VARTABPTR↑.FUNCTABPTR↑.LEFTARG,
                          TOKENTABPTR↑.VARTABPTR↑.VARNAME) THEN
                            PARMPTR:=LPARMPTR↑.PTRVAL
                          ELSE
                            PARMPTR:=RPARMPTR↑.PTRVAL;
                          HOLD:=TOKENTABPTR;
                          TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
                          VALIDSV:=TRUE;
                        END;
                    END;
                END;
              SIMPLEVARIABLE:=VALIDSV;
            END; (* SIMPLE VARIABLE *)


        PROCEDURE INDEX(VAR VALIDI:BOOLEAN);
          VAR
            VALIDE1,VALIDE2:BOOLEAN;
          BEGIN (* INDEX *)
            VALIDI:=FALSE;
            EXPRESSION(VALIDE1);
            IF VALIDE1 THEN
              BEGIN
                NPV:=1; (* NO. OF INDEX EXPRESSIONS *)
                WHILE SPECSYMBOL(XSEMICOLSYM) DO
                  BEGIN
                    NPV:=NPV+1;
                    EXPRESSION(VALIDE2);
                    IF NOT VALIDE2 THEN ERROR(39);
                          (* ↑INVALID INDEX EXPRESSION↑ *)
                  END;
                VALIDI:=TRUE;
              END;
          END; (* INDEX *)


          BEGIN (* VARIABLE *)
            VALIDVAR:=FALSE; NPV:=0;
            IF NOT ASSIGN THEN
              IF SPECSYMBOL(XQUADSYM) THEN
                BEGIN
```

```
              INPUTVAL;
              VALIDVAR:=TRUE
            END
          ELSE
            BEGIN
              IF SPECSYMBOL(XRIGHTBRACKET) THEN
                BEGIN
                  INDEX(VALIDINDEX);
                  IF (NOT VALIDINDEX) OR (NOT SPECSYMBOL(XLEFTBRACKET))
                    THEN ERROR(34); (* INVALID INDEX EXPRESSION *)
                END;
              IF SIMPLEVARIABLE THEN
                BEGIN
                  STACKPOINTERS;
                  VALIDVAR:=TRUE
                END
            END
        ELSE
          IF SPECSYMBOL(XQUADSYM) THEN
            BEGIN
              OUTPUTVAL;
              VALIDVAR:=TRUE
            END
          ELSE
            BEGIN
              IF SPECSYMBOL(XRIGHTBRACKET) THEN
                BEGIN
                  INDEX(VALIDINDEX);
                  IF (NOT VALIDINDEX) OR (NOT SPECSYMBOL(XLEFTBRACKET))
                    THEN ERROR(34); (* INVALID INDEX EXPRESSION *)
                END;
              IF SIMPLEVARIABLE THEN
                BEGIN
                  LINKRESULTS;
                  VALIDVAR:=TRUE;
                END;
            END;
      VARIABLE:=VALIDVAR;
    END; (* VARIABLE *)


PROCEDURE PRIMARY(VAR VALID:BOOLEAN);  (* RECURSIVE ENTRY *)
  VAR
    VALIDX:BOOLEAN;
    ASSIGN:BOOLEAN;


  FUNCTION VECTOR:BOOLEAN;
    VAR
      VEC:BOOLEAN;
    BEGIN (* VECTOR *)
      VEC:=FALSE;
      IF TOKENTABPTR↑.NOUN=CONSTANT THEN
        BEGIN
          AUXOPERTABPTR:=OPERTABPTR;
          NEW(OPERTABPTR);
          PTRLASTOPER:=OPERTABPTR;
          OPERTABPTR↑.LASTOPER:=AUXOPERTABPTR;
          OPERTABPTR↑.OPERPTR:=TOKENTABPTR↑.VALTABPTR;
          HOLD:=TOKENTABPTR;
          TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
          VEC:=TRUE;
        END;
      VECTOR:=VEC;
    END; (* VECTOR *)

  BEGIN (* PRIMARY *)
    VALID:=TRUE;
    IF NOT VECTOR THEN
```

```
          BEGIN
            ASSIGN:=FALSE;
            IF NOT VARIABLE THEN
              IF SPECSYMBOL(XRIGHTPAR) THEN
                BEGIN
                  EXPRESSION(VALIDX);
                  IF NOT VALIDX THEN ERROR(14)
                        (* ↑NON-VALID EXP WITHIN PARENS↑ *)
                  ELSE
                    IF NOT SPECSYMBOL(XLEFTPAR) THEN ERROR(15)
                        (* ↑RIGHT PAREN NOT BALANCED WITH LEFT PAREN↑ *)
                    ELSE
                      VALID:=TRUE
                END
              ELSE
                IF NOT FUNCTCALL THEN VALID:=FALSE
                ELSE
                  BEGIN
                    CALLSUBR;
                    PRIMARY(VALID);
                    END;
          END;
      END; (* PRIMARY *)


  PROCEDURE EXPRESSION; (* RECURSIVE *)
    VAR
      DONEXP,VALIDPRI,VALIDFUNC,VALIDASSN:BOOLEAN;
      CODE:INTEGER;


      PROCEDURE ASSIGNMENT(VAR VALIDA:BOOLEAN);
        BEGIN (* ASSIGNMENT *)
          VALIDA:=FALSE;
          IF SPECSYMBOL(XLEFTARROW) THEN
            BEGIN
              ASSIGN:=TRUE;ASSIGN1:=TRUE;
              IF VARIABLE THEN VALIDA:=TRUE
              ELSE ERROR(8); (* RESULT OF AN ASSN NOT A VALID VARIABLE *)
              VALIDA:=TRUE;
              ASSIGN:=FALSE;
            END;
        END; (* ASSIGNMENT *)


      FUNCTION MOP:BOOLEAN;
        VAR
          VALIDM:BOOLEAN;
        BEGIN (* MOP *)
          VALIDM:=FALSE;
          IF (TOKENTABPTR↑.NOUN=MONADOPER) OR
             (TOKENTABPTR↑.NOUN=REDUCTOPER) THEN
            BEGIN
              IF TOKENTABPTH↑.NOUN=MONADOPER THEN
                CODE:=MOPTAB[TOKENTABPTR↑.MONINDX].OPINDEX
              ELSE
                CODE:=REDTAB[TOKENTABPTR↑.REDINDX].OPINDEX;
              HOLD:=TOKENTABPTR;
              TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
              VALIDM:=TRUE;
            END;
            MOP:=VALIDM;
          END; (* MOP *)


      FUNCTION DOP:BOOLEAN;
        VAR
          VALIDD:BOOLEAN;
        BEGIN (* DOP *)
```

```
                  VALIDD:=FALSE;
                  IF TOKENTABPTR↑.NOUN=DYADOPER THEN
                    BEGIN
                      CODE:=DOPTAB[TOKENTABPTR↑.DOPINDX].OPINDEX;
                      HOLD:=TOKENTABPTR;
                      TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
                      IF (CODE>80) THEN VALIDD:=TRUE
                      ELSE
                        IF TOKENTABPTR↑.NOUN=SPECOPER THEN
                          IF SPECSYMBOL(XPERIOD) THEN
                              BEGIN
                                IF TOKENTABPTR↑.NOUN=DYADOPER THEN
                                  BEGIN
                                    IF DOPTAB[TOKENTABPTR↑.DOPINDX].OPINDEX<=80
                                      THEN BEGIN
                                        CODE:=CODE+(100*
                                          DOPTAB[TOKENTABPTR↑.DOPINDX].OPINDEX);
                                        HOLD:=TOKENTABPTR;
                                        TOKENTABPTR:=TOKENTABPTR↑.NEXTOKEN;
                                        VALIDD:=TRUE
                                      END
                                    ELSE
                                      ERROR(27) (* ↑INVALID INNER PRODUCT EXP *)
                                  END
                                ELSE
                                  IF TOKENTABPTR↑.NOUN=SPECOPER THEN
                                    BEGIN
                                      IF SPECSYMBOL(XLITTLECIRCLE) THEN
                                        BEGIN
                                          CODE:=10*CODE;
                                          VALIDD:=TRUE
                                        END
                                      ELSE
                                        ERROR(26) (* ↑INVAL OUTER PROD EXP↑ *)
                                    END
                                  ELSE ERROR(26) (* SAME AS ABOVE *)
                              END
                          ELSE
                            VALIDD:=TRUE
                        ELSE
                          VALIDD:=TRUE;
                    END;
                  DOP:=VALIDD;
                END; (* DOP *)

