A programming system for the simulation of digital machines

by

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INTRODUCTION

Motivation

The purpose of the work reported on here was to develop a programming system for the simulation of digital machines. The digital machines of interest in this work comprise the class of stored program, automatic digital computers within the much more extensive universe of digital machines in general. The current interest in, and the importance of, this subset of digital machines served as the justification for restricting the focus of attention to one specific area.

The simulation system discussed here is made up of two equally important elements. The first is a machine-readable, formal notation for specifying the structure and the behavior of digital processors at the register-transfer level. The second is a translator or language processor for converting a machine description in the above notation into a simulator which is capable of "executing" programs written in the machine language of the processor being simulated.

The computer description language developed here serves two purposes. First, the language is capable of specifying in a precise manner the structure of the digital machine being studied. Compared to existing informal notations for describing machine structure, precision of description is

achieved at the cost of a rigid language structure. However, since the language structure intentionally reflects the structure of most present day digital processors, the result is a computer description language which is precise and at the same time easy to use. In addition, the rigid structure of the language developed here makes it possible to machine-read the computer description and opens the door to a wide variety of automatic calculations using the machine description as input.

Second, the language is capable of specifying the behavioral characteristics of the digital machine being studied. It is this second capability of the language which makes the simulation of machine behavior possible. If machine descriptions in the language were capable of specifying only machine structure their usefulness would be restricted. They could be used for formal documentation of the machine design or they could serve as input to an automated procedure for developing interconnection diagrams and/or Boolean equations. But machine descriptions that omit specifying the bahavior of the machine are incapable of serving as input data to an automated simulation system.

The translator or language processor developed here serves two purposes. First, from the user's viewpoint, it converts the machine description into a machine simulator. And it is the machine simulator which allows the user to

observe and study machine behavior. Formally, the simulator constructed from the machine description is capable of mapping an initial machine state onto a sequence of output states. When the simulator is creating the output sequence it is simulating the behavior of the digital machine.

Second, the translator provides the precise semantic meaning for the computer description language. The form or syntax of the language is specified by the language definition. The language definition by itself conveys no meaning. It is only when one knows what meaning the language processor attaches to any given statement in the language that one knows what the statement means.

Together the computer description language and its associated language processor make up a programming system for the simulation of digital machines. Such a simulation system may be used (1) by the computer designer as a design tool to assist him in the analysis and evaluation of alternative machine designs or, (2) by the computer instructor as an educational tool to assist him in the illustration of fundamental computer structural and behavioral concepts.

Relation to Other Work

The language discussed below leans heavily on the pioneering work of Chu (11) and the more recent work of Bell

and Newell (04). The concept of a block-structured language, after the work of Naur (27), also influenced the language. The work of Bartee, Lebow, and Reed (01) was influential in determining the machine level at which machine behavior was to be described. The language which emerged from the work done here is thought to take advantage of the best features of previous efforts in this area without incorporating their various inadequacies.

The translator discussed below owes no such debts to previous work in the area of language processors. Those authors recognizing the usefulness of developing a machine simulation system stop short of discussing processors for their computer description languages. Other authors do not even discuss the possibility of developing a simulator. The technique implemented by the translator here is a general technique applicable to all language processors. Bolliet (06) has applied the method of syntactic functions, in an incomplete manner, to an ALGOL-like higher level programming language.

The first chapter below describes the syntactic details of the computer description language developed here. The second chapter below supplies the semantic meaning of the language and discusses the implementation details of the language translator. The third chapter below discusses the results which were obtained and the implications which follow

from these results. Various program listings, the formal syntactic definition of the language, and a sample machine description will be found in the appendices.

THE BAPSIM LANGUAGE

Introduction and Background

The first goal of the research reported on here was to define a machine-readable formal notation for specifying the structure and behavior of digital processors at the register-transfer level. Although no such notation has been accepted as a standard, the desireability of a convenient, concise method for describing the details of digital machines has been recognized for some time.

Bartee, Lebow, and Reed (01) present a rigorous treatment of digital machines by considering their operation at the register-transfer level. This approach to machine description recognizes that (1) machine structure may be defined in terms of registers and data paths, and (2) machine behavior may be defined in terms of information flow between registers along the existing data paths. Rather informally, the authors of this standard textbook develop a printable symbology which they use to describe certain fundamental concepts of computer behavior. Loaded with subscripts, superscripts, and Greek characters, however, their printable notation is far from machine-readable.

Gorman and Anderson (19) present the conceptual details of an experimental programming system to be used by the logic

designer as an aid in the development of logic equations for digital computers. In a companion effort, Proctor (29) discusses "a system descriptive language" used to provide the description of the digital computer under investigation. Along with his co-workers, Proctor must be given credit for recognizing the usefulness of developing a formal language for machine description which is machine-readable.

Schlaeppi (31) provides an informal description of a proposed "behavioral hardware language" for describing machine logic, timing and sequencing and suggests possible uses for such a language. In fact, he suggests the possibility of constructing a processor for such a language which would automatically translate the description of an object machine into a simulator capable of executing sample programs written in the language of the object machine. Just such a language processor is the second goal of the research reported on here.

Chu (11) proposes modelling "a computer design language" along the lines of a high level programming language and discusses the advantages of such a technique. The high level programming language he selects is ALGOL. Chu also recognizes the possibility of developing a translator for use with such a language as a step toward the simulation of the object machine on an existing machine.

Bell and Newell (04) press the case for development of a

computer descriptive language and present the details of their efforts in this area in their book (03). Their notation achieves the goals of precision and flexibility of description necessary in such a language, but lacks the virtues of lucidity and convenience. Further, as their notational system now exists, it is not machine-readable. In passing, these authors note the usefulness of developing a simulator for executing object machine programs.

Language Requirements

The purpose to be fulfilled by the language being defined is sufficient to dictate a number of general requirements the language must meet.

First, the language must be easy to learn. This requirement is best met by making the language as close as possible to natural language or, next best, making it as close as possible to an existing programming language. The additional requirements that the language be unambiguous, concise, and precise exclude the possibility of using a natural language model for a computer design language. However, making the computer design language mirror, wherever possible, the constructs and concepts of existing high level programming languages will contribute significantly to the "naturalness" of the language.

Second, the requirement that the language be convenient to use can be met by ensuring that the elements from which a machine description is constructed correspond directly and obviously to the structural and behavioral elements of the object machine being described. For example, in describing digital machines at the register-transfer level, there must exist an element of the design language which directly models the hardware registers of the object machine.

Third, in order that the language be concise, it must suppress all details of machine description and machine behavior which are of no interest or are of interest only in so far as their functions must be defined. For example, at the register-transfer level, the details of the instruction decoding operation are usually of no interest. In the case of elementary machines, a simple mapping from operation code to operation microsequence is sufficient.

Fourth, one of the most important benefits to be derived by the computer programmer from using a high level programming language is the ability to name and refer to symbolically, objects defined in terms of primitive language constructs. By requiring the language used in describing machine operation to have the same sort of hierarchical structure, the same benefits of lucidity and flexibility may be realized.

The above requirements have guided the development of

the BAPSIM computer description language described in detail below. The extent to which these requirements have been met will be left for the reader to determine for himself.

The Meta-Language

The syntax of the BAPSIM computer description language will be described in what follows with the aid of a modified version of the meta-notation developed by Brooker and Morris(08). The use of this meta-notation will be explained first by a series of examples. Consider the meta-definition

DIGIT = '0'|'1'|'2'|'3'|'4'|'5'|'6'|'7'|'8'|'9'

The sequence of five characters on the left hand side of the equals sign is a meta-linguistic variable used to denote any occurrence of the syntactic unit of the same name. The equals sign is a meta-linguistic character that is to be read as "is defined to be". Quote marks are meta-linguistic characters used to delimit character strings which occur literally. The vertical slash is a meta-linguistic connective which means "or". In words, this definition states that "a digit is defined to be the literal occurrence of a character zero, or a literal occurrence of a character one, or a literal occurrence of a character two,...,or a literal occurrence of a character nine".

Similarly, the syntactic unit "letter" is defined:

LETTER = 'A'|'B'|...|'Y'|'Z'

In the possibly more familiar Backus Normal meta-notation, the definition of a digit would appear as:

<digit> ::= 0|1|2|3|4|5|6|7|8|9

The differences between the meta-notation to be used here and the meta-notation developed in the ALGOL 60 report are based on a desire for clarity and simplicity in the meta-notation. In the definition of any usefully large language, meta-linguistic variables occur much more frequently than literal character strings. By delimiting character strings rather than meta-linguistic variables the language definition is shorter and easier to read.

To avoid ambiguity in specifying the juxtaposition of syntactic units it is necessary (and sufficient) to require that the un-delimited meta-linguistic variables used to denote the syntactic units of the language be unbroken character strings. Use of the break character, '_', instead of the blank results in an unambiguous, easy-to-read notation. An example will clarify this last point.

In Backus Normal form, <unsigned integer> is a valid meta-linguistic variable. Merely dropping the delimiting brackets results in an ambiguous construction if it appears

on the right hand side of a syntactic definition. Does it refer to the single syntactic unit "unsigned integer" or does it refer to the two syntactic units "unsigned" and "integer"? In the notation used here, if it does indeed refer to the single syntactic unit, the embedded blank must be replaced by the break character, i.e., UNSIGNED_INTEGER. In the present notation UNSIGNED INTEGER will denote the occurrence of any member of the syntactic unit "unsigned" followed by the occurrence of any member of the syntactic unit "integer".

The meta-notation used here replaces the recursive definitions occurring so frequently in the ALGOL 60 report with iterative definitions. The full implications of this change will be discussed later when the syntax-directed (10) BAPSIM translator is described.

In Backus Normal form the definition of an "identifier" would be:

<identifier> ::= <letter>|<identifier><letter>|
<identifier><digit>

This definition is an excellent example of a definition which is left recursive.

In the meta-notation used here, the definition of an "identifier" is:

IDENTIFIER = LETTER $ (LETTER|DIGIT)

The dollar sign introduced in the last definition is a meta-linguistic character that is to be read as "zero or more occurrences of". In words, this non-recursive definition of an "identifier" states that "an identifier is defined to be a letter followed by zero or more occurrences of a letter or a digit, in any order". Similarly, the syntactic unit "integer" is defined to be:

INTEGER = DIGIT $ (DIGIT)

In what follows, the syntactic units "identifier" and "integer" will be considered primitive units or terminal symbols and will be denoted by .ID and .INT respectively. As the BAPSIM language is defined, identifiers and integers may be of any length. The BAPSIM translator, which constructs from the BAPSIM machine description a simulator for the object machine, however, requires that identifiers be limited to character strings of length eight or less and integers be limited to character strings of length five or less.

The special meta-linguistic symbol .EMPTY will be used to indicate the optional occurrence of a member of a syntactic unit. Strictly speaking, this special symbol refers to an occurrence of the null string of characters. For example, the meta-definition:

A = X (Y|.EMPTY)

states that "an A is defined to be an X followed by either a Y or the null string". In other words, "an A is either an X or an XY".

The BAPSIM Vocabulary

The BAPSIM computer description language is built up from the basic symbols shown in TABLE 1. As explained in the previous section, the quote marks and the vertical slash which appear in TABLE 1 are meta-linguistic characters and are not a part of the BAPSIM language.