FUNCTION ITSBOOLEAN(TEST:REAL):BOOLEAN;
BEGIN
IF (TEST = 1.0) OR (TEST = 0.0)
 THEN ITSBOOLEAN:=TRUE
 ELSE ITSBOOLEAN:=FALSE
END; (* ITSBOOLEAN *)


PROCEDURE DYADCOMP(VAR SFLOAT:REAL; VALUE:REAL; CODE:INTEGER);
        (* COMPUTE RESULT OF DYADIC OPERATION *)
BEGIN
CASE CODE OF (*LEFT CODES - REDUCTION OPS / RIGHT CODES - DYADIC OPS*)
  2,52: SFLOAT:=VALUE + SFLOAT; (*ADDITION*)
  3,53: SFLOAT:=VALUE - SFLOAT; (*SUBTRACTION*)
  4,54: SFLOAT:=VALUE * SFLOAT; (*MULTIPLICATION*)
  5,55: IF SFLOAT = 0.0
          THEN ERROR(20) (*ATTEMPTED DIVISION BY ZERO*)
          ELSE SFLOAT:=VALUE / SFLOAT; (*DIVISION*)
  6,56: IF VALUE > 0.0
          THEN SFLOAT:=EXP(SFLOAT*LN(VALUE)) (*NUMBER RAISED TO A POWER*)
          ELSE SFLOAT:=1.0 / (EXP(SFLOAT*LN(ABS(VALUE))));
  21,71: IF VALUE = SFLOAT    (*EQUALITY*)
          THEN SFLOAT:=1.0
```

```
               ELSE SFLOAT:=0.0;
    22,72: IF VALUE <> SFLOAT  (*INEQUALITY*)
               THEN SFLOAT:=1.0
               ELSE SFLOAT:=0.0;
    23,73: IF VALUE < SFLOAT   (*LESS THAN*)
               THEN SFLOAT:=1.0
               ELSE SFLOAT:=0.0;
    24,74: IF VALUE <= SFLOAT  (*LESS THAN OR EQUAL TO*)
               THEN SFLOAT:=1.0
               ELSE SFLOAT:=0.0;
    25,75: IF VALUE >= SFLOAT  (*GREATER THAN OR EQUAL TO*)
               THEN SFLOAT:=1.0
               ELSE SFLOAT:=0.0;
    26,76: IF VALUE > SFLOAT   (*GREATER THAN*)
               THEN SFLOAT:=1.0
               ELSE SFLOAT:=0.0;
    27,77: IF (ITSBOOLEAN(VALUE)) AND (ITSBOOLEAN(SFLOAT)) THEN
           IF (VALUE = 1.0) AND (SFLOAT = 1.0)   (* AND *)
               THEN SFLOAT:=1.0
               ELSE SFLOAT:=0.0
           ELSE ERROR(19); (* VALUE NOT BOOLEAN *)
    28,78: IF (ITSBOOLEAN(VALUE)) AND (ITSBOOLEAN(SFLOAT)) THEN
           IF (VALUE = 1.0) OR (SFLOAT = 1.0)   (* OR *)
               THEN SFLOAT:=1.0
               ELSE SFLOAT:=0.0
           ELSE ERROR(19); (* VALUE NOT BOOLEAN *)
    29   : IF VALUE > SFLOAT      (*MAXIMUM OR CEILING*)
               THEN SFLOAT:=VALUE;
    30   : IF VALUE < SFLOAT      (*MINIMUM OR FLOOR*)
               THEN SFLOAT:=VALUE;
    31   : IF (VALUE*SFLOAT) < 0.0
               THEN ERROR(50) (*NUMBER AND BASE OF DIFFERENT SIGN*)
               ELSE SFLOAT:=(LN(ABS(SFLOAT))) / (LN(ABS(VALUE))) (*LOG TO A BASE*)
END (*CASE*)
END; (* DYADCOMP *)


PROCEDURE INDEXGENERATOR(ARG:TYPEVALTABPTR);
       (* MONADIC IOTA OPERATOR *)
VAR
IOTAINDEX,TOPVALUE:INTEGER;
BEGIN
IF ARG↑.DIMENSIONS <> 0
 THEN ERROR(21) (*ARGUMENT NOT A SCALAR*)
 ELSE
   IF ARG↑.FIRSTVALUE↑.REALVAL < 0.0
     THEN ERROR(22) (* ARGUMENT IS NEGATIVE *)
     ELSE
       IF (ARG↑.FIRSTVALUE↑.REALVAL) - (1.0*TRUNC(ARG↑.FIRSTVALUE↑.REALVAL))
          <> 0.0
         THEN ERROR(23) (*ARGUMENT IS NOT AN INTEGER*)
         ELSE
           BEGIN
             NEW(NEWVALTABLINK);
             OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
             NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
             NEWVALTABLINK↑.FORWARDORDER:=TRUE;
             NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
             NEWVALTABLINK↑.DIMENSIONS:=1; (*RESULT IS A VECTOR*)
             NEW(NEWDIM);
             NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM;
             TOPVALUE:=TRUNC(ARG↑.FIRSTVALUE↑.REALVAL); (*LAST INDEX GENERD*)
             NEWDIM↑.DIMENLENGTH:=TOPVALUE;
             NEWDIM↑.NEXTDIMEN:=NIL;
             IOTAINDEX:=1;
             SWITCH:=TRUE;
             WHILE IOTAINDEX <= TOPVALUE DO
               BEGIN
                 NEW(NEWVALUES);
```

```
                          NEWVALUES↑.REALVAL:=IOTAINDEX;
                          IF SWITCH = TRUE
                            THEN
                              BEGIN
                                SWITCH:=FALSE;
                                NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                              END
                            ELSE
                              NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
                          NEWVALPTR:=NEWVALUES;
                          IOTAINDEX:=IOTAINDEX + 1
                        END;
                      IF SWITCH = TRUE
                        THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL
                         (*RESULT IS VECTOR OF LENGTH 0*)
                        ELSE NEWVALUES↑.NEXTVALUE:=NIL
                    END
END; (* INDEXGENERATOR *)


PROCEDURE RAVEL(ARG:TYPEVALTABPTR);
        (* MONADIC COMMA OPERATOR *)
VAR
ELEMENTS:INTEGER;
BEGIN
NEW(NEWVALTABLINK);
OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
NEWVALTABLINK↑.FORWARDORDER:=ARG↑.FORWARDORDER;
NEWVALTABLINK↑.DIMENSIONS:=1; (*RESULT IS A VECTOR*)
NEW(NEWDIM);
NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM;
NEWDIM↑.NEXTDIMEN:=NIL;
SWITCH:=TRUE;
VALPTR:=ARG↑.FIRSTVALUE;
ELEMENTS:=0;
WHILE VALPTR <> NIL DO
 BEGIN (*DUPLICATE VALUES INTO RESULT*)
   NEW(NEWVALUES);
   NEWVALUES↑.REALVAL:=VALPTR↑.REALVAL;
   ELEMENTS:=ELEMENTS + 1;
   IF SWITCH = TRUE
     THEN
       BEGIN
         SWITCH:=FALSE;
         NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
       END
     ELSE
       NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
   NEWVALPTR:=NEWVALUES;
   VALPTR:=VALPTR↑.NEXTVALUE
 END;
NEWDIM↑.DIMENLENGTH:=ELEMENTS;
IF SWITCH = TRUE
 THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL
 ELSE NEWVALUES↑.NEXTVALUE:=NIL
END; (* RAVEL *)


PROCEDURE SHAPEOF(ARG:TYPEVALTABPTR);
        (* MONADIC RHO OPERATOR *)
BEGIN
NEW(NEWVALTABLINK);
OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
NEWVALTABLINK↑.FORWARDORDER:=TRUE;
NEWVALTABLINK↑.DIMENSIONS:=1; (*RESULT IS A VECTOR*)
```

```
NEW(NEWDIM);
NEWDIM↑.DIMENLENGTH:=ARG↑.DIMENSIONS;
NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM;
NEWDIM↑.NEXTDIMEN:=NIL;
SWITCH:=TRUE;
DIMPTR:=ARG↑.FIRSTDIMEN;
WHILE DIMPTR <> NIL DO
 BEGIN (*ARGUMENT DIMENSIONS BECOME RESULT VALUES*)
   NEW(NEWVALUES);
   NEWVALUES↑.REALVAL:=DIMPTR↑.DIMENLENGTH;
   IF SWITCH = TRUE
     THEN
       BEGIN
         SWITCH:=FALSE;
         NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
       END
     ELSE
       NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
   NEWVALPTR:=NEWVALUES;
   DIMPTR:=DIMPTR↑.NEXTDIMEN
 END;
IF SWITCH = TRUE
 THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL (*RESULT IS A VECTOR OF LENGTH 0*)
 ELSE NEWVALUES↑.NEXTVALUE:=NIL
END; (* SHAPEOF *)


PROCEDURE REDUCTION(ARG:TYPEVALTABPTR);
VAR
COUNTER,ROWLENGTH:INTEGER;
SFLOAT:REAL;
BEGIN
IF (ARG↑.DIMENSIONS = 0) OR (ARG↑.FIRSTVALUE = NIL)
 THEN ERROR(24) (*ARGUMENT IS A SCALAR OR VECTOR OF LENGTH ZERO*)
 ELSE
   IF (ARG↑.DIMENSIONS = 1) AND (ARG↑.FIRSTDIMEN↑.DIMENLENGTH = 1)
     THEN ERROR(51) (*ARGUMENT IS A VECTOR OF LENGTH ONE*)
     ELSE
       BEGIN
         NEW(NEWVALTABLINK);
         OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
         NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
         NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
         IF ARG↑.FORWARDORDER = TRUE
           THEN REVERSELINKLIST(ARG);
         NEWVALTABLINK↑.FORWARDORDER:=FALSE;
         NEWVALTABLINK↑.DIMENSIONS:=ARG↑.DIMENSIONS - 1;
         DIMPTR:=ARG↑.FIRSTDIMEN;
         SWITCH:=TRUE;
         WHILE DIMPTR↑.NEXTDIMEN <> NIL DO
           BEGIN (*BUILD DIMENSIONS OF RESULT*)
             NEW(NEWDIM);
             IF SWITCH = TRUE
               THEN
                 BEGIN
                   SWITCH:=FALSE;
                   NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
                 END
               ELSE
                 NEWPTR↑.NEXTDIMEN:=NEWDIM;
             NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
             NEWPTR:=NEWDIM;
             DIMPTR:=DIMPTR↑.NEXTDIMEN
           END;
         IF SWITCH = TRUE
           THEN NEWVALTABLINK↑.FIRSTDIMEN:=NIL
              (*ARG IS VECTOR,RESULT IS SCALAR*)
           ELSE NEWDIM↑.NEXTDIMEN:=NIL;
```

```
            ROWLENGTH:=DIMPTR↑.DIMENLENGTH;
            VALPTR:=ARG↑.FIRSTVALUE;
            SWITCH:=TRUE;
            WHILE VALPTR <> NIL DO
              BEGIN (*PERFORM REDUCTION*)
                SFLOAT:=VALPTR↑.REALVAL; (*SFLOAT GETS LAST VALUE IN ROW*)
                VALPTR:=VALPTR↑.NEXTVALUE;
                FOR COUNTER:=2 TO ROWLENGTH DO
                  BEGIN
                    DYADCOMP(SFLOAT,VALPTR↑.REALVAL,CODE);
                    VALPTR:=VALPTR↑.NEXTVALUE
                  END;
                NEW(NEWVALUES);
                NEWVALUES↑.REALVAL:=SFLOAT;
                IF SWITCH = TRUE
                  THEN
                    BEGIN
                      SWITCH:=FALSE;
                      NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                    END
                  ELSE
                    NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
                NEWVALPTR:=NEWVALUES
              END;
            NEWVALUES↑.NEXTVALUE:=NIL
          END;
END; (*REDUCTION*)


PROCEDURE MONADIC(ARG:TYPEVALTABPTR; TOKEN:TOKENPTR);
        (* OPERATIONS WITH CODES BETWEEN 1 AND 31 *)
BEGIN
IF TOKEN↑.NOUN = REDUCTOPER
 THEN REDUCTION(ARG)
 ELSE
   IF CODE > 20
     THEN
       CASE CODE OF
         21: INDEXGENERATOR(ARG);
         22: SHAPEOF(ARG);
         23: RAVEL(ARG)
       END (*CASE*)
     ELSE
       BEGIN
         NEW(NEWVALTABLINK);
         OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
         NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
         NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
         NEWVALTABLINK↑.FORWARDORDER:=ARG↑.FORWARDORDER;
         NEWVALTABLINK↑.DIMENSIONS:=ARG↑.DIMENSIONS;
         SWITCH:=TRUE;
         DIMPTR:=ARG↑.FIRSTDIMEN;
         WHILE DIMPTR <> NIL DO
           BEGIN (*DUPLICATE DIMENSIONS OF ARG INTO RESULT*)
             NEW(NEWDIM);
             NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
             IF SWITCH = TRUE
               THEN
                 BEGIN
                   SWITCH:=FALSE;
                   NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
                 END
               ELSE
                 NEWPTR↑.NEXTDIMEN:=NEWDIM;
             NEWPTR:=NEWDIM;
             DIMPTR:=DIMPTR↑.NEXTDIMEN
           END;
         IF SWITCH = TRUE
           THEN NEWVALTABLINK↑.FIRSTDIMEN:=NIL (*RESULT IS A SCALAR*)
```

```
               ELSE NEWDIM↑.NEXTDIMEN:=NIL;
             SWITCH:=TRUE;
             VALPTR:=ARG↑.FIRSTVALUE;
             WHILE VALPTR <> NIL DO
               BEGIN
                 NEW(NEWVALUES);
                 IF SWITCH = TRUE
                   THEN
                     BEGIN
                       SWITCH:=FALSE;
                       NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                     END
                   ELSE
                     NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
                 NEWVALPTR:=NEWVALUES;
                 CASE CODE OF
                   I: IF ITSBOOLEAN(VALPTR↑.REALVAL)  (* LOGICAL NEGATION *)
                        THEN NEWVALUES↑.REALVAL:=I.0 - VALPTR↑.REALVAL
                        ELSE ERROR(19); (*VALUE NOT BOOLEAN *)
                   2: NEWVALUES↑.REALVAL:=VALPTR↑.REALVAL; (* NO-OP *)
                   3: NEWVALUES↑.REALVAL:=0.0 - VALPTR↑.REALVAL; (* NEGATION *)
                   4: IF VALPTR↑.REALVAL > 0.0  (* SIGNUM *)
                        THEN NEWVALUES↑.REALVAL:=I.0
                        ELSE
                          IF VALPTR↑.REALVAL < 0.0
                            THEN NEWVALUES↑.REALVAL:=-1.0;
                   5: IF VALPTR↑.REALVAL = 0.0  (* RECIPROCAL *)
                        THEN ERROR(54) (*ATTEMPTED INVERSE OF ZERO*)
                        ELSE NEWVALUES↑.REALVAL:=1.0 / VALPTR↑.REALVAL;
                   6: NEWVALUES↑.REALVAL:=EXP(VALPTR↑.REALVAL)
                 END; (*CASE*)
                 VALPTR:=VALPTR↑.NEXTVALUE
               END;
             IF SWITCH = TRUE
               THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL
               ELSE NEWVALUES↑.NEXTVALUE:=NIL
           END
END; (* MONADIC *)


PROCEDURE CATENATE(LEFTARG,RIGHTARG:TYPEVALTABPTR);
          (* DYADIC COMMA OPERATOR - JOINS 2 ARGUMENTS *)
VAR
RESULTLENGTH:INTEGER;
BEGIN (*CATENATE*)
IF (RIGHTARG↑.DIMENSIONS > I) OR (LEFTARG↑.DIMENSIONS > I)
 THEN ERROR(53) (*ARGUMENT(S) WITH RANK GREATER THAN I*)
 ELSE
   BEGIN
     NEW(NEWVALTABLINK);
     OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
     NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
     NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
     IF LEFTARG↑.FORWARDORDER = FALSE
       THEN REVERSELINKLIST(LEFTARG);
     IF RIGHTARG↑.FORWARDORDER = FALSE
       THEN REVERSELINKLIST(RIGHTARG);
     NEWVALTABLINK↑.FORWARDORDER:=TRUE;
     NEWVALTABLINK↑.DIMENSIONS:=1; (*RESULT IS A VECTOR*)
     NEW(NEWDIM);
     NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM;
     NEWDIM↑.NEXTDIMEN:=NIL;
     RESULTLENGTH:=0;
     IF LEFTARG↑.DIMENSIONS = 0
       THEN RESULTLENGTH:=RESULTLENGTH + I (*LEFT ARG IS A SCALAR*)
       ELSE RESULTLENGTH:=RESULTLENGTH + LEFTARG↑.FIRSTDIMEN↑.DIMENLENGTH;
     IF RIGHTARG↑.DIMENSIONS = 0
       THEN RESULTLENGTH:=RESULTLENGTH + 1 (*RIGHT ARG IS A SCALAR*)
       ELSE RESULTLENGTH:=RESULTLENGTH + RIGHTARG↑.FIRSTDIMEN↑.DIMENLENGTH;
```