TABLE 1. THE BAPSIM VOCABULARY

Identifiers	LETTER $ (LETTER|DIGIT)
Integers	DIGIT $ (DIGIT)
Operators	
Arithmetic	'.ADD.'|'.SUB.'
Logical	'-'|'*'|'+'|'.NOT.'|'.AND.'| '.OR.'|'.XOR.'
Functional	'.SHL.'|'.SHR.'|'.CIRL.'|'.CIRR.'
Relational	'.EQ.'|'.NE.'|'.LT.'|'.GT.'| '.LE.'|'.GE.'
Sequential	'<-'|':='|'GO TO'|'IF'|'THEN'|'DO'
Delimiters	'('|')'|','|'<'|'>'|'-'|'END'| 'SIMULATION'|'DECLARE'|'FETCH'| 'DECODE'|'EXECUTE'
Declarators	'REGISTER'|'SUBREGISTER'|'MEMORY'| 'INITIALIZE'|'MONITOR'|'TERMINAL'| 'OPERATION'

Identifiers

Identifiers are names given to the structural and behavioral elements of the object machine being described. As such, identifiers are used to name the four kinds of machine structural elements of interest -- registers, subregisters, memories, and terminals -- and the one behavioral element of interest -- the operation. In general, operations are nothing more than named collections of primitive machine operations. The capability for the user to name, define, and refer to collections of primitive machine operations as he wishes gives the language the desired hierarchical structure. This provision also enables the suppression of detail essential to a clear machine description.

Identifiers naming structural elements of the machine must be declared before they are used. Identifiers naming machine operations corresponding to the object machine's instruction set must not be explicitly declared; contextual declarations are sufficient in these cases. All identifiers naming user-defined collections of primitive machine operations must be explicitly declared.

Integers

The only numbers that may appear in a BAPSIM computer

description are unsigned decimal integers of length five or less. These integers are used in the declaration of registers, subregisters, and memories; in referring to individual bits of a register or subregister or to individual words of a memory; and in referring to binary bit patterns contained in a register, subregister, or memory word.

Operators

Five types of operators are recognized as primitive symbols of the BAPSIM language: arithmetic, logical, functional, relational, and sequential. Some of these operators are unary -- they are associated with one identifier operand -- and some are binary -- they are associated with two identifier operands or one identifier operand and one integer operand -- and some can be either unary or binary. In the latter case, the exact operation denoted by the operator is determined from the context in which the operator appears.

The two arithmetic operators are binary in nature and correspond to the usual arithmetic operations of addition and subtraction.

The single-character logical operators shown in TABLE 1 (¬,*,+) may appear only in terminal statements and correspond naturally to the logical operations of complementation, logical product, and logical sum.

The multi-character logical operators .NOT. , .AND. , and .OR. may appear in both IF-statements and transfer statements; the logical operator denoting the exclusive-or operation, .XOR. , may appear only in transfer statements. The logical operator denoting the logical complement operation, .NOT. , is a unary operator; the operator denoting the exclusive-or operation is a binary operator. The remaining two multi-character logical operators, .AND. and .OR. , may be either unary or binary operators depending on the context in which they appear. The result of applying the unary-and operator to a register or subregister operand is a single bit whose value is '1' if all of the bits of the operand are '1' and '0' otherwise. The result of applying the unary-or operator to a register or subregister operand is a single bit whose value is '1' if any of the bits of the operand are '1' and '0' if all of the bits of the operand are '0'. The other operators are applied bit-by-bit to the operand(s).

The functional operators appearing in TABLE 1 represent a class of operator which does not appear in the definition of any existing high level programming language. They have been included in the BAPSIM computer description language because they correspond directly and obviously to elementary machine operations occurring at the register-transfer level.

The functional operators shift left, .SHL. , and shift

right, .SHR. , may be either unary or binary operators. As defined here, the shift left operation shifts the bits of a register or subregister operand one bit to the left and inserts a '0' at the right end; the shift right operation shifts the bits of a register or subregister operand one bit to the right and inserts a '0' at the left end. Other shift operations, such as shifting and retaining the left- or right-most bit, are recognized as valid fundamental machine operations at the register-transfer level but have not been implemented in the current version of BAPSIM.

When appearing as unary operators in transfer statements the associated operand is an identifier naming the register or subregister which is to undergo the one-bit shift operation. When appearing as binary operators in transfer statements the first operand is an identifier as in the case of a unary operator and the second operand is an integer specifying how many times the one-bit shift operation is to be performed. Multiple shifts are thus provided for.

The functional operators circulate left, .CIRL. , and circulate right, .CIRR. , may appear only as unary operators in transfer statements. The circulate operations are nothing more than end-around one-bit shift operations. A reasonable extension to the current version of the BAPSIM language would be to allow the two circulate operators to also appear as binary operators in transfer statements as in the case of the

two shift operators, thereby allowing multiple circulate operations. The infrequent occurrence of such multiple circulate operations excluded this provision in the current version of the BAPSIM language.

The relational operators appearing in TABLE 1 may appear only in IF-statements and carry obvious meanings. Those readers familiar with FORTRAN will immediately recognize the source of the particular notation used for representing these operators.

The sequential operator '<-' is used only in transfer statements and serves to denote a register-transfer operation. This operator may be read as "is replaced by" or "becomes". The intuitive appeal of the chosen notation should be obvious. The sequential operator ':=' is used only in terminal statements and serves to denote the familiar assignment operation of high level programming languages. By selecting different notations for the register-transfer operation and the terminal-assignment operation the essential difference between the two operations is emphasized. The remaining four sequential operators are borrowed directly from existing high level programming languages. The DO operator, however, has a slightly unconventional, though quite natural, meaning: DO followed by an identifier naming an explicitly defined operation serves to call for the operation named. Thus, DO in BAPSIM is equivalent to CALL

in FORTRAN or PL/1. The DO of FORTRAN or PL/1 has no equivalent in BAPSIM.

Delimiters

The single-character delimiters shown in TABLE 1 are used in a standard manner. Details of their use will be explained below. The multiple character delimiters are used to implement the block structure of programs (i.e., machine descriptions) written in BAPSIM. As might be expected from the number of program structure delimiters in the language, legal BAPSIM programs have a rigid structure. However, far from being a hinderance to machine description, this rigid structure required of BAPSIM programs actually facilitates writing, reading, and understanding machine descriptions. The reason for this is that the structure of BAPSIM programs directly reflects the structural and behavioral elements of the machine being described. The structural elements of a machine -- the registers, the subregisters, the memories, and the terminals -- are all specified in a program declare block. User defined operations, representing machine behavioral elements, also must be declared in the declare block. Specification of machine elements for performing the basic fetch, decode, and execute operations common to all present day digital computers also must be done within program blocks corresponding to these basic operations. The END

delimiter is used to signal the end of a basic program block.

Declarators

The first five declarators shown in TABLE 1 correspond to the five types of machine elements; the first four are structural elements and the fifth is a behavioral element. The final two declarators, INITIALIZE and MONITOR , serve to define an initiation procedure and an output procedure, respectively, for the simulator constructed by the BAPSIM translator. These two declarators supplement the actual machine description and, for this reason, must not appear in the same block as the other declarators which are an integral part of any machine description.

Program Structure

The BAPSIM vocabulary described in the preceding section provides the raw materials from which BAPSIM programs are constructed. This section will discuss the syntax of machine descriptions written in BAPSIM. The meta-language discussed previously will be used to formally define the syntax of BAPSIM programs.

A BAPSIM program consists of one outer block which contains three inner blocks. Here a block is taken to be a delimited sequence of statements that constitutes a

functional section of a program.

```
PROGRAM = SIMULATION_BLOCK

SIMULATION_BLOCK = 'SIMULATION' STRUCTURE_BLOCK
                   BEHAVIOR_BLOCK  IN_OUT_BLOCK
                   'END SIMULATION'
```

The structure block of a BAPSIM program contains all of the program declarations and thus reflects the structural characteristics of the machine being described. In addition, user-defined operations must be declared in the structure block. Even though these operations actually reflect certain behavioral characteristics of the machine being described, it was deemed appropriate to group all of the program declares at the beginning of each program.

```
STRUCTURE_BLOCK = 'DECLARE' DECLARATION_STMT
                  $ ( ';' DECLARATION_STMT )
                  'END DECLARE'
```

The behavior block of a BAPSIM program is, in turn, made up of three other blocks, each of which reflects a specific behavioral aspect of the machine being described.

```
BEHAVIOR_BLOCK = FETCH_BLOCK  DECODE_BLOCK  EXECUTE_BLOCK
```

The fetch block of a BAPSIM program contains a sequence

of statements which specifies the fetch operation of the digital machine being described. Operand address calculation and next-instruction address calculation sequences may also be specified in the fetch block.

FETCH_BLOCK = 'FETCH' SIMPLE_SEQUENCE 'END FETCH'

The decode block of a BAPSIM program contains a sequence of statements which specifies the instruction decoding operation of the object machine. In the description of simple machines the decode sequence need be nothing more than a series of IF-statements which serve to map the value contained in a register or subregister into the name of the machine operation being decoded. In the description of more complex machines, specifying the decoding operation may require the use of other types of statements as well.

DECODE_BLOCK = 'DECODE' SIMPLE_SEQUENCE 'END DECODE'

The execute block of a BAPSIM program contains a sequence of statements which specifies the instruction interpretation operations of the object machine being described. Each machine instruction must be named -- so that it may be referred to in the decode block -- and the micro-operations required to "execute" the machine instruction must be specified. In most cases these micro-operations are merely the elementary register-transfer operations. Each of these

elementary operations is specified by a simple statement in the BAPSIM language. These simple statements were defined to reflect the elementary machine operations.

```
EXECUTE_BLOCK = 'EXECUTE'  COMPOUND_STMT
                $ ( ';' COMPOUND_STMT )
                'END EXECUTE'
```

It should be noted here that the syntactic unit COMPOUND_STMT appearing in the definition of an EXECUTE_BLOCK is nothing more nor less than a labeled simple sequence, the label serving to name the operation specified by the simple sequence.

The input/output block of a BAPSIM program contains the statements required to specify the initiation procedure and the output procedure required for the simulator constructed by the BAPSIM translator. Since these statements are not a part of the actual machine description, but rather a supplement to it, they must appear in a separate block in the BAPSIM machine description.

```
IN_OUT_BLOCK = INITIALIZATION_STMT  MONITOR_STMT
```

All of the various blocks (i.e., programs segments) making up a BAPSIM program have now been defined and described. The purpose of this section has been to explain the block structure of a BAPSIM machine description and to

highlight the manner in which this block structure is intended to reflect the structure and behavior of the object machine being described.

Program Statements

The statements which comprise BAPSIM machine descriptions fall into two broad categories: declaration statements, which serve to specify the machine structure, and simple statements, which are used to specify machine behavior.

Declaration statements

The set of program statements referred to collectively as declaration statements is made up of five members: register declarations, subregister declarations, memory declarations, terminal declarations, and operation declarations. Each of these statement types is defined, using the meta-notation described earlier, in Appendix 1 which shows the complete syntactic definition of the BAPSIM language. In this section the various program declaration statement types will be illustrated by example.

Register declaration statements are required to specify the single- or multi-bit hardware registers of the object machine. The machine registers are named and their lengths are specified as shown below:

```
REGISTER      A(0-31),Q(0-31),OV;
```

This register declaration statement specifies two 32-bit registers, A and Q, and one 1-bit register, OV. In the case of multi-bit registers, bit positions are assumed to be numbered zero through n-1, where n is the length of the register in bits, starting from the left. This convention is required by the BAPSIM translator in its construction of the object machine simulator and is not a part of the BAPSIM language.

Subregister declaration statements provide the facility for naming, and hence referring to, contiguous portions of previously declared registers. Assuming register A has previously been declared as in the above example, we might have:

```
SUBREGISTER      A(OP)=A(0-7),A(ADDRESS)=A(8-31);
```

This subregister declaration statement associates with the first eight bits of register A the name OP and with the final twenty-four bits of register A the name ADDRESS. If register A may also contain sign-magnitude fixed-point data, we may want to include the following additional subregister declaration:

```
SUBREGISTER      A(SIGN)=A(0),A(MAG)=A(1-31);
```

This statement associates the name SIGN with the first (i.e., left-most) bit of register A and the name MAG with the final

(i.e., right-most) thirty-one bits of register A.