```
      NEWDIM↑.DIMENLENGTH:=RESULTLENGTH;
      SWITCH:=TRUE;
      IF RESULTLENGTH = 0
        THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL (*RESULT IS VECTOR OF LENGTH 0*)
        ELSE
          BEGIN (*TRANSFER VALUES TO RESULT*)
            LEFTVALPTR:=LEFTARG↑.FIRSTVALUE;
            WHILE LEFTVALPTR <> NIL DO
              BEGIN (*TRANSFER LEFT ARG VALUES (IF ANY) *)
                NEW(NEWVALUES);
                IF SWITCH = TRUE
                  THEN
                    BEGIN
                      SWITCH:=FALSE;
                      NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                    END
                  ELSE
                    NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
                NEWVALUES↑.REALVAL:=LEFTVALPTR↑.REALVAL;
                NEWVALPTR:=NEWVALUES;
                LEFTVALPTR:=LEFTVALPTR↑.NEXTVALUE
              END;
            RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
            WHILE RIGHTVALPTR <> NIL DO
              BEGIN (*TRANSFER RIGHT ARG VALUES (IF ANY) *)
                NEW(NEWVALUES);
                IF SWITCH = TRUE
                  THEN
                    BEGIN
                      SWITCH:=FALSE;
                      NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                    END
                  ELSE
                    NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
                NEWVALUES↑.REALVAL:=RIGHTVALPTR↑.REALVAL;
                NEWVALPTR:=NEWVALUES;
                RIGHTVALPTR:=RIGHTVALPTR↑.NEXTVALUE
              END;
            NEWVALUES↑.NEXTVALUE:=NIL
          END (*TRANSFER OF VALUES*)
  END
END; (* CATENATE *)


PROCEDURE INDEXOF(LEFTARG,RIGHTARG:TYPEVALTABPTR);
      (* DYADIC IOTA OPERATOR *)
VAR
MAPINDEX,ICOUNT,TESTLENGTH,ONEMORE:INTEGER;
BEGIN (* INDEXOF *)
IF LEFTARG↑.DIMENSIONS <> 1
 THEN ERROR(29) (* LEFT ARGUMENT IS NOT A VECTOR *)
 ELSE
   BEGIN
     NEW(NEWVALTABLINK);
     OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
     NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
     NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
     IF LEFTARG↑.FORWARDORDER = FALSE
       THEN REVERSELINKLIST(LEFTARG);
     NEWVALTABLINK↑.FORWARDORDER:=RIGHTARG↑.FORWARDORDER;
     NEWVALTABLINK↑.DIMENSIONS:=RIGHTARG↑.DIMENSIONS;
     IF RIGHTARG↑.DIMENSIONS = 0
       THEN NEWVALTABLINK↑.FIRSTDIMEN:=NIL (*RIGHT ARGUMENT IS A SCALAR*)
       ELSE
         BEGIN (*BUILD DIMENSIONS OF RESULT*)
           SWITCH:=TRUE;
           DIMPTR:=RIGHTARG↑.FIRSTDIMEN;
           WHILE DIMPTR <> NIL DO
             BEGIN
```

```
                NEW(NEWDIM);
                IF SWITCH = TRUE
                  THEN
                    BEGIN
                      SWITCH:=FALSE;
                      NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
                    END
                  ELSE
                    NEWPTR↑.NEXTDIMEN:=NEWDIM;
                NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
                NEWPTR:=NEWDIM;
                DIMPTR:=DIMPTR↑.NEXTDIMEN
              END;
            NEWDIM↑.NEXTDIMEN:=NIL
          END;
      SWITCH:=TRUE;
      RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
      WHILE RIGHTVALPTR <> NIL DO
        BEGIN
          NEW(NEWVALUES);
          IF SWITCH = TRUE
            THEN
              BEGIN
                SWITCH:=FALSE;
                NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
              END
            ELSE
              NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
          ICOUNT:=1;
          LEFTVALPTR:=LEFTARG↑.FIRSTVALUE;
          TESTLENGTH:=LEFTARG↑.FIRSTDIMEN↑.DIMENLENGTH; (*LENGTH OF LEFT ARG*)
          ONEMORE:=TESTLENGTH + 1;  (*LENGTH OF LEFT ARG PLUS ONE*)
          MAPINDEX:=ONEMORE;
          WHILE (ICOUNT <= TESTLENGTH) AND (MAPINDEX = ONEMORE) DO
            BEGIN (*TRY TO MATCH VALUE IN RIGHT ARG WITH ONE IN LEFT ARG*)
              IF LEFTVALPTR↑.REALVAL = RIGHTVALPTR↑.REALVAL
                THEN MAPINDEX:=ICOUNT; (*VALUE MATCH*)
              ICOUNT:=ICOUNT + 1;
              LEFTVALPTR:=LEFTVALPTR↑.NEXTVALUE
            END;
          NEWVALUES↑.REALVAL:=MAPINDEX;
          NEWVALPTR:=NEWVALUES;
          RIGHTVALPTR:=RIGHTVALPTR↑.NEXTVALUE
        END; (*IF NO MATCH, INDEX BECOMES ONE MORE THAN LENGTH OF LEFT ARG*)
      NEWVALUES↑.NEXTVALUE:=NIL
    END
END; (* INDEXOF *)


PROCEDURE RESHAPE(LEFTARG,RIGHTARG:TYPEVALTABPTR);
        (* DYADIC RHO OPERATOR - CHANGE DIMENSIONS OF *)
VAR
RESULTLENGTH,ELEMENTS:INTEGER;
DIMPTR:↑DIMENINFO; NEWPTR:↑VALUES;
BEGIN (* RESHAPE *)
IF LEFTARG↑.DIMENSIONS  > 1
 THEN ERROR(56) (* LEFT ARGUMENT NOT A VECTOR OR A SCALAR *)
 ELSE
   BEGIN
     NEW(NEWVALTABLINK);
     OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
     NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
     NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
     IF LEFTARG↑.FORWARDORDER = FALSE
       THEN REVERSELINKLIST(LEFTARG);
     IF RIGHTARG↑.FORWARDORDER = FALSE
       THEN REVERSELINKLIST(RIGHTARG);
     NEWVALTABLINK↑.FORWARDORDER:=TRUE;
     IF LEFTARG↑.FIRSTDIMEN=NIL
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            THEN NEWVALTABLINK↑.DIMENSIONS:=I ELSE
        NEWVALTABLINK↑.DIMENSIONS:=LEFTARG↑.FIRSTDIMEN↑.DIMENLENGTH;
        RESULTLENGTH:=1;
        LEFTVALPTR:=LEFTARG↑.FIRSTVALUE;
        SWITCH:=TRUE;
        WHILE LEFTVALPTR <> NIL DO (*LEFT ARG VALUES ARE DIMENSIONS OF RESULT*)
          BEGIN (*BUILD RESULT DIMENSIONS*)
            RESULTLENGTH:=RESULTLENGTH*TRUNC(LEFTVALPTR↑.REALVAL);
            NEW(NEWDIM);
            NEWDIM↑.DIMENLENGTH:=TRUNC(LEFTVALPTR↑.REALVAL);
            LEFTVALPTR:=LEFTVALPTR↑.NEXTVALUE;
            IF SWITCH = TRUE
              THEN
                BEGIN
                  SWITCH:=FALSE;
                  NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
                END
              ELSE
                DIMPTR↑.NEXTDIMEN:=NEWDIM;
            DIMPTR:=NEWDIM
          END;
        NEWDIM↑.NEXTDIMEN:=NIL;
        RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
        ELEMENTS:=0; SWITCH:=TRUE;
        WHILE ELEMENTS < RESULTLENGTH DO
            BEGIN (*DUPLICATE RIGHT ARG VALUES INTO RESULT VALUES*)
            ELEMENTS:=ELEMENTS + 1;
            NEW(NEWVALUES);
            IF RIGHTVALPTR = NIL (*EXTEND RIGHT ARGUMENT IF NECESSARY*)
              THEN RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
            NEWVALUES↑.REALVAL:=RIGHTVALPTR↑.REALVAL;
            IF SWITCH = TRUE
              THEN
                BEGIN
                  SWITCH:=FALSE;
                  NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                END
              ELSE
                NEWPTR↑.NEXTVALUE:=NEWVALUES;
            NEWPTR:=NEWVALUES;
            RIGHTVALPTR:=RIGHTVALPTR↑.NEXTVALUE
          END;
        NEWVALUES↑.NEXTVALUE:=NIL;
      END
END; (* RESHAPE *)


PROCEDURE INNERPRODUCT(LEFTARG,RIGHTARG:TYPEVALTABPTR);
VAR
INPRO1CODE,INPRO2CODE,LEFTSKIP,RIGHTSKIP:INTEGER;
ICOUNT,JCOUNT,KCOUNT,LCOUNT,MCOUNT:INTEGER;
LASTLEFTDIM,FIRSTRIGHTDIM,COMMONLENGTH:INTEGER;
LPTR:↑VALUES;
HOLD:REAL;
SFLOAT,VALUE:REAL;
BEGIN  (*INNER PRODUCT IS MATRIX MULTIPLICATION*)
DIMPTR:=LEFTARG↑.FIRSTDIMEN;
IF LEFTARG↑.FIRSTDIMEN <> NIL
 THEN
   WHILE DIMPTR↑.NEXTDIMEN <> NIL DO
     DIMPTR:=DIMPTR↑.NEXTDIMEN;  (*GET LAST DIMEN OF LEFT ARG(IF ANY)*)
IF (DIMPTR <> NIL) AND (RIGHTARG↑.FIRSTDIMEN <> NIL)
 THEN
   IF DIMPTR↑.DIMENLENGTH <> RIGHTARG↑.FIRSTDIMEN↑.DIMENLENGTH
     THEN ERROR(52) (*LAST DIM OF LEFT ARG NOT = TO FIRST DIM OF RIGHT ARG*)
     ELSE
       BEGIN
         INPRO1CODE:=CODE DIV 100;   (*SEPARATE OPERATORS*)
         INPRO2CODE:=CODE -  100*INPRO1CODE;
```