Memory declaration statements provide a means for naming and defining the size of the memories of the object machine.

```
MEMORY      M(MAR)=M(0-127,0-31);
```

This memory declaration statement asserts that the object machine being described has a single 128-word memory. The memory word length is thirty-two bits and the memory is accessed by the memory address register having the name MAR.

Terminal declaration statements name and define the number of terminals to be used in the description of object machine behavior. As Chu (11) points out, having this set of special identifiers, used to designate signals at critical circuit points, is convenient in some situations and necessary in others. The use of terminals in a machine description will be illustrated in the section below on terminal statements. A sample terminal declaration follows:

```
TERMINAL      K(0-7),SUM,T5,CARRY(0-14);
```

This statement associates the name K with a group of eight terminals, the names SUM and T5 with single terminals, and the name CARRY with a group of fifteen terminals.

Operation declaration statements are used to declare the presence of user-defined collections of primitive machine operations in the behavioral description of the object machine.

Such declarations are necessary in order that the BAPSIM translator be able to differentiate between user-defined operations and the operations corresponding to the object machine instruction set. The object machine simulator constructed by the BAPSIM translator treats these two types of operations in different ways. An alternative to requiring the explicit declaration of user-defined operations would be to adopt some sort of naming convention to distinguish between the two types of operations, say require all user-defined operations, and only user-defined operations, to begin with the letter Z. The associated reduction in naming flexibility, from the viewpoint of the programmer, was considered to be less desirable than requiring explicit declarations.

```
OPERATION      MULT,ROOT,ADDRESS;
```

This operation declaration statement alerts the BAPSIM translator to the existence of three user-defined operations (MULT,ROOT,ADDRESS) in the description of the object machine.

Simple statements

The set of program statements referred to collectively as simple statements is made up of five members: DO-statements, IF-statements, GO_TO-statements, transfer statements, and terminal statements. Each of these statement

types is defined in Appendix 1. In this section the various simple statement types will be illustrated by example.

DO-statements serve to invoke the specified user-defined operation. When executed by the simulator for the object machine, DO-statements in BAPSIM are equivalent to CALL-statements in FORTRAN or PL/1. For example, the statement

```
DO  ROOT
```

calls for the execution of the statements appearing in the definition of the user-defined operation ROOT. After the operation called for by the DO-statement is complete, "control" returns to a point immediately following the DO-statement. Any identifier appearing in a BAPSIM program immediately following the keyword DO must have previously been declared to be a user-defined operation.

IF-statements serve to specify the conditional occurrence of an action. For example, the statement

```
IF ( OP .EQ. 1 )  THEN  DO ADD
```

specifies that the user-defined operation ADD will be carried out if and only if the register, subregister, or terminal named OP has a value equal to 1. In general, the action following the keyword THEN will be carried out if and only if the condition following the keyword IF is true. Readers familiar with PL/1 or ALGOL should note that this is the only

conditional construction allowed in BAPSIM. The construction IF...THEN...ELSE, legal in other high level programming languages, is not a valid BAPSIM construction.

GO_TO-statements serve to specify unconditional transfers of control within a BAPSIM program. The identifier appearing in the GO_TO-statement must appear elsewhere in the machine description as a statement label. The meaning and use of GO_TO-statements in BAPSIM are identical to the meaning and use of GO TO-statements in other high level programming languages.

Transfer statements are the heart of the BAPSIM language since they serve to specify the object machine register-transfer operations. These operations, being nothing more nor less than the primitive machine operations, completely define the behavioral characteristics of the machine being described. Transfer statements specify the information transfer from one register to another as well as the logical operation, if any, performed during the transfer. For example, a simple direct transfer of information between two registers is specified in BAPSIM as:

A <- Q

This statement calls for the transfer of the contents of register Q to register A. Examples of more complex transfer statements and word descriptions of their meaning follow.

```
X <- M(MAR)
```

This statement represents a memory fetch operation. It calls for the transfer of a word, specified by the contents of the memory address register MAR, out of memory M into register X.

```
M(MAR) <- X
```

This statement is a memory store operation whose meaning is exactly analogous to the preceding memory fetch operation.

```
A <- .SHR. X
```

This statement specifies a shift and transfer operation. The contents of register X are transfered to register A shifted one bit to the right. The contents of register X are unaltered by this operation.

```
A <- A .ADD. X
```

This statement specifies an addition operation. The contents of register A are added to the contents of register X -- in a strict binary sense -- and the result is returned to register A. The operation is the basic machine addition operation and implies the existence of an adder of some sort in the object machine. The logical details of the adder are not specified by this operation and are of no concern when viewing the object machine on the register-transfer level.

Terminal statements specify the signals at critical circuit points called terminals. Terminals may be thought of as 1-bit registers whose value is specified as some logical function of other 1-bit registers, subregisters or terminals. For example, the output-carry terminal, OV, of a full adder may be considered a terminal whose value is specified by the terminal statement

$$OV := K(0)*(\neg A(0))*(\neg R(0))+(\neg K(0))*A(0)*R(0)$$

Use of the sequential operator ':=' serves to distinguish terminal statements from transfer statements and highlights the fact that the operations specified by these two types of statements are different in essence. The only logical operators which may appear in terminal statements are the logical product operator '*', the logical sum operator '+', and the logical complement operator '¬'. These three operators are sufficient for specifying any logical function which may be associated with a terminal. It should be noted that the logical operators which appear in terminal statements are not the same operators which appear in transfer statements. The reason for this distinction is that terminal statements may be much longer than transfer statements and single-character operators make the longer statements easier to read (and write). The example given above has no equivalent transfer statement; a terminal statement is necessary to specify the

operation. There are cases where a terminal statement is merely more convenient to use than a transfer statement. For example,

```
A(0)  <-  A(0)  .AND.  R(0)
```

and

```
A(0)  :=  A(0)*R(0)
```

are equivalent.

Simple statements may optionally specify timing information for use by the simulator in simulating machine behavior. If timing data is to be supplied, the format is:

```
SIMPLE_STMT <TIME>
```

where TIME is an integer which specifies the time, in relative units, required to perform the operation specified by the simple statement. For example, if a memory access operation takes 1.5 microseconds in a certain machine, the simple statement describing this operation might appear as:

```
X  <-  MEM(MAR)  <15>
```

In this case, the basic time unit is clearly one-tenth of a microsecond and the memory access operation is performed in fifteen of these basic time units.

As a further example, if the machine being simulated

employs an adder (of some sort) which is capable of adding the contents of two registers and returning the result to one of the two registers in 2.0 microseconds, the simple statement describing the machine's addition operation might be:

A <- A .ADD. X <4>

In this case, the basic time unit was chosen to be one-half of a microsecond.

The choice of the basic time unit is left to the BAPSIM programmer in order to provide him with the ability to describe machines of widely varying speed. The only restriction on the choice of the basic time unit is that all machine operations must take place in time intervals which are integral multiples of the basic time unit.

If timing information is specified in the object machine description, the simulator keeps track of the (simulated) time required to perform all of the operations in each of the (simulated) fetch-decode-execute cycles. At the end of each cycle the accumulated time is printed out along with the machine state. This feature, then, provides information about the time required for the object machine to execute a given program.

In the case of synchronous machines, where each and every fetch-decode-execute cycle takes place in the same amount of time, the timing information provided is not too

useful since the total time is merely the product of the time per cycle and the number of cycles executed. In the case of asynchronous machines, where the time required for each cycle is a function of the operations performed during the cycle, the timing information provided automatically by the simulation run would be difficult to obtain in any other way.

A Sample Program

The purpose of this section is to further clarify, by means of an example, the structure of BAPSIM programs and the syntax of BAPSIM statements.

The digital computer described in this section (referred to in what follows as TELCOMP) does not exist in hardware. Rather it is a hypothetical machine designed to be used as a pedagogical tool for illustrating fundamental concepts common to all digital computers. For precisely this reason, it is also an excellent vehicle for illustrating the structure of BAPSIM machine descriptions and the syntax of BAPSIM program statements.

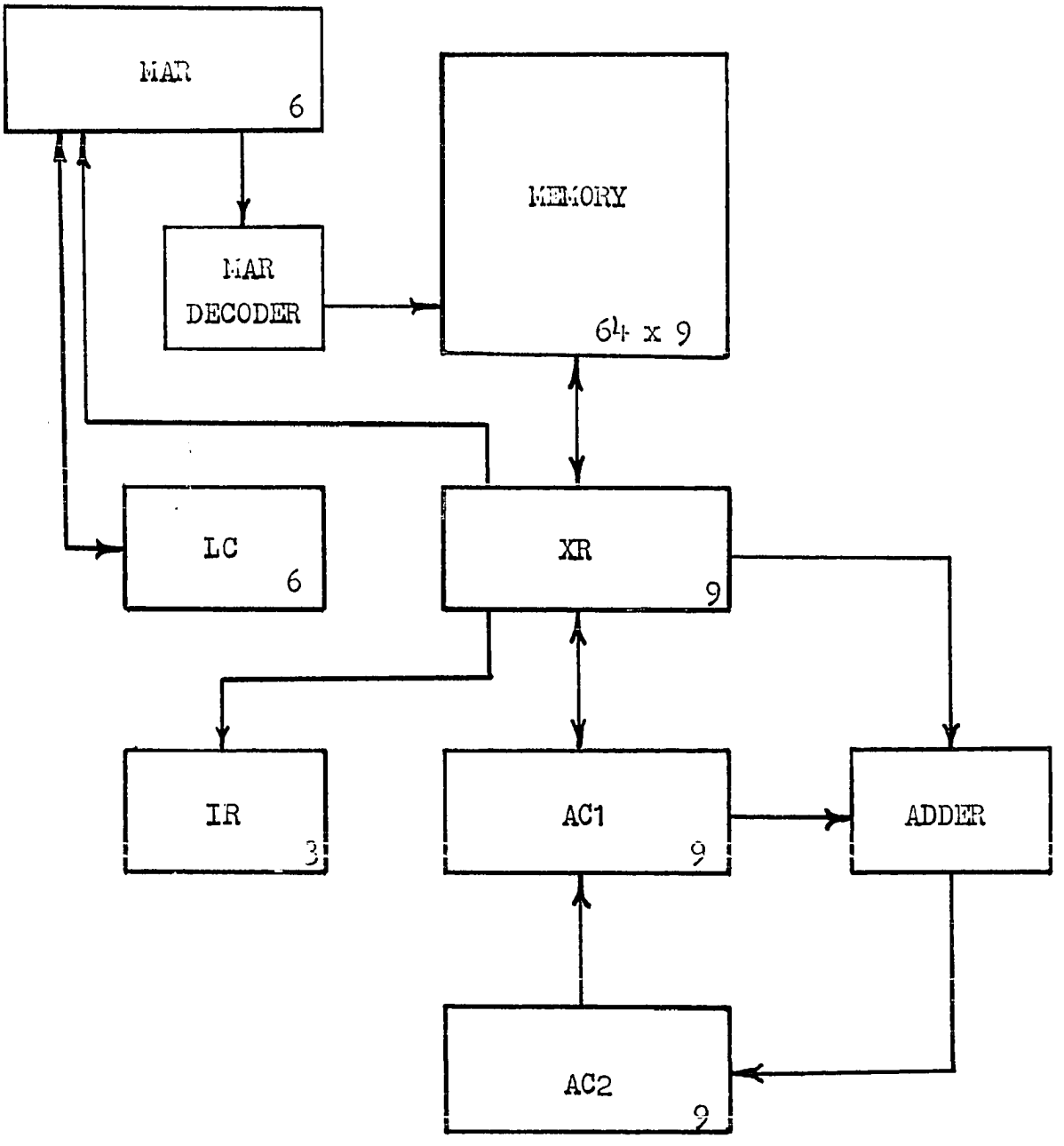

FIGURE 1. THE TELCOMP COMPUTER.