```
NEW(NEWVALTABLINK);
OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
IF LEFTARG↑.FORWARDORDER = FALSE
  THEN REVERSELINKLIST(LEFTARG);
IF RIGHTARG↑.FORWARDORDER = FALSE
  THEN REVERSELINKLIST(RIGHTARG);
NEWVALTABLINK↑.FORWARDORDER:=TRUE;
NEWVALTABLINK↑.DIMENSIONS:=LEFTARG↑.DIMENSIONS + RIGHTARG↑.DIMENSIONS
-2;
IF NEWVALTABLINK↑.DIMENSIONS < 0
  THEN NEWVALTABLINK↑.DIMENSIONS:=0;
SWITCH:=TRUE;
LASTLEFTDIM:=0;
IF LEFTARG↑.FIRSTDIMEN <> NIL
  THEN
    BEGIN (*COPY ALL BUT LAST OF LEFT ARG DIMS INTO RESULT*)
      LEFTSKIP:=1;
      DIMPTR:=LEFTARG↑.FIRSTDIMEN;
      WHILE DIMPTR↑.NEXTDIMEN <> NIL DO
        BEGIN (*COPY LEFT ARG DIMENSIONS*)
          NEW(NEWDIM);
          NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
          LEFTSKIP:=LEFTSKIP*DIMPTR↑.DIMENLENGTH;
          IF SWITCH = TRUE
            THEN
              BEGIN
                SWITCH:=FALSE;
                NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
              END
            ELSE
              NEWPTR↑.NEXTDIMEN:=NEWDIM;
          NEWPTR:=NEWDIM;
          DIMPTR:=DIMPTR↑.NEXTDIMEN
        END;
      LASTLEFTDIM:=DIMPTR↑.DIMENLENGTH
    END;
IF RIGHTARG↑.FIRSTDIMEN <> NIL
  THEN
    BEGIN (*COPY ALL BUT FIRST OF RIGHT ARG DIMS INTO RESULT*)
      RIGHTSKIP:=1;
      DIMPTR:=RIGHTARG↑.FIRSTDIMEN↑.NEXTDIMEN;
      WHILE DIMPTR <> NIL DO
        BEGIN (*COPY RIGHT ARG DIMENSIONS*)
          NEW(NEWDIM);
          NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
          RIGHTSKIP:=RIGHTSKIP*DIMPTR↑.DIMENLENGTH;
          IF SWITCH = TRUE
            THEN
              BEGIN
                SWITCH:=FALSE;
                NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
              END
            ELSE
              NEWPTR↑.NEXTDIMEN:=NEWDIM;
          NEWPTR:=NEWDIM;
          DIMPTR:=DIMPTR↑.NEXTDIMEN
        END
    END;
IF SWITCH = TRUE
  THEN NEWVALTABLINK↑.FIRSTDIMEN:=NIL
  ELSE NEWDIM↑.NEXTDIMEN:=NIL;
IF LEFTARG↑.FIRSTVALUE = NIL
  THEN LEFTSKIP:=0;
IF RIGHTARG↑.FIRSTVALUE = NIL
  THEN RIGHTSKIP:=0;
SWITCH:=TRUE;
IF RIGHTARG↑.FIRSTDIMEN <> NIL
```

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          THEN FIRSTRIGHTDIM:=RIGHTARG↑.FIRSTDIMEN↑.DIMENLENGTH
          ELSE FIRSTRIGHTDIM:=0;
        IF FIRSTRIGHTDIM > LASTLEFTDIM
          THEN COMMONLENGTH:=FIRSTRIGHTDIM
          ELSE COMMONLENGTH:=LASTLEFTDIM;
        ICOUNT:=0;
        LEFTVALPTR:=LEFTARG↑.FIRSTVALUE;
        WHILE ICOUNT < LEFTSKIP DO
          BEGIN (*LOOP FOR EACH ROW IN LEFT ARG*)
            LPTR:=LEFTVALPTR; (*HOLD START OF ROW POSITION*)
            JCOUNT:=0;
            WHILE JCOUNT < RIGHTSKIP DO
              BEGIN (*LOOP FOR EACH COLUMN IN RIGHT ARG*)
                LEFTVALPTR:=LPTR;
                RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
                LCOUNT:=0;
                WHILE LCOUNT < JCOUNT DO
                  BEGIN (*SKIP TO STARTING VALUE IN RIGHT ARG*)
                    RIGHTVALPTR:=RIGHTVALPTR↑.NEXTVALUE;
                    IF RIGHTVALPTR = NIL
                      THEN RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE; (*EXTEND ARG*)
                    LCOUNT:=LCOUNT + 1
                  END;
                KCOUNT:=0;
                WHILE KCOUNT < COMMONLENGTH DO
                  BEGIN (*LOOP FOR EACH ELEMENT IN ROW/COLUMN*)
                    SFLOAT:=RIGHTVALPTR↑.REALVAL;
                    DYADCOMP(SFLOAT,LEFTVALPTR↑.REALVAL,INPRO2CODE);
                    VALUE:=SFLOAT;
                    IF KCOUNT = 0
                      THEN (*SET IDENTITY VALUE FOR FIRST TIME THROUGH*)
                        CASE INPRO1CODE OF
                          52,53,78: SFLOAT:=0.0;
                          54,55,56,77: SFLOAT:=1.0;
                          71,72,73,74,75,76:     (*NULL CASE*)
                        END (*CASE*)
                      ELSE
                        SFLOAT:=HOLD;
                    DYADCOMP(SFLOAT,VALUE,INPRO1CODE);
                    HOLD:=SFLOAT; (*SAVE SUMMER RESULT*)
                    LEFTVALPTR:=LEFTVALPTR↑.NEXTVALUE;
                    IF LEFTVALPTR = NIL
                      THEN LEFTVALPTR:=LEFTARG↑.FIRSTVALUE; (*EXTEND ARG*)
                    MCOUNT:=0;
                    WHILE MCOUNT < RIGHTSKIP DO
                      BEGIN (*SKIP TO NEXT VALUE IN RIGHT ARG*)
                        MCOUNT:=MCOUNT + 1;
                        RIGHTVALPTR:=RIGHTVALPTR↑.NEXTVALUE;
                        IF RIGHTVALPTR = NIL
                          THEN RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
                      END;
                    KCOUNT:=KCOUNT + 1
                  END;
                NEW(NEWVALUES);
                NEWVALUES↑.REALVAL:=SFLOAT;
                IF SWITCH = TRUE
                  THEN
                    BEGIN
                      SWITCH:=FALSE;
                      NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                    END
                  ELSE
                    NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
                NEWVALPTR:=NEWVALUES;
                JCOUNT:=JCOUNT + 1;
              END;
            ICOUNT:=ICOUNT + 1
          END;
      IF SWITCH = TRUE
```

```
                  THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL
                  ELSE NEWVALUES↑.NEXTVALUE:=NIL
              END
END; (* INNERPRODUCT *)


PROCEDURE OUTERPRODUCT(LEFTARG,RIGHTARG:TYPEVALTABPTR);
VAR
OUTPRDCODE:INTEGER;
SFLOAT:REAL;
BEGIN
OUTPROCODE:=CODE DIV 10;
NEW(NEWVALTABLINK);
OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
IF LEFTARG↑.FORWARDORDER = FALSE
 THEN REVERSELINKLIST(LEFTARG);
IF RIGHTARG↑.FORWARDORDER = FALSE
 THEN REVERSELINKLIST(RIGHTARG);
NEWVALTABLINK↑.FORWARDORDER:=TRUE;
NEWVALTABLINK↑.DIMENSIONS:=LEFTARG↑.DIMENSIONS + RIGHTARG↑.DIMENSIONS;
SWITCH:=TRUE;
DIMPTR:=LEFTARG↑.FIRSTDIMEN;
WHILE DIMPTR <> NIL DO
 BEGIN (*COPY LEFT ARG DIMENSIONS TO RESULT*)
   NEW(NEWDIM);
   NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
   IF SWITCH = TRUE
     THEN
       BEGIN
         SWITCH:=FALSE;
         NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
       END
     ELSE
       NEWPTR↑.NEXTDIMEN:=NEWDIM;
   NEWPTR:=NEWDIM;
   DIMPTR:=DIMPTR↑.NEXTDIMEN
 END;
DIMPTR:=RIGHTARG↑.FIRSTDIMEN;
WHILE DIMPTR <> NIL DO
 BEGIN  (*COPY DIMENSIONS OF RIGHT ARG TO RESULT*)
   NEW(NEWDIM);
   NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
   IF SWITCH = TRUE
     THEN
       BEGIN
         SWITCH:=FALSE;
         NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
       END
     ELSE
       NEWPTR↑.NEXTDIMEN:=NEWDIM;
   NEWPTR:=NEWDIM;
   DIMPTR:=DIMPTR↑.NEXTDIMEN
 END;
IF SWITCH = TRUE
 THEN NEWVALTABLINK↑.FIRSTDIMEN:=NIL
 ELSE NEWDIM↑.NEXTDIMEN:=NIL;
SWITCH:=TRUE;
LEFTVALPTR:=LEFTARG↑.FIRSTVALUE;
WHILE LEFTVALPTR <> NIL DO
 BEGIN
   RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
   WHILE RIGHTVALPTR <> NIL DO
     BEGIN
       SFLOAT:=RIGHTVALPTR↑.REALVAL;
       DYADCOMP(SFLOAT,LEFTVALPTR↑.REALVAL,OUTPROCODE);
       NEW(NEWVALUES);
       IF SWITCH = TRUE
```

```
               THEN
                 BEGIN
                   SWITCH:=FALSE;
                   NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                 END
               ELSE
                 NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
             NEWVALUES↑.REALVAL:=SFLOAT;
             NEWVALPTR:=NEWVALUES;
             RIGHTVALPTR:=RIGHTVALPTR↑.NEXTVALUE
           END;
         LEFTVALPTR:=LEFTVALPTR↑.NEXTVALUE
       END;
     IF SWITCH = TRUE
       THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL
       ELSE NEWVALUES↑.NEXTVALUE:=NIL
     END; (* OUTERPRODUCT *)


     PROCEDURE DYADIC(LEFTARG,RIGHTARG:TYPEVALTABPTR);
             (* OPERATORS WITH CODES OF 52 AND HIGHER *)
     VAR
     COMPATIBLE:BOOLEAN;
     ARG:TYPEVALTABPTR;
     SFLOAT:REAL;
     BEGIN
     IF CODE > 1000
       THEN INNERPRODUCT(LEFTARG,RIGHTARG)
       ELSE
         IF CODE > 100
           THEN OUTERPRODUCT(LEFTARG,RIGHTARG)
           ELSE
             IF CODE > 80
               THEN
                 CASE CODE OF
                   87: INDEXOF(LEFTARG,RIGHTARG);
                   88: RESHAPE(LEFTARG,RIGHTARG);
                   89: CATENATE(LEFTARG,RIGHTARG);
                 END (*CASE*)
               ELSE
                 BEGIN (*SIMPLE DYADICS*)
                   COMPATIBLE:=TRUE;
                   IF (LEFTARG↑.DIMENSIONS >= 1) AND (RIGHTARG↑.DIMENSIONS >= 1)
                     THEN
                       IF LEFTARG↑.DIMENSIONS <> RIGHTARG↑.DIMENSIONS
                         THEN COMPATIBLE:=FALSE (*DIFFERENT RANKS/NEITHER SCALAR*)
                         ELSE
                           BEGIN (*RANKS MATCH - CHECK LENGTHS*)
                             LEFTDIMPTR:=LEFTARG↑.FIRSTDIMEN;
                             RIGHTDIMPTR:=RIGHTARG↑.FIRSTDIMEN;
                             WHILE LEFTDIMPTR <> NIL DO
                               BEGIN
                                 IF LEFTDIMPTR↑.DIMENLENGTH <>
                                                RIGHTDIMPTR↑.DIMENLENGTH
                                   THEN COMPATIBLE:=FALSE; (*DIFFERENT LENGTH(S)*)
                                 LEFTDIMPTR:=LEFTDIMPTR↑.NEXTDIMEN;
                                 RIGHTDIMPTR:=RIGHTDIMPTR↑.NEXTDIMEN
                               END
                           END;
                   IF COMPATIBLE = TRUE (*ARGUMENTS SUITIBLE FOR DYADIC OPERATION*)
                     THEN
                       BEGIN (*BUILD DIMENSIONS OF RESULT*)
                         IF RIGHTARG↑.DIMENSIONS > LEFTARG↑.DIMENSIONS
                           THEN ARG:=RIGHTARG
                           ELSE ARG:=LEFTARG; (*RESULT HAS SHAPE OF LARGER ARG*)
                         NEW(NEWVALTABLINK);
                         OLDVALTABLINK↑.NEXTVALTABLINK:=NEWVALTABLINK;
                         NEWVALTABLINK↑.NEXTVALTABLINK:=NIL;
                         NEWVALTABLINK↑.INTERMEDRESULT:=TRUE;
```

```
                  IF LEFTARG↑.FORWARDORDER <> RIGHTARG↑.FORWARDORDER
                    THEN REVERSELINKLIST(LEFTARG);
                  NEWVALTABLINK↑.FORWARDORDER:=ARG↑.FORWARDORDER;
                  NEWVALTABLINK↑.DIMENSIONS:=ARG↑.DIMENSIONS;
                  SWITCH:=TRUE;
                  DIMPTR:=ARG↑.FIRSTDIMEN;
                  WHILE DIMPTR <> NIL DO
                    BEGIN (*COPY DIMENSIONS TO RESULT*)
                      NEW(NEWDIM);
                      NEWDIM↑.DIMENLENGTH:=DIMPTR↑.DIMENLENGTH;
                      IF SWITCH = TRUE
                        THEN
                          BEGIN
                            SWITCH:=FALSE;
                            NEWVALTABLINK↑.FIRSTDIMEN:=NEWDIM
                          END
                        ELSE
                          NEWPTR↑.NEXTDIMEN:=NEWDIM;
                      NEWPTR:=NEWDIM;
                      DIMPTR:=DIMPTR↑.NEXTDIMEN
                    END;
                  IF SWITCH = TRUE
                    THEN NEWVALTABLINK↑.FIRSTDIMEN:=NIL (*RESULT IS A SCAL*)
                    ELSE NEWDIM↑.NEXTDIMEN:=NIL;
                  SWITCH:=TRUE;
                  RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE;
                  LEFTVALPTR:=LEFTARG↑.FIRSTVALUE;
                  VALPTR:=ARG↑.FIRSTVALUE;
                  WHILE VALPTR <> NIL DO
                    BEGIN (*PERFORM OPERATION*)
                      NEW(NEWVALUES);
                      SFLOAT:=RIGHTVALPTR↑.REALVAL;
                      DYADCOMP(SFLOAT,LEFTVALPTR↑.REALVAL,CODE);
                      NEWVALUES↑.REALVAL:=SFLOAT;
                      IF SWITCH = TRUE
                        THEN
                          BEGIN
                            SWITCH:=FALSE;
                            NEWVALTABLINK↑.FIRSTVALUE:=NEWVALUES
                          END
                        ELSE
                          NEWVALPTR↑.NEXTVALUE:=NEWVALUES;
                      NEWVALPTR:=NEWVALUES;
                      VALPTR:=VALPTR↑.NEXTVALUE;
                      LEFTVALPTR:=LEFTVALPTR↑.NEXTVALUE;
                      RIGHTVALPTR:=RIGHTVALPTR↑.NEXTVALUE;
                      IF LEFTVALPTR = NIL
                        THEN LEFTVALPTR:=LEFTARG↑.FIRSTVALUE; (*EXTEND ARG*)
                      IF RIGHTVALPTR = NIL
                        THEN RIGHTVALPTR:=RIGHTARG↑.FIRSTVALUE  (*EXTEND *)
                    END;
                  IF SWITCH = TRUE
                    THEN NEWVALTABLINK↑.FIRSTVALUE:=NIL (*VECTOR OF LEN 0*)
                    ELSE NEWVALUES↑.NEXTVALUE:=NIL
                END
              ELSE ERROR(55) (*ARGUMENTS IMCOMPATIBLE FOR DYADIC OPERATION*)
          END
END; (* DYADIC *)


      PROCEDURE FUNCALL(VAR VALIDFUNK:BOOLEAN);
        VAR
          VALIDPM:BOOLEAN;
        BEGIN (* FUNCALL *)
          VALIDFUNK:=FALSE;
          IF FUNCTCALL THEN
            BEGIN
              IF TOKENTABPTR↑.NOUN<>STATEND THEN
                BEGIN
```

```
                  SUBRTABPTR↑.TOKENCALLINGSUBR:=TOKENTABPTR;
                  PRIMARY(VALIDPM);
                  IF NOT VALIDPM THEN ERROR(17);
                         (* ↑LEFTARG OF DYADIC FUNC CALL NOT A PRIMARY↑ *)
                END;
              CALLSUBR;
              VALIDFUNK:=TRUE;
            END;
        END; (* FUNCALL *)


      BEGIN (* EXPRESSION *)
        PRIMARY(VALIDPRI);
        IF NOT VALIDPRI THEN
          BEGIN
            IF TOKENTABPTR↑.NOUN=STATEND THEN
          BEGIN
            VALIDEXP:=TRUE;
            ASSIGN1:=TRUE
          END
            ELSE VALIDEXP:=FALSE
          END
        ELSE BEGIN
          DONEXP:=FALSE;
          WHILE NOT DONEXP DO
            BEGIN
              FUNCALL(VALIDFUNC);
              IF VALIDFUNC THEN
                BEGIN
                  EXPRESSION(VALIDEXP);
                  DONEXP:=TRUE
                END
              ELSE
                BEGIN
                  ASSIGNMENT(VALIDASSN);
                  IF VALIDASSN AND (TOKENTABPTR↑.NOUN=STATEND) THEN
                    BEGIN
                      DONEXP:=TRUE;
                      VALIDEXP:=TRUE;
                    END;
                  IF NOT VALIDASSN THEN
                    IF MOP THEN
                     BEGIN
                       MONADIC(OPERTABPTR↑.OPERPTR,HOLD);
                       OPERTABPTR↑.OPERPTR:=NEWVALTABLINK
                     END
                    ELSE
                      IF NOT DOP THEN
                        BEGIN
                          VALIDEXP:=TRUE;
                          DONEXP:=TRUE
                        END
                      ELSE
                        BEGIN
                          PRIMARY(VALIDPRI);
                          IF NOT VALIDPRI THEN
                            ERROR(13) (* DYAD OPER NOT PRECEDED BY A PRI *)
                            ELSE
                              BEGIN
                                DYADIC(OPERTABPTR↑.OPERPTR,
                                OPERTABPTR↑.LASTOPER↑.OPERPTR);
                                AUXOPERTABPTR:=OPERTABPTR;
                                OPERTABPTR:=OPERTABPTR↑.LASTOPER;
                                PTRLASTOPER:=OPERTABPTR;
                                DISPOSE(AUXOPERTABPTR);
                                OPERTABPTR↑.OPERPTR:=NEWVALTABLINK;
                              END;
                        END;
              END;
```

```
            END;
          END;
        END; (* EXPRESSION *)


      BEGIN (* PARSER *)
        ASSIGN:=FALSE; ASSIGN1:=FALSE;
        DONEPARSE:=FALSE;
        REPEAT
          EXPRESSION(VALIDEXP); (* CHECKS FOR VALID EXPRESSION *)
          IF NOT VALIDEXP THEN ERROR(10) (* +INVALID EXPRESSION+ *)
          ELSE
           IF SPECSYMBOL(XRIGHTARROW) THEN IF NOT((OPERTABPTR+.OPERPTR+.FIRSTVALUE
            =NIL) AND (OPERTABPTR+.OPERPTR+.DIMENSIONS>0))THEN
                                                                (* BRANCH *)
                  (* RESULT OF EXPRESSION IS AT OPERTABPTR *)
                 IF OPERTABPTR+.OPERPTR+.FIRSTVALUE+.REALVAL
                   -1.0*TRUNC(OPERTABPTR+.OPERPTR+.FIRSTVALUE+.REALVAL)<>0.0 THEN
                     ERROR(12) (* STMT.NUM.TO BRANCH TO NOT AN INTEGER *)
                 ELSE
                 IF SUBRTABPTR = NIL THEN
                  BEGIN (* FUNCTION MODE *)
                    TOKENTABPTR:=HOLD;
                    DONEPARSE:=TRUE
                  END
                 ELSE
                  IF TRUNC(OPERTABPTR+.OPERPTR+.FIRSTVALUE+.REALVAL) IN
                    [1..      (SUBRTABPTR+.CALLEDSUBR+.NUMOFSTATEMENTS)] THEN
                    BEGIN
                      VFUNCHOLD:=SUBRTABPTR+.CALLEDSUBR+.FIRSTATEMENT;
                      FOR CNT:=1 TO TRUNC(OPERTABPTR+.OPERPTR+.FIRSTVALUE+.
                        REALVAL) DO BEGIN
                          VFUNCPTR:=VFUNCHOLD;
                          TOKENTABPTR:=VFUNCPTR+.NEXTSTMNT;
                          VFUNCHOLD:=VFUNCPTR+.NEXTVFUNCPTR
                        END;
                      AUXOPERTABPTR:=OPERTABPTR;
                      OPERTABPTR:=OPERTABPTR+.LASTOPER;
                      DISPOSE(AUXOPERTABPTR);
                      PTRLASTOPER:=OPERTABPTR;
                      TOKENTABPTR:=VFUNCPTR+.NEXTSTMNT
                    END

           ELSE (* SUCCESSOR *)
           ELSE (* SUCCESSOR *)
             BEGIN
              IF NOT ASSIGN1 THEN
              OUTPUTVAL;
              ASSIGN1:=FALSE;
              IF SUBRTABPTR=NIL THEN
                BEGIN(* INTERPRETIVE *)
                  HOLD:=TOKENTABPTR;
                  TOKENTABPTR:=TOKENTABPTR+.NEXTOKEN;
                  DONEPARSE:=TRUE
                END
              ELSE (* FUNCTION *)
                BEGIN
                  VFUNCPTR:=VFUNCPTR+.NEXTVFUNCPTR;
                  DONESUCCESSOR:=FALSE;
                  REPEAT
                    IF VFUNCPTR<>NIL THEN
                      BEGIN
                        TOKENTABPTR:=VFUNCPTR+.NEXTSTMNT;
                        DONESUCCESSOR:=TRUE
                      END
                    ELSE
                      BEGIN
                        RETURNTOCALLINGSUBR;
                        IF TOKENTABPTR+.NOUN=STATEND THEN
                        DONESUCCESSOR:=TRUE;
```

```
                        END;
                    UNTIL DONESUCCESSOR;
                 END;
              END
          UNTIL DONEPARSE;
          RELEASE;                (* RELEASE MEMORY *)
       END; (* PARSER *)


BEGIN (* SCANNER *)
INITIALIZECHARACTERSET;
READINERRORMSGS;
INITPARSER; (* INITIALIZE TABLES ETC. *)
FILLUPTABLES;
FUNCTIONMODE:=FALSE;
FIRSTFUNCTION:=TRUE;
OLDVALTABLINK:=NIL;
OLDFUNCTABPTR:=NIL;
OLDVARTABPTR:=NIL;
OLDTOKENPTR:=NIL; NEWTOKENPTR:=NIL;
NEWFUNCTABPTR:=NIL; NEWVFUNCPTR:=NIL;
HOLDTOKENPTR:=NIL; TOKENERROR:=FALSE;
NEWVALTABLINK:=NIL; NEWVARTABPTR:=NIL;
GETAPLSTATEMENT;
WHILE (APLSTATEMENT[1] <> CHARACTER[FORWARDSLASH]) OR
    (APLSTATEMENT[2] <> CHARACTER[ASTERISK]) DO (*  /* ENDS PROGRAM *)
 BEGIN
   SKIPSPACES;
   TOKENSWITCH:=TRUE;
   WHILE (POSITION <= LINELENGTH) AND (NOT TOKENERROR)
         AND (NOT LINETOOLONG) DO
     BEGIN (* SCANNING *)
       IF APLSTATEMENT[POSITION] = CHARACTER[DEL]  (* FUNCTION DELIMITER *)
         THEN (* DEL ENCOUNTERED *)
           IF FUNCTIONMODE
             THEN
               BEGIN  (* END OF CURRENT FUNCTION *)
                  IF NEWFUNCTABPTR <> NIL THEN
                 NEWFUNCTABPTR↑.NUMOFSTATEMENTS:=FUNCSTATEMENTS;
                 IF FUNCSTATEMENTS > 0
                   THEN
                    BEGIN
                       NEWFUNCTABPTR↑.NEXTFUNCTABPTR:=OLDFUNCTABPTR;
                       OLDFUNCTABPTR:=NEWFUNCTABPTR;
                       NEWVFUNCPTR↑.NEXTVFUNCPTR:=NIL
                    END
                   ELSE SERROR(75); (* FUNCTION DEFINED WITH NO STATEMENTS*)
                 FUNCTIONMODE:=FALSE;
                 POSITION:=POSITION + 1
               END
             ELSE PROCESSFUNCTIONHEADER (* START OF A NEW FUNCTION *)
         ELSE (* NOT A DEL ENCOUNTERED *)
           BEGIN
             IF TOKENSWITCH = TRUE
               THEN
                 BEGIN (* THIS IS START OF A NEW STATEMENT *)
                   TOKENSWITCH:=FALSE;
                   HOLDTOKENPTR:=OLDTOKENPTR; (*SAVE STARTING POSITION*)
                   MAKETOKENLINK;
                   NEWTOKENPTR↑.NOUN:=STATEND;
                   NEWTOKENPTR↑.ENDADJ:=0;
                   HASLABEL:=FALSE
                 END;
             MAKETOKENLINK;
             IDENTIFIER(NAME,ITSANIDENTIFIER);
             IF NOT ITSANIDENTIFIER
               THEN TRYTOGETANUMBER
               ELSE
                 BEGIN (* PROCESS IDENTIFIER *)
```

```
                    SKIPSPACES;
                    IF (APLSTATEMENT[POSITION] = CHARACTER[COLON]) AND
                       (NEWTOKENPTR↑.NEXTOKEN↑.NOUN = STATEND)
                      THEN
                        BEGIN (* PROCESS STATEMENT LABEL *)
                          SAVELABEL:=NAME;
                          HASLABEL:=TRUE;
                          POSITION:=POSITION + 1
                        END
                      ELSE
                        BEGIN (* PROCESS VARIABLE NAME *)
                          IF NOT FUNCTIONMODE
                            THEN NEWTOKENPTR↑.NOUN:=GLOBVAR
                            ELSE
                              IF NAMESMATCH(NAME,NEWFUNCTABPTR↑.RESULTNAME)
                                THEN NEWTOKENPTR↑.NOUN:=FORMRES
                                ELSE
                                  IF  (NAMESMATCH(NAME,NEWFUNCTABPTR↑.LEFTARG))
                                 OR (NAMESMATCH(NAME,NEWFUNCTABPTR↑.RIGHTARG))
                                    THEN NEWTOKENPTR↑.NOUN:=FORMARG
                                    ELSE NEWTOKENPTR↑.NOUN:=GLOBVAR;
                          IF NEWTOKENPTR↑.NOUN <> GLOBVAR
                            THEN TESTFUNCPTR:=NEWFUNCTABPTR
                            ELSE TESTFUNCPTR:=NIL;
                          IF NOT NAMEINVARTABLE(NAME,VARPOINTER,TESTFUNCPTR)
                            THEN
                              BEGIN
                                ADDNAMETOVARTABLE(NAME);
                                NEWTOKENPTR↑.VARTABPTR:=NEWVARTABPTR
                              END
                            ELSE NEWTOKENPTR↑.VARTABPTR:=VARPOINTER
                        END
                 END
           END;
       SKIPSPACES;
     END;
   IF NEWTOKENPTR <> NIL THEN
   IF (TOKENERROR) OR (NEWTOKENPTR↑.NOUN = STATEND)
     THEN DESTROYSTATEMENT
     ELSE
       IF FUNCTIONMODE
         THEN
           BEGIN
             FUNCSTATEMENTS:=FUNCSTATEMENTS + 1;
             IF FUNCSTATEMENTS > 0
               THEN
                 BEGIN (* CATALOG FUNCTION STATEMENT *)
                   NEW(NEWVFUNCPTR);
                   IF FUNCSTATEMENTS = 1
                     THEN NEWFUNCTABPTR↑.FIRSTATEMENT:=NEWVFUNCPTR
                     ELSE OLDVFUNCPTR↑.NEXTVFUNCPTR:=NEWVFUNCPTR;
                   OLDVFUNCPTR:=NEWVFUNCPTR;
                   IF HASLABEL
                     THEN NEWVFUNCPTR↑.STATLABEL:=SAVELABEL;
                   NEWVFUNCPTR↑.NEXTSTMNT:=NEWTOKENPTR
                 END
           END
         ELSE
           IF APLSTATEMENT[1] <> CHARACTER[DEL]
             THEN
               BEGIN
                 PARSER(NEWTOKENPTR,NEWVALTABLINK);
            100: DESTROYSTATEMENT
               END;
   READLN;
    TOKENERROR:=FALSE;
   GETAPLSTATEMENT;
 END;
END.
```