FIGURE 1 is a block diagram of the TELCOMP computer illustrating in an informal manner the structural characteristics of the machine. The relationship between this pictorial description of the machine and the formal BAPSIM machine description will be discussed below. In referring to the BAPSIM program (Appendix 2) reference will be made to the identification information appearing as 8-character strings to the right of the figure. This information is not a part of the BAPSIM language and would not appear in an actual BAPSIM program.

The BAPSIM translator, which constructs from the BAPSIM machine description a simulator for the object machine, recognizes all program cards with an asterisk '*' in column 1 as comment cards. Comment cards are merely listed by the BAPSIM translator and hence are not a part of the formal machine description. They allow the programmer to supplement his formal machine description with English language explanations and identification information.

The formal machine description begins on line 1030. The literal occurrence of SIMULATION signals the beginning of a simulation block and hence the beginning of a BAPSIM program. Similarly, the literal occurrence of DECLARE (line 1090) signals the beginning of a structure block. The body of the structure block is made up of three declaration statements which serve to specify the machine structure. These

declaration statements are the formal counterpart of the blocks of FIGURE 1.

The first declaration statement (lines 1100 and 1110) is a register declaration statement specifying the seven registers within the object machine. The location counter, named LC, and the memory address register, named MAR, are declared to be 6-bit registers. The exchange register, named XR, the first accumulator, named AC1, and the second accumulator, named AC2, are declared to be 9-bit registers. Further, TELCOMP contains a 3-bit instruction register, named IR, and a 1-bit stop/run flip-flop, named SR. Note that commas are used to separate the individual register declarations and a semi-colon serves to end the entire register declaration statement.

Also note that the register declaration statement discussed in the preceding paragraph appears on two lines (i.e., is punched on two cards). The BAPSIM translator ignores card boundaries, column position (except when checking for a comment card), and blanks (except when checking for a literal symbol) in its scan of the input string. This allows the programmer considerable freedom in punching his machine description and permits the writing of easily readable programs.

The second statement of the structure block (line 1120) is a subregister declaration statement specifying the two

(sub) fields making up the exchange register. The left-most field, named OP, is three bits long and extends from bit zero of the exchange register through bit two. The right-most field, named ADDR, is six bits long and extends from bit three of register XR through bit eight. Implicit in these subregister declarations is information about the TELCOMP instruction format. When the exchange register contains a word to be interpreted as an instruction (as opposed to a data word) the bits zero through two are considered to be the operation code and the bits three through eight are considered to be the operand address. Thus, the TELCOMP computer is a single address machine with a maximum of eight different machine instructions.

Similarly, a data word format could be defined. The subregister declaration statement corresponding to TELCOMP's 2's complement integer data word might appear as:

```
SUBREGISTER     XR(SGN)=XR(0),XR(MAG)=XR(1-8);
```

The third statement of the structure block (line 1130) is a memory declaration statement. TELCOMP has a single 64-word, 9-bit memory, named M, which is accessed via a memory address register named MAR.

The literal occurrence of END DECLARE (line 1140) signals the end of the structure block. A note on syntax: the final statement in a block must not be followed by a semi-

colon. The delimiter indicating the end of the block also serves to indicate the end of the last statement within the block.

The structure block just described specifies the machine hardware elements of interest at the register-transfer level. The implementation details of this hardware are suppressed since they are not of interest at this level of description. In contrast to the block diagram, note that the formal description of TELCOMP has not defined the data paths between registers. However, these data paths are to be found implicitly in the transfer statements which describe the behavioral characteristics of the object machine.

The literal occurrence of FETCH (line 1170) signals the beginning of a fetch block. The body of the fetch block is made up of the following five transfer statements which define the fetch cycle of the machine. The first of these transfer statements (line 1180) is an example of a direct transfer between registers; the contents of the location counter LC are transferred unaltered to the memory address register. Implicit in this statement is the fact that a data path of some sort exists between these two registers.

The second statement in the body of the fetch block (line 1190) is an example of a memory access transfer statement. The contents of the memory word whose address is contained in the memory address register are transferred

unaltered to the exchange register. Again, a data path from the memory word to the exchange register is implied. Also note that the details of the address decoding operation are not specified or implied by this transfer statement. Such details are of interest to the logic designer or to the student of logic design, but they are concerned with a machine level "below" the register-transfer level. At the level of concern here, such details may be, and are, suppressed.

The next two statements (lines 1200 and 1210) are further examples of direct transfers. The fifth and final statement in the body of the fetch block (line 1220) is an example of a transfer statement which calls for a logical operation to be performed during the transfer operation. The logical operation is specified by the binary arithmetic operator .ADD.. This statement may be read as "increment the location counter by one". During the addition operation the contents of the operand register LC are taken to be a binary integer and a binary integer 1 is added in the least significant (i.e., right-most) bit position. The result is stored back in register LC.

The five transfer statements making up the body of the fetch block are examples of simple statements (they do not have a label prefixed to them) and they are separated by commas. They need not have been punched on separate cards,

however, their order is important. Note that the final statement in the block is not followed by a comma. The literal occurrence of END FETCH (line 1230) signals both the end of the last statement within the block and the end of the block itself.

The literal occurrence of DECODE (line 1260) signals the beginning of a decode block. The body of the decode block is made up of eight IF-statements, separated by commas, which serve to associate with each of the eight possible integer bit patterns in the 3-bit instruction register IR the name of an object machine instruction. Each of these eight machine instruction names appears in the execute block as a label on a compound statement.

The sequence of statements making up the body of the decode block describes the TELCOMP instruction decoding operation on a functional level and suppresses all of the implementation details of interest to the logic designer. On the functional level of interest here, the instruction decoding operation merely serves to invoke the proper sequence of machine micro-operations. In this simple case, the particular sequence of micro-instructions invoked depends only upon the contents of the instruction register IR. More complex dependencies are specified by including other BAPSIM statements in the decoding sequence.

There is an implicit flow of control, or sequence of op-

erations, which is reflected in the BAPSIN program structure: the instruction fetch operation is performed first, followed by the instruction decoding operation, followed in turn by the instruction execution operation. This fetch-decode-execute (FDE) cycle is found in all present day digital computers and is reflected in the structure of the object machine simulator constructed by the BAPSIM translator.

The literal occurrence of END DECODE (line 1350) signals both the end of the last statement in the sequence making up the body of the decode block and the end of the block itself. The literal occurrence of EXECUTE (line 1380) signals the beginning of an execute block. The body of the execute block is made up of eight compound statements which serve to describe the sequence of micro-operations associated with each object machine instruction. Note that a compound statement is nothing more than a labeled sequence of simple statements. The simple statements are separated by commas; the compound statements are separated by semi-colons. The labels correspond to the instruction mnemonics; the mnemonics are associated with specific operation codes in the decode block.

The first compound statement in the execute block, labeled ADD, describes the TELCOMP addition operation. The addition operation is "executed" by TELCOMP by performing three micro-operations: an operand fetch (line 1390), a register-register add (line 1400), and a direct transfer

(line 1410).

In a similar manner, the second compound statement, labeled SUB, describes the TELCOMP subtraction operation as a sequence of seven micro-operations (line 1420 - line 1480). The micro-operation of line 1430 illustrates the use of the unary logical operator .NOT..

The TELCOMP shift right operation, SRO, is described by a sequence of three micro-operations. The third operation of this sequence (line 1510) illustrates the use of the BAPSIM functional operator .SHR.. In this operation the contents of the second accumulator, AC2, are transferred to the first accumulator, AC1, shifted one bit position to the right. The contents of the second accumulator, AC2, are left unaltered by this operation.

The TELCOMP unconditional transfer operation, TRU (line 1520), is "executed" by performing a single direct transfer micro-operation.

The TELCOMP transfer on negative accumulator operation, TRN, is specified by a single IF-statement micro-operation (line 1530). The condition for the single direct transfer is that the left-most bit of the first accumulator, AC1(0), is a '1'. If this condition is not met the direct transfer is not performed.

The next two TELCOMP machine instructions, store accumulator STA and clear accumulator CLA, are obvious. The

final instruction, however, deserves an explanation.

The purpose of the stop instruction (line 1570) is to halt the fetch-decode-execute cycle. In all cases, this operation is specified in a BAPSIM machine description by the simple statement GO TO STOP. During the execution of the simulated fetch-decode-execute cycle, one and only one machine instruction (i.e., series of micro-operations) will be invoked. Hence following the execution of a machine instruction there is an implied flow of control back to the fetch portion of the cycle -- control does not flow through more than one machine instruction as implied by the structure of the execute block. Thus, there is an implied GO TO FETCH statement after each of the compound statements making up the execute block. The correct flow of control is implemented in the object machine simulator constructed by the BAPSIM translator. See the general simulator flowchart in Appendix 5. Obviously, there must be some way to get out of the fetch-decode-execute cycle or the computer would "run" indefinitely. The statement GO TO STOP serves precisely this purpose.

The literal occurrence of END EXECUTE (line 1580) serves to signal the end of the execute block. Note that there is no semi-colon delimiter following the final statement of the execute block.

At this point in the BAPSIM program (line 1580) the

structural and behavioral characteristics of the object machine have been completely described. It remains for the programmer to specify information for use by the BAPSIM translator in constructing the object machine simulator.

The first of the two statements making up the input-output block is an initialization statement (line 1610). This statement informs the BAPSIM translator that when the simulator is run, input data corresponding to the named registers, subregisters, and memories will be provided by the programmer. The translator uses this information to include in the simulator provisions for accepting this data input. The input data supplied by the programmer defines the initial state of the machine for the purpose of simulation.

At the end of each fetch-decode-execute cycle the simulator provides printed output which may be thought of as a snapshot indicating the machine state. Those registers of interest to the programmer during the simulation run -- i.e., those registers the programmer uses to define the machine state -- are specified in a monitor statement (line 1630). This statement tells the translator that at the end of every fetch-decode-execute cycle of the simulation the contents of the six registers listed are to be printed out for inspection. Simulator input-output operations will be discussed further in a following section.

The literal occurrence of END SIMULATION (line 1660)

signals the end of the simulation block and hence the end of the BAPSIM machine description of the TELCOMP computer.

THE BAPSIM TRANSLATOR

Introduction

The purpose of the BAPSIM translator is to convert an object machine description written in the BAPSIM language into a simulator which is capable of "executing" programs written in the machine language of the machine being simulated. Since the simulator is a PL/1 program, from one point of view the BAPSIM translator may be thought of as a program-writing program.

Once the source language has been defined, three questions must be answered prior to the development of any translator/compiler:

1. What programming language is the translator/compiler to be written in?
2. What is the target language?
3. What translation technique is going to be used?

Answers to the first two of these questions will be briefly discussed next. The third question will be dealt with in more detail later.

In the case of compilers, the target language is usually the machine language of a particular machine (or series of machines) and, traditionally, compilers have been written in

the assembly language of the specified machine(s).

Recently, however, the use of higher level programming languages in the implementation of complex software systems has been gaining in popularity, as the advantages of such a method have come to be known and accepted. Certainly, not the least of these advantages has to do with the time required to write and debug large programs. It is simply easier to design and implement a large program, or group of programs, in a higher level programming language than it is to implement the same system in assembly language. As an example of this approach, one could cite the MULTICS supervisory system which was written in PL/1. In addition, there exists at least one FORTRAN compiler which was written in PL/1.

In order to explore the possibilities of such a technique, the decision was made to write the translator/compiler for the BAPSIM simulation system in a high level language. And, since the process of translation/compilation is, for the most part, a symbol manipulation process, PL/1 was selected as the language to be used. This decision was based primarily on PL/1's extensive and exceptional facilities for character processing.