# Authors Directory

Stephen R Alpert
Worcester Polytechnic Institute
Worcester MA 01609

Larry R Atkin
Health Information Services
542 Michigan Av
Evanston IL 60202

Kenneth L Bowles
Professor, Director
Institute for Information Systems
University of California San Diego
La Jolla CA 92093

Kin-Man Chung
124 Scottswood Dr
Urbana IL 61801

Vincent DiChristofaro
1327 McKinley St
Philadelphia PA 19111

Gary A Ford, Assistant Professor
Dept of Mathematics
Arizona State University
Tempe AZ 85281

Charles H Forsyth
Computer Communications Networks Group
University of Waterloo
Waterloo Ontario
CANADA N2L 3G1

Peter W Frey
Dept of Psychology
Northwestern University
Evanston IL 60201

Carl Helmers
Editorial Director, BYTE Publications Inc.
70 Main St
Peterborough NH 03458

Randall J Howard
Computer Communications Networks Group
University of Waterloo
Waterloo Ontario
CANADA N2L 3G1

Alan Kaniss
1327 McKinley St
Philadelphia PA 19111

Larry Kheriaty
Computer Center
Western Washington University
Bellingham WA 98225

Dr B Gregory Louis
OB/GYN Dept
St Michael's Hospital
30 Bond Street
Toronto CANADA M5B 1W8

David A Mundie
104B Oakhurst Cir
Charlottesville VA 22903

John Santini
1327 McKinley St
Philadelphia PA 19111

Allan M Schwartz
114-2 Nimitz Dr
West Lafayette IN 47906

Stephen P Smith
POB 841
Parksley VA 23421

Herbert Yuen
POB 2591 Station A
Champaign IL 61820

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*Lynn Woodbury, designer-production manager*
*Patricia Curran, production editor*
*Richard Farley, production art*
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