The second question to be answered was: what is the target language? Unconventionally, but very successfully, PL/1 was also chosen as the target language. There were two reasons for this choice: (1) the nature of the simulation

process being implemented, and (2) the desire for program mobility.

The BAPSIM simulation system is intended to model digital machines at the register-transfer level. At this level, the fundamental data item is the bit string; one of PL/1's basic data items is the bit string.

One of the reasons for using higher level programming languages is the ability to run programs in the language on different machines -- i.e., program mobility. Such mobility is essentially lost in compilers or translators if the target language is not equally mobile. A FORTRAN compiler written in PL/1 is not really mobile if it generates S/360 machine code. Of course, mobility is not usually required in a compiler. However, in a translator or monitor it can be most useful.

In summary, by choosing PL/1 as both the language of the translator and as the target language, complete mobility of the simulation system is assured.

The question of translation technique remains to be answered. The first section below will deal only with the syntactic analysis phase of the translator. The equally important semantic analysis portion of the translator will be dealt with in a following section.

Syntactic Analysis Techniques

Syntactic analysis techniques fall into two broad categories: (1) general algorithms, and (2) special algorithms.

General algorithms are those which allow the syntactic analysis of a whole class of computer languages for which the syntax can be expressed with the aid of some code or formalism. These algorithms require two kinds of data: (1) the syntactic rules of the particular source language being analyzed, and (2) the source program to be analyzed.

Special algorithms (for syntactic analysis) are those with a structure which reflects the syntax of a particular language and which are therefore applicable only to that language. These algorithms require only one kind of input data -- the source program to be analyzed.

Since the BAPSIM language discussed above is the only language of interest in the work reported on here, generality in the translator was not required. Further, the efficiency (i.e., fast parsing speed) and ease of use associated with translators implementing one of the special algorithms were considered to be desirable.

Syntactic analysis techniques may also be classified according to the particular parsing algorithm they employ. Top-to-bottom parsers begin with the most general syntactic unit in the language grammar and, by making successive

substitutions for the non-terminal syntactic units, attempt to produce (construct) the given input string. In opposition, bottom-to-top parsing algorithms start with the given input string and, by applying the productions of the language grammar backwards, attempt to recognize the input as an occurrence of the most general syntactic unit.

General comparisons between the two parsing methods are difficult for two reasons. First, parsing efficiency is more a function of the language to be parsed than of the parsing method used. Some languages may be parsed more efficiently using the top-to-bottom method and others may be parsed more efficiently using the bottom-to-top method. Simple languages may be parsed efficiently by either method.

Second, the top-to-bottom method does have one drawback. It does not work for language definitions that are left recursive. This defect is not too important, however, since it is always possible to transform a given left recursive language definition into an equivalent grammar which is not left recursive (26).

Since the BAPSIM language definition is not left recursive, the choice of parsing method to be employed in the translator was dictated by another consideration discussed in the next section.

The Method of Syntactic Functions

The special algorithm which was selected for use in the BAPSIM translator is referred to in the literature as the method of syntactic functions. This top-to-bottom approach to the syntax analysis problem associates with each syntactic definition in the language a corresponding Boolean function in the translator. This direct relationship between the syntax of the language and the structure of the translator makes the translator easy to write initially and easy to modify if the syntax of the language is altered or extended.

To illustrate the method of syntactic functions, consider the problem of analyzing (in this case recognizing) lists of identifiers. In Backus-Normal form, the syntactic definition of a list might appear as follows:

<list> ::= <identifier> ! ',' <list>

<list> and <identifier> are syntactic units and the notation ',' is used to indicate the literal occurrence of a comma. In words, this definition states that "the syntactic unit <list> is defined as any occurrence of the syntactic unit <identifier> or a literal occurrence of a comma followed by any occurrence of the syntactic unit <list>". Note that in Backus-Normal form, <list> is defined in terms of itself. However, the definition is not ambiguous being "grounded" by

the first alternative in the above definition.

The syntactic function (procedure) corresponding to this syntactic definition is given in PL/1 as:

```
LIST: PROCEDURE  RETURNS(BIT(1))  RECURSIVE;
      IF IDENTIFIER THEN
           IF COMMA THEN
                IF LIST THEN GO TO TRUE;
                      ELSE GO TO FALSE;
                ELSE GO TO TRUE;
                ELSE GO TO FALSE;
FALSE: RETURN('0'B);
      GO TO EXIT;
 TRUE: RETURN('1'B);
 EXIT: END LIST;
```

where IDENTIFIER is another Boolean procedure which returns true ('1'B) if the character string pointed to by the text pointer is an identifier, and returns false ('0'B) otherwise. When an identifier is found, and before true is returned to the calling procedure, the text pointer is advanced one position beyond the identifier. COMMA is another Boolean procedure which returns true if the character pointed to by the text pointer is a ',' and returns false otherwise. Again, the text pointer is advanced one position if and only

if a comma is found.

For those readers familiar with PL/1 or ALGOL it should be evident how the structure of this procedure reflects the structure of the syntactic unit being analyzed (<list>).

To illustrate how the choice of meta-language influences the syntax analysis process, consider the same example using the meta-language developed above. Using this meta-notation, the syntactic definition of a list would be as follows:

```
LIST  =  IDENTIFIER $ ( ',' IDENTIFIER )
```

In words this definition states: "a list is defined to be an identifier followed by zero or more occurrences of the combination comma-identifier".

The most important thing to note about this definition is that the definition of a list is no longer recursive -- i.e., LIST is no longer defined in terms of itself.

The syntactic function (procedure) corresponding to this second syntactic definition is given in PL/1 as:

```
   LIST: PROCEDURE  RETURNS(BIT(1));
         IF ¬IDENTIFIER THEN GO TO FALSE;
     L1: IF ¬COMMA THEN GO TO TRUE;
         IF ¬IDENTIFIER THEN GO TO FALSE;
         GO TO L1;
  FALSE: RETURN('0'B);
```

```
        GO TO EXIT;
TRUE:   RETURN('1'B);
EXIT:   END LIST;
```

where IDENTIFIER and COMMA are as defined in the earlier example. Note that since the definition of LIST is no longer recursive, the corresponding syntactic function (procedure) need not be recursive.

Again, note how the structure of the syntactic unit (LIST) under consideration is reflected in the structure of the procedure. In the second example, an iterative technique has been used instead of the recursive technique of the first example. The change from recursion to iteration is not always possible however. In the cases requiring recursion -- for example, the CONDITION portion of the BAPSIM IF-statement -- the RECURSIVE option allowed with PL/1 procedures considerably simplifies the problem of implementation.

Implementation Details

With this general discussion of method out of the way we may proceed to consider the implementation details of such a technique. Appendix 3 contains a program listing of the syntax analysis portion of the BAPSIM translator and should be consulted while reading this section.

With reference to Appendix 3, note that the BAPSIM syntax analyzer contains three functionally distinct sections of code: (1) code for the necessary housekeeping chores (lines 1080 - 1960), (2) the main part or heart of the program (lines 2000 - 2100 and lines 7960 - 7980), and (3) the Boolean function procedures. These procedures fall into two categories: (1) primitive procedures, which recognize the primitive elements of the BAPSIM vocabulary and handle error conditions, and (2) the non-primitive procedures which correspond one-for-one with the syntactic units of the BAPSIM language.

One of the most important housekeeping chores involves reading the BAPSIM machine description. The input data is considered to be a finite character string which, of necessity, is punched onto a sequence of cards. The cards are read one at a time into an 80-character buffer, named CARD, and made available from there to the rest of the program. Also associated with the task of reading the input stream is a text pointer, named I, which keeps track of the correct position in the text being read and analyzed. As the input string is read, the text pointer is advanced by the various primitive procedures and when the end of the buffer is reached an end-of-card (EOC) condition is raised.

This condition causes four things to occur. First, the buffer CARD is refilled with the next eighty characters of

the input string. Second, the first character of the card just read is examined. If the character is an asterisk '*', indicating a comment card has been read, the comment is printed in the source listing and another card is read into the buffer. If the character is not an asterisk, the statement counter is incremented by one and the statement number and card are printed in the source listing. Third, the text pointer is reset to the beginning of the buffer. Finally, control transfers back to the primitive procedure which was responsible for raising the end-of-card condition and the syntax analysis process continues.

The heart of the BAPSIM translator is the single PL/1 IF-statement on lines 2060 and 2070. This statement serves to invoke all of the necessary procedures, in the proper order, for determining whether or not a valid BAPSIM program has been supplied as input. The elegant simplicity of this syntactic analysis technique should now be apparent.

Primitive procedures

The first of the primitive procedures is a one-parameter Boolean function labeled LITERAL. This procedure compares the character string passed to it by a calling procedure with the character string (of the same length) appearing at the current position of the text pointer. Note that extraneous blanks are ignored before the comparison is made. Also note

that the literal being tested for may not extend across a card boundary. If a literal occurrence of the character string passed to it is found at the current position of the text pointer, the function LITERAL returns true ('1'B) to the calling procedure after advancing the text pointer beyond the string just recognized. If no such match is found, the text pointer is not advanced and LITERAL returns false ('0'B) to the calling procedure.

In the examples above illustrating the method of syntactic functions, the existence of a Boolean function named COMMA was assumed. Implementing such a function could be accomplished by calling LITERAL with a comma as the argument -- i.e., LITERAL(','). Thus, LITERAL is a general Boolean function for recognizing the literal occurrence of any character string passed to it.

The second of the primitive procedures is a zero-parameter Boolean function labeled ID. This procedure checks for the occurrence, at the current position of the text pointer, of a valid BAPSIM identifier. Again, extraneous blanks preceding the identifier are ignored. When a valid BAPSIM identifier is recognized it is stored in a varying length character string named SYMBOL. If the identifier is greater than eight characters in length, a new character string is stored in SYMBOL which consists of the first four characters of the original identifier concatenated with the

last four characters of the original identifier. Thus, in practice, BAPSIM identifiers are limited to character strings of length eight. During the syntactic analysis phase of the translation process, the identifier stored in SYMBOL by the procedure ID is never used. It is used, however, during the semantic evaluation phase of the translation process.

The third of the primitive procedures is a zero-parameter Boolean function labeled INT. This procedure checks for the occurrence of a valid BAPSIM integer. Its operation is analogous to the operation of procedure ID except that integers are not "shrunk" if they exceed eight characters. Again, the integer stored in SYMBOL is never used in the syntactic analysis phase of the translation process.

The fourth of the primitive procedures is a zero-parameter procedure labeled ERROR. This procedure is called whenever the character string at the current position of the text pointer does not correspond to the character string expected by the syntax analyzer -- i.e., whenever an invalid machine description is provided as input to the analyzer. Error handling is extremely simple. The offending card column is flagged with a dollar sign '$' and the translation process is aborted. For a language as simple syntactically as BAPSIM this technique has proven itself to be adequate.

Three additions to the error handling routine were considered and all were rejected as being unnecessary for the

purposes of the work reported on here. The first addition would have called the error routine with an integer argument whenever an input syntax error was detected. The error routine would then output an error message, determined by the integer passed to it, which contained more complete diagnostic information. The second addition would have been to provide some sort of error recovery procedure. The complexity of such a procedure to handle all possible errors was considered to be prohibitive to its implementation. Another possibility would have been simply to advance the text pointer beyond the offending statement (after flagging the error) and continuing with the translation process. This provision would have made it possible to detect more than one error on each run of the translator. Further development of the BAPSIM translator will certainly include this provision.

Non-primitive procedures

The remaining section of the syntax analyzer consists of the fifty-four function procedures corresponding to the fifty-four non-primitive syntactic units of the BAPSIM language. By comparing any syntactic procedure with its associated syntactic definition the relationship between the structure of the definition and the structure of the procedure should be apparent. It is precisely this direct correspondence which results in a syntax analyzer that is easily modified to

reflect changes in, and extentions to, the language being analyzed.

Two of the fifty-four non-primitive procedures (TERMINAL_STMT, TRANSFER_STMT) are extraordinary. The reason for the added complexity of these two procedures is that the BAPSIM language is not defined so that each choice among alternative syntactic units can be made by examining only the first element of that syntactic unit. In other words, certain character strings in the language may represent the occurrence of more than one syntactic unit of the language. Precisely which syntactic unit a given instance of a character string represents depends on the context in which the character string appears.

More specifically, character strings of the form .ID or .ID(.INT) may represent the occurrence of either the syntactic unit DEST or the syntactic unit TERMINAL. If a character string having one of these two forms is followed by the sequential operator '<-' it is taken to be an occurrence of the syntactic unit DEST. However, if the character string is followed by the sequential operator ':=' it is taken to be an occurrence of the syntactic unit TERMINAL.

Consider the problem of recognizing a terminal statement. The BAPSIM translator first checks for a transfer statement (since transfer statements occur more frequently in BAPSIM machine descriptions than terminal statements). If we

have a valid terminal statement, the translator recognizes the initial portion of the statement as an occurrence of the syntactic unit DEST and then checks for the sequential operator '<-'. Of course, the transfer operator is not found (remember we have assumed that we have a valid terminal statement) and so the procedure TRANSFER_STMT must report back to its calling procedure (SIMPLE_STMT) a failure. At this point, however, the text pointer would be pointing just beyond the character string incorrectly identified as an occurrence of DEST. If the translator were now merely to check for a terminal statement, failure would result since the translator is looking for an occurrence of TERMINAL and the text pointer is pointing to the sequential operator ':='.

The solution to this problem is to reset the text pointer to the beginning of the terminal statement before TRANSFER_STMT reports back a failure. With this provision included, the translator continues by checking for and finding an occurrence of TERMINAL, followed by an occurrence of ':=', followed by the remainder of the terminal statement.

The Simulator

The simulator constructed by the BAPSIM translator is a PL/1 program which is capable of "executing" programs written in the machine language of the object machine. The input to

the simulator consists of bit strings specifying the initial state of the object machine's hardware elements. The output of the simulator is a series of snapshots of the object machine state at the end of each fetch-decode-execute cycle.

The purpose of the semantic evaluation portion of the BAPSIM translator is to generate the PL/1 simulator. As may be seen by referring to the program listing of the complete BAPSIM translator in Appendix 4, the semantic evaluation code is interspersed with the syntactic analysis code. The reason for this is that the code for the PL/1 simulator is generated "on the fly" as the syntactic analysis process is carried out. With this technique, elements of the PL/1 simulator are generated as soon as their corresponding elements in the machine description are recognized. In what follows, the more important segments of the semantic evaluation code will be discussed.

Primitive procedures

Two additional primitive procedures are associated with generating the PL/1 simulator. The first of these is a zero-parameter procedure labeled STAR. Recall that whenever an identifier or integer is recognized it is stored in a varying length character string called SYMBOL. The purpose of the procedure STAR is simply to retrieve the last identifier or integer recognized -- i.e., to retrieve the current contents

of SYMBOL.

The second of the primitive semantic evaluation procedures is a one-parameter procedure labeled OUT. This procedure is responsible for actually "writing" the PL/1 simulator. As individual statements of the simulator are generated, they are passed to OUT. This procedure converts them to 80-character records and writes them out into a file named ASSM. This file is subsequently read back in, as input to the PL/1 compiler, when the simulator is compiled prior to execution. In addition, procedure OUT prints out the code being generated for the simulator alongside the BAPSIM source code. This juxtaposition is useful in illustrating the relationships between elements of the source program and corresponding elements of the PL/1 simulator. Procedure OUT also keeps track of the number of semantic action records generated during the translation process. The final count is printed out as an item of statistical information at the conclusion of the translation process.

Code generation

Referring to the translator program listing in Appendix 4, observe that the occurrence of SIMULATION (line 1426) in the BAPSIM machine description gives rise to the first two lines of simulator code. Similarly, when the translator recognizes END SIMULATION (line 1440) the final five lines of

simulator code are generated.

The code generated by the translator upon recognition of END DECLARE is a bit unusual. See line 1482 in Appendix 4. The PL/1 %INCLUDE statement is a preprocessor statement which is executed during a preliminary scan of the PL/1 simulator. The statement is used here to incorporate strings of external text into the source program (i.e., the PL/1 simulator) being scanned. The external text to be included must be a member of a partitioned data set. The identifier in the %INCLUDE statement (in this case DCLS) specifies the name of the data set member which is to be included at this point in the PL/1 source text.

The data set member DCLS contains the PL/1 code for the declarations which are common to every simulator constructed by the translator. Of course, this declaration code could have been generated directly by the translator. The indirect method was selected because it decreased the size of the BAPSIM translator.

Two other %INCLUDE statements are generated by the BAPSIM translator. The occurrence of END DECODE causes %INCLUDE ENDCODE to be created (line 1554). The data set member ENDCODE contains the PL/1 code required for the simulator to handle the occurrence of illegal operation codes during the instruction decoding operation. See Appendix 7. This external text is incorporated into every simulator con-

structed by the translator.

The occurrence of END EXECUTE causes %INCLUDE PRIMPROC to be generated (line 1618). The data set member PRIMPROC contains the PL/1 code required to implement fourteen of the primitive object machine operations. See Appendix 8. The text for all of these operations is included in every simulator constructed by the translator even though the simulator for a particular object machine may not require some of them. Admittedly, keeping track of the primitive operations required by a particular simulator and then including only those operations would be a more elegant approach to the problem. However, it would also be a more complex and costly approach than the one chosen here.

Simulator I/O

The translator procedure INITIALIZATION_STMT (line 1640) is responsible for creating the PL/1 code which handles the input operations for the simulator. The code generated here determines what form the simulator input initialization data must have. The first datum, required by every simulator, is associated with the GET LIST(CH#CK) statement (line 1654). The integer expected by this statement specifies the maximum number of object machine fetch-decode-execute cycles the simulator is to execute.

Each of the identifiers in a BAPSIM initialization list,

corresponding to those object machine hardware elements whose initial state is to be specified, gives rise to a GET DATA statement in the simulator. Hence, the format for specifying the initial state of the object machine is a sequence of PL/1 data lists. The PL/1 reference manual gives a complete description of the rules for supplying data to a GET DATA statement, obviating the necessity of going into the details here.

The object machine machine-language program is input by specifying an initial memory state. That is, the simulator reads the machine-language program into (simulated) memory and then executes it.

The translator procedure MONITOR_STMT (line 1694) is responsible for creating the PL/1 code which handles the output operations for the simulator. At the end of each simulated fetch-decode-execute cycle a snapshot of the object machine state is printed out. The first item printed out is the cycle number. Following the cycle number appears a printed listing of the bit patterns contained in each of the object machine hardware elements called out in the BAPSIM monitor list.

If timing information has been specified in the BAPSIM machine description, the time at the end of each fetch-decode-execute cycle will be printed out immediately following the cycle number. The time, recall, is in relative units.

Primitive operations

The simulator implements fourteen of the sixteen primitive BAPSIM machine operations by means of procedure calls. The two operations direct transfer and logical complement are implemented directly since PL/1 includes them as primitive operations. The remaining fourteen primitive operations must be implemented indirectly since they have no counterparts in the PL/1 language. It is this latter fact which serves as a justification for the development of a new programming language. To the BAPSIM user the primitive language operations and the primitive object machine operations are the same. The user is thus able to describe a given object machine in a straightforward, natural manner. It is a case of providing the user with a notational system which matches exactly the problem to be described.

The details of implementing the basic object machine operations are of no concern to the BAPSIM user since they are transparent to him. They are included here for the sake of completeness and with the hope that they may be of interest to the student of language implementation. Appendix 8 is a listing of the partitioned data set member PRIMPROC which contains the code for the fourteen primitive machine operation procedures.

The procedure #SET is invoked whenever a register,

subregister, or memory word is to be set to a specific bit pattern. Clearing a register or setting a flip-flop (i.e., a single-bit register) are its most common uses. The BAPSIM statement A <- 0 gives rise to the statement CALL #SET(A,0); in the simulator. When this latter statement is executed, during the simulation of the object machine, the procedure #SET will clear register A. Similarly, the BAPSIM statement C <- 7 gives rise to the statement CALL #SET(C,7);. When this statement is executed, the integer 7 is converted to its binary equivalent ('111'B) and this binary value is stored in register C. The assignment of the binary value to register C is from the right. That is, if register C is five bits long, the value stored in C as a result of this statement is '00111'B. If register C is two bits long, the value stored in C is '11'B.

The procedure UA#D is invoked whenever a unary-and operation is specified. The BAPSIM statement C <- .AND. X gives rise to the statement CALL UA#D(C,X); in the simulator. When this latter statement is executed, the one-bit register C will be set to '1' if all of the bits of register X are '1'. Register C will be set to '0' otherwise. If register C is a multi-bit register a length error will result during the simulation run since the unary-and operation is undefined in such a case.

The procedure #UOR is invoked whenever a unary-or opera-

tion is specified. The statement D <- .OR. Y gives rise to the statement CALL #UOR(D,Y); in the simulator. When this latter statement is executed, the one-bit register D will be set to '1' if any of the bits of register Y are '1'. Register D will be set to '0' otherwise. If register D is a multi-bit register a length error will result during the simulation run since the unary-or operation is undefined in such a case.

The procedure US#L is invoked whenever a shift left operation is specified. The statement A <- .SHL. Q gives rise to the statement CALL US#L(A,Q); in the simulator. When this latter statement is executed, the contents of register Q are transferred to register A shifted one bit to the left. The right-most bit of register A is filled with a '0'. The contents of register Q are unaltered by this operation. If the two registers involved in this transfer operation are not the same length an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure US#R is invoked whenever a shift right operation is specified. The statement A <- .SHR. Q gives rise to the statement CALL US#R(A,Q); in the simulator. When this latter statement is executed, the contents of register Q are transferred to register A shifted one bit position to the right. The left-most bit of register A is filled with a '0'. The contents of register Q are unaltered by this operation.

If the two registers involved in this transfer operation are not the same length an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure CI#L is invoked whenever a circulate left operation is specified. The statement A <- .CIRL. Q gives rise to the statement CALL CI#L(A,Q); in the simulator. When this latter statement is executed, the contents of register Q are transferred to register A shifted end-around one bit position to the left. The contents of register Q are unaltered by this operation. If the two registers involved in this transfer operation are not the same length an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure CI#R is invoked whenever a circulate right operation is specified. This procedure is analogous to the procedure which implements the circulate left operation.

The procedure #ADD is invoked whenever a binary addition operation is specified. The statement A <- A .ADD. X gives rise to the statement CALL #ADD(A,A,X); in the simulator. When this latter statement is executed, the contents of register X are added, in a strict binary sense, to the contents of register A and the result is stored back in register A. If the result of the addition operation is larger than the maximum binary integer register A is capable of holding, a

special one-bit flag, named OVERFLOW, is set to '1'. This overflow indicator is available to the BAPSIM programmer without an explicit declaration. No other BAPSIM program element may be assigned this name. Hence, OVERFLOW is a reserved word in the BAPSIM language from the user's viewpoint.

The second operand associated with the addition operator may also be an integer. The statement L <- L .ADD. 1 gives rise to the statement CALL #ADD(L,L,1); in the simulator. When this latter statement is executed, the contents of register L (treated as a binary integer) are incremented by one. OVERFLOW is set to '1' if the addition operation results in an overflow out of the left-most bit position of register L.

The procedure #SUB is invoked whenever a binary subtraction operation is specified. The statement C <- C .SUB. 1 gives rise to the statement CALL #SUB(C,C,1); in the simulator. When this latter statement is executed, the contents of register C (treated as a binary integer) are decremented by one. If the result of the subtraction operation is less than zero an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure #BOR is invoked whenever a binary-or operation is specified. The statement A <- A .OR. X gives rise to the statement CALL #BOR(A,A,X); in the simulator. When this latter statement is executed, the contents of register X

are or-ed bit-by-bit with the contents of register A and the result is stored back in register A. If the two register operands are not the same length an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure BA#D is invoked whenever a binary-and operation is specified. The statement A <- A .AND. X gives rise to the statement CALL BA#D(A,A,X); in the simulator. When this latter statement is executed, the contents of register X are and-ed bit-by-bit with the contents of register A and the result is stored back in register A. If the two register operands are not the same length an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure BX#R is invoked whenever an exclusive-or operation is specified. The statement A <- A .XOR. X gives rise to the statement CALL BX#R(A,A,X); in the simulator. When this latter statement is executed, the contents of register X are exclusive-or-ed bit-by-bit with the contents of register A and the result is stored back in register A. If the two register operands are not the same length an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure BS#L is invoked whenever a multiple shift left operation is specified. The statement A <- X .SHL. 4

gives rise to the statement CALL BS#L(A,X,4); in the simulator. When this latter statement is executed, the contents of register X are transferred to register A shifted four bit positions to the left. The contents of register X are unaltered by this operation. If the two registers involved in this transfer operation are not the same length an error message will be printed during the simulation run indicating an invalid operation has been performed.

The procedure BS#R is invoked whenever a multiple shift right operation is specified. This procedure is analogous to the procedure which implements the multiple shift left operation.

CONCLUSIONS

Work on the BAPSIM programming system has demonstrated the possibility of developing a means for specifying and simulating the behavior of digital machines. In addition, the successful application of the techniques used in implementing the simulation system suggests that the case for special purpose programming languages and their associated language processors may be stronger than previously thought.

The main advantage of special purpose languages, that a language tailored to a certain class of problems is easier to learn and use than a general purpose programming language, has been recognized for some time. The main disadvantage, that a special purpose language processor must be provided along with every special purpose language if it is to have any practical application, has been known for an equally long time. And it is the time and effort required to provide the language processor that have been deciding negative factors in most decisions regarding the development of special purpose programming systems.

The work done in developing the BAPSIM simulation system has shown that the development of special purpose language processors need not be the expensive, time-consuming, often ad hoc procedure it has been in the past. Use of the meta-

language employed in the definition of the BAPSIM language together with the method of syntactic functions results in a straightforward, clearly defined technique for developing the language processor. In fact, if the language processor is written in a high level programming language with symbol manipulation capabilities, development of the processor will probably no longer be the most time consuming part of the development of a special purpose programming system. Using the BAPSIM simulation system as an example, it is the language definition phase of the development procedure which will require the most attention and time. The reason for this, of course, is that there now exists no algorithmic procedure for use in the definition of a language. And until there exists such a procedure, languages will continue to be developed in a trial and error, iterate and correct manner.

The BAPSIM simulation language was developed in just such a way. The work of others in the field of computer description languages was examined and their results used as a starting point. Features common to all previous efforts were extracted and formalized into a machine-readable notation. Additional language elements were included as dictated by the fact that the end result was to be a computer description language to be used in the simulation of machine behavior. An attempt was then made to describe a simple machine (TELCOMP) in the language. Language deficiencies were noted

and appropriate additions and corrections were made. The updated version of the language was then applied to a more complex machine (Bartee, Lebow, and Reed, Chapter 9). Inadequacies in the language were again observed and corrective measures were taken. This trial and error, design and analyze technique was continued through two more machines, the Fabri-Tek Bi-Tran Six and the Digital Equipment Corporation PDP-8. The BAPSIM language and translator have been tested on all four of the above mentioned machines. Numerous machine language programs were run and checked for each of these machines in the process of debugging the translator and the simulators which it constructs. The simulation system has proven itself capable of describing and simulating general purpose digital processors of sufficient complexity to justify its development and to attract the attention of students of computer design.

The BAPSIM simulation system has also demonstrated the advantages to be gained by the use of higher level programming languages in the development of special purpose programming systems. Systems programs -- compilers, translators, monitors, and the like -- need no longer be written in assembly language. Current high level languages, such as PL/1, provide the systems programmer with virtually all of the manipulative power available to the user of assembly languages and in a form which is easier to utilize. The result

is a decrease in the time required to write and debug the systems program involved.

In the case of special purpose language translators, generating "object" code in a higher level language also has demonstrated merit. The most obvious advantage such a technique has to offer is that a processor for the generated code already exists and need not be written. The associated disadvantage, of course, is that an existing general purpose processor for the generated code is probably not as efficient as a special purpose processor written specifically for the generated code. For translators which do not generate large quantities of "object" code, such as the BAPSIM translator, use of an existing compiler is to be preferred.

Any answer to the question of efficiency in the processing of the generated "object" code must also take into account the availability of extremely fast compilers for existing high level programming languages. All (except the best systems programmers) who have at their command the use of a high level compiler such as the WATFOR or WATFIV FORTRAN compilers or the Cornell PL/1 compiler would be ill-advised to overlook the possibility of including one of these general purpose language processors in their special purpose programming systems. The best systems programmers, of course, will write special purpose language processors which are capable

of directly generating executable code, thereby eliminating the need for the second processor.

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APPENDICES

Appendix 1. The BAPSIM Syntax

```
/* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPA1010
/*                                                                   */APPA1020
/*                    THE  'BAPSIM'  SYNTAX                          */APPA1030
/*                                                                   */APPA1040
/* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPA1050
                                                                      APPA1060
                                                                      APPA1070
PROGRAM  =  SIMULATION_BLOCK                                          APPA1080
SIMULATION_BLOCK  =  'SIMULATION'  STRUCTURE_BLOCK                    APPA1090
                     BEHAVIOR_BLOCK  IN_OUT_BLOCK                     APPA1100
                     'END SIMULATION'                                 APPA1110
STRUCTURE_BLOCK  =  'DECLARE'  DECLARATION_STMT                       APPA1120
                    $ ( ';'  DECLARATION_STMT )  'END DECLARE'        APPA1130
BEHAVIOR_BLOCK  =  FETCH_BLOCK  DECODE_BLOCK  EXECUTE_BLOCK           APPA1140
FETCH_BLOCK  =  'FETCH'  SIMPLE_SEQUENCE  'END FETCH'                 APPA1150
SIMPLE_SEQUENCE  =  SIMPLE_STMT  $ ( ','  SIMPLE_STMT )              APPA1160
DECODE_BLOCK  =  'DECODE'  SIMPLE_SEQUENCE  'END DECODE'              APPA1170
EXECUTE_BLOCK  =  'EXECUTE'  COMPOUND_STMT                            APPA1180
                  $ ( ';'  COMPOUND_STMT )  'END EXECUTE'             APPA1190
IN_OUT_BLOCK  =  INITIALIZATION_STMT  MONITOR_STMT                    APPA1200
INITIALIZATION_STMT  =  'INITIALIZE'  .ID  $ ( ','  .ID )           APPA1210
MONITOR_STMT  =  'MONITOR'  .ID  $ ( ','  .ID )                      APPA1220
DECLARATION_STMT  =  REGISTER_DCL | SUBREGISTER_DCL |                 APPA1230
                     MEMORY_DCL | TERMINAL_DCL | CONSTANT_DCL |      APPA1240
                     OPERATION_DCL                                    APPA1250
REGISTER_DCL  =  'REGISTER'  REGISTER_ID  $ ( ',' REGISTER_ID )       APPA1260
REGISTER_ID  =  .ID  ( '('  .INT  '-'  .INT  ')' | .EMPTY )          APPA1270
SUBREGISTER_DCL  =  'SUBREGISTER'  SREXP  $ ( ',' SREXP )             APPA1280
SREXP  =  .ID  '('  .ID  ')'  '='  .ID  '('  .INT                     APPA1290
          ( ')' | '-'  .INT  ')'  )                                   APPA1300
MEMORY_DCL  =  'MEMORY'  MEMEXP  $ ( ','  MEMEXP )                   APPA1310
MEMEXP  =  MEMLHS  '='  MEMRHS                                        APPA1320
MEMLHS  =  .ID  '('  .ID  ( ')' | '('  .ID  ')'  ')'  )      *        APPA1330
MEMRHS  =  .ID  '('  .INT  '-'  .INT  ','  .INT  '-'  .INT  ')'      APPA1340
TERMINAL_DCL = 'TERMINAL' REGISTER_ID  $ ( ','  REGISTER_ID )        APPA1350
CONSTANT_DCL  =  'CONSTANT' CONSEXP  $ ( ','  CONSEXP )              APPA1360
CONSEXP  =  .ID  '='  .INT                                            APPA1370
OPERATION_DCL  =  'OPERATION'  .ID  $ ( ','  .ID )                   APPA1380
```

```
COMPOUND_STMT  =  .ID  ':'  SIMPLE_STMT  $ ( ',' SIMPLE_STMT )  APPA1390
SIMPLE_STMT = ( DO_STMT | IF_STMT | GO_TO_STMT | TRANSFER_STMT  APPA1400
              TERMINAL_STMT )  ( '<' .INT '>' | .EMPTY )       APPA1410
DO_STMT  =  'DO'  .ID                                          APPA1420
IF_STMT  =  'IF'  CONDITION  'THEN'  SIMPLE_STMT               APPA1430
CONDITION  =  '('  BOOLEAN_TERM  ')'                          APPA1440
BOOLEAN_TERM  =  BOOLEAN_FACTOR  $ ( '.OR.'  BOOLEAN_FACTOR )  APPA1450
BOOLEAN_FACTOR  =  BOOLEAN_SEC  $ ( '.AND.'  BOOLEAN_SEC )     APPA1460
BOOLEAN_SEC  =  ( '.NOT.' | .EMPTY )  BOOLEAN_PRIM             APPA1470
BOOLEAN_PRIM = LOGICAL_VALUE | RELATION | '(' BOOLEAN_TERM ')' APPA1480
RELATION  =  SAE  ( REL_OP  SAE | .EMPTY )                     APPA1490
REL_OP  =  '.EQ.' | '.NE.' | '.LT.' | '.GT.' | '.LE.' | '.GE.' APPA1500
SAE  =  .INT | DEST                                            APPA1510
LOGICAL_VALUE  =  '.TRUE.' | '.FALSE.'                         APPA1520
GO_TO_STMT  =  'GO TO'  .ID                                    APPA1530
TRANSFER_STMT  =  DEST  '<-'  ( .INT | UNARY_EXP | BINARY_EXP )APPA1540
DEST          =.ID('('(.ID ')'|.INT(')'|'-' .INT ')'))|.EMPTY) APPA1550
UNARY_EXP  =  UNARY_OP  UNARY_SOURCE                           APPA1560
UNARY_OP  =  '.AND.' | '.OR.' | '.NOT.' | '.SHL.' | '.SHR.' |  APPA1570
             '.CIRL.' | '.CIRR.'                               APPA1580
UNARY_SOURCE=.ID('('(.ID ')'|.INT(')'|'-' .INT ')'))|.EMPTY)   APPA1590
BINARY_EXP  =  OP1  ( BINARY_OP  ( OP2 | .INT ) | .EMPTY )     APPA1600
BINARY_OP  =  '.ADD.' | '.SUB.' | '.OR.' | '.AND.' | '.XOR.' |  APPA1610
              '.SHL.' | '.SHR.' | '.CNT.'                      APPA1620
OP1           =.ID('('(.ID ')'|.INT(')'|'-' .INT ')'))|.EMPTY) APPA1630
OP2           =.ID('('(.ID ')'|.INT(')'|'-' .INT ')'))|.EMPTY) APPA1640
TERMINAL_STMT  =  TERMINAL  ':='  LABEL                        APPA1650
TERMINAL  =  .ID  ( '(' .INT ')' | .EMPTY )                    APPA1660
LABEL  =  TERM  $ ( BOP  TERM )                                APPA1670
TERM  =  DEF1 | DEF2                                           APPA1680
DEF1  =  .ID  ( '(' .INT ')' | .EMPTY )                        APPA1690
DEF2  =  '('  '¬'  DEF1  ')'                                   APPA1700
BOP  =  '*' | '+'                                              APPA1710
```

Appendix 2. A Sample Program

```
*                                                                          APPB1010
*                                                                          APPB1020
 SIMULATION                                                               APPB1030
*                                                                          APPB1040
*                                                                          APPB1050
*                    TELCOMP  SIMULATION  STUDY                            APPB1060
*                                                                          APPB1070
*                                                                          APPB1080
 DECLARE                                                                  APPB1090
         REGISTER  LC(0-5),MAR(0-5),XR(0-8),AC1(0-8),AC2(0-8),            APPB1100
                   IR(0-2),SR;                                            APPB1110
         SUBREGISTER   XR(OP) = XR(0-2),   XR(ADDR) = XR( 3 - 8 );        APPB1120
         MEMORY    M(MAR)  =  M(0-63,0-8)                                 APPB1130
 END DECLARE                                                              APPB1140
*                                                                          APPB1150
*                                                                          APPB1160
 FETCH                                                                    APPB1170
                   MAR  <-  LC,                                           APPB1180
                   XR  <-  M(MAR),                                        APPB1190
                   IR  <-  OP,                                            APPB1200
                   MAR  <-  ADDR,                                         APPB1210
                   LC <- LC  .ADD.  1                                     APPB1220
 END FETCH                                                                APPB1230
*                                                                          APPB1240
*                                                                          APPB1250
 DECODE                                                                   APPB1260
         IF (  IR  .EQ.  0  )  THEN  GO TO ADD,                           APPB1270
         IF (  IR  .EQ.  1  )  THEN  GO TO SUB,                           APPB1280
         IF (  IR  .EQ.  2  )  THEN  GO TO SRO,                           APPB1290
         IF (  IR  .EQ.  3  )  THEN  GO TO TRU,                           APPB1300
         IF (  IR  .EQ.  4  )  THEN  GO TO TRN,                           APPB1310
         IF (  IR  .EQ.  5  )  THEN  GO TO STA,                           APPB1320
         IF (  IR  .EQ.  6  )  THEN  GO TO CLA,                           APPB1330
         IF (  IR  .EQ.  7  )  THEN  GO TO STP                            APPB1340
 END DECODE                                                               APPB1350
*                                                                          APPB1360
*                                                                          APPB1370
 EXECUTE                                                                  APPB1380
```

```
    ADD:  XR  <-  M(MAR),                                                    APPB1390
          AC2  <-  XR  .ADD.  AC1,                                           APPB1400
          AC1  <-  AC2;                                                      APPB1410
    SUB:   XR  <-  M(MAR),                                                   APPB1420
          XR  <-  .NOT.  XR,                                                 APPB1430
          AC2  <-  XR  .ADD.  AC1,                                           APPB1440
          XR  <-  1,                                                         APPB1450
          AC1  <-  AC2,                                                      APPB1460
          AC2 <-  XR  .ADD.  AC1,                                            APPB1470
          AC1  <-  AC2;                                                      APPB1480
    SRO:   XR  <- 0,                                                         APPB1490
          AC2  <-  XR  .ADD.  AC1,                                           APPB1500
          AC1  <-  .SHR.  AC2;                                               APPB1510
    TRU:   LC  <-  MAR;                                                      APPB1520
    TRN:   IF ( AC1(0)  .EQ.  1  )  THEN  LC  <-  MAR;                       APPB1530
    STA:   XR  <-  AC1,                                                      APPB1540
          M(MAR)  <-  XR;                                                    APPB1550
    CLA:   AC1  <-  0;                                                       APPB1560
    STP:   SR  <-  0,  GO  TO  STOP                                          APPB1570
 END EXECUTE                                                                 APPB1580
*                                                                            APPB1590
*                                                                            APPB1600
 INITIALIZE          LC,M,IR,MAR,XR,AC1,AC2                                  APPB1610
*                                                                            APPB1620
 MONITOR             LC,IR,MAR,XR,AC1,AC2                                    APPB1630
*                                                                            APPB1640
*                                                                            APPB1650
 END SIMULATION                                                              APPB1660
```

Appendix 3. The Syntax Analyzer

```
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPC1010
        /*                                                               */APPC1020
        /*       THIS  IS  THE  'BAPSIM'  ANALYZER  IN  PL/1             */APPC1030
        /*                                                               */APPC1040
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPC1050
                                                                          APPC1060
                                                                          APPC1070
(SIZE,SUBSCRIPTRANGE,STRINGRANGE):    /*     CONDITION  ENABLING       */APPC1080
COMPILE:PROC  OPTIONS(MAIN);                                              APPC1090
                                                                          APPC1100
                                                                          APPC1110
DECLARE                                                                   APPC1120
        CARD  CHAR(80),  C(80)  CHAR(1)  DEF  CARD,                       APPC1130
        I  FIXED BINARY(31),          /*   TEXT  POINTER   */           APPC1140
        J  FIXED BINARY(31)  INITIAL(0),   /*  STATEMENT  COUNTER  */     APPC1150
        SYMBOL  CHAR(32) VARYING,                                         APPC1160
                                                                          APPC1170
                                                                          APPC1180
        /*  THE  PRIMITIVE PROCEDURES ARE DECLARED NEXT  */               APPC1190
                                                                          APPC1200
                                                                          APPC1210
        LITERAL              ENTRY( CHAR(*) )    RETURNS( BIT(1) ),       APPC1220
        ID                   ENTRY               RETURNS( BIT(1) ),       APPC1230
        INT                  ENTRY               RETURNS( BIT(1) ),       APPC1240
        ERROR                ENTRY,                                       APPC1250
                                                                          APPC1260
                                                                          APPC1270
        /*  THE DEFINED PROCEDURES ARE DECLARED NEXT  */                  APPC1280
                                                                          APPC1290
        PROGRAM              ENTRY     RETURNS( BIT(1) ),                 APPC1300
        SIMULATION_BLOCK     ENTRY     RETURNS( BIT(1) ),                 APPC1310
        STRUCTURE_BLOCK      ENTRY     RETURNS( BIT(1) ),                 APPC1320
        BEHAVIOR_BLOCK       ENTRY     RETURNS( BIT(1) ),                 APPC1330
        FETCH_BLOCK          ENTRY     RETURNS( BIT(1) ),                 APPC1340
        SIMPLE_SEQUENCE      ENTRY     RETURNS( BIT(1) ),                 APPC1350
        DECODE_BLOCK         ENTRY     RETURNS( BIT(1) ),                 APPC1360
        EXECUTE_BLOCK        ENTRY     RETURNS( BIT(1) ),                 APPC1370
        IN_OUT_BLOCK         ENTRY     RETURNS( BIT(1) ),                 APPC1380
```

```
INITIALIZATION_STMT  ENTRY     RETURNS( BIT(1) ),          APPC1390
MONITOR_STMT         ENTRY     RETURNS( BIT(1) ),          APPC1400
DECLARATION_STMT     ENTRY     RETURNS( BIT(1) ),          APPC1410
REGISTER_DCL         ENTRY     RETURNS( BIT(1) ),          APPC1420
REGISTER_ID          ENTRY     RETURNS( BIT(1) ),          APPC1430
SUBREGISTER_DCL      ENTRY     RETURNS( BIT(1) ),          APPC1440
SREXP                ENTRY     RETURNS( BIT(1) ),          APPC1450
MEMORY_DCL           ENTRY     RETURNS( BIT(1) ),          APPC1460
MEMEXP               ENTRY     RETURNS( BIT(1) ),          APPC1470
MEMLHS               ENTRY     RETURNS( BIT(1) ),          APPC1480
MEMRHS               ENTRY     RETURNS( BIT(1) ),          APPC1490
TERMINAL_DCL         ENTRY     RETURNS( BIT(1) ),          APPC1500
CONSTANT_DCL         ENTRY     RETURNS( BIT(1) ),          APPC1510
CONSEXP              ENTRY     RETURNS( BIT(1) ),          APPC1520
OPERATION_DCL        ENTRY     RETURNS( BIT(1) ),          APPC1530
COMPOUND_STMT        ENTRY     RETURNS( BIT(1) ),          APPC1540
SIMPLE_STMT          ENTRY     RETURNS( BIT(1) ),          APPC1550
DO_STMT              ENTRY     RETURNS( BIT(1) ),          APPC1560
IF_STMT              ENTRY     RETURNS( BIT(1) ),          APPC1570
CONDITION            ENTRY     RETURNS( BIT(1) ),          APPC1580
BOOLEAN_TERM         ENTRY     RETURNS( BIT(1) ),          APPC1590
BOOLEAN_FACTOR       ENTRY     RETURNS( BIT(1) ),          APPC1600
BOOLEAN_SEC          ENTRY     RETURNS( BIT(1) ),          APPC1610
BOOLEAN_PRIM         ENTRY     RETURNS( BIT(1) ),          APPC1620
RELATION             ENTRY     RETURNS( BIT(1) ),          APPC1630
REL_OP               ENTRY     RETURNS( BIT(1) ),          APPC1640
SAE                  ENTRY     RETURNS( BIT(1) ),          APPC1650
LOGICAL_VALUE        ENTRY     RETURNS( BIT(1) ),          APPC1660
GO_TO_STMT           ENTRY     RETURNS( BIT(1) ),          APPC1670
TRANSFER_STMT        ENTRY     RETURNS( BIT(1) ),          APPC1680
DEST                 ENTRY     RETURNS( BIT(1) ),          APPC1690
UNARY_EXP            ENTRY     RETURNS( BIT(1) ),          APPC1700
UNARY_OP             ENTRY     RETURNS( BIT(1) ),          APPC1710
UNARY_SOURCE         ENTRY     RETURNS( BIT(1) ),          APPC1720
BINARY_EXP           ENTRY     RETURNS( BIT(1) ),          APPC1730
BINARY_OP            ENTRY     RETURNS( BIT(1) ),          APPC1740
OP1                  ENTRY     RETURNS( BIT(1) ),          APPC1750
OP2                  ENTRY     RETURNS( BIT(1) ),          APPC1760
```

```
        TERMINAL_STMT          ENTRY     RETURNS( BIT(1) ),                  APPC1770
        TERMINAL               ENTRY     RETURNS( BIT(1) ),                  APPC1780
        LABEL                  ENTRY     RETURNS( BIT(1) ),                  APPC1790
        TERM                   ENTRY     RETURNS( BIT(1) ),                  APPC1800
        DEF1                   ENTRY     RETURNS( BIT(1) ),                  APPC1810
        DEF2                   ENTRY     RETURNS( BIT(1) ),                  APPC1820
        BOP                    ENTRY     RETURNS( BIT(1) ),                  APPC1830
        DUMMY     FIXED BINARY(15);   /* HAS THE ';' TO END DCL'S */          APPC1840
        /*  THIS IS THE END OF THE DECLARATIONS  */                           APPC1850
                                                                             APPC1860
                                                                             APPC1870
ON CONDITION(EOC)              /*  END-OF-CARD CONDITION  */                 APPC1880
   BEGIN;     L1: GET EDIT( CARD )  ( A(80) );                               APPC1890
                  IF C(1)='*' THEN DO; PUT EDIT(CARD)(COL(50),A(80));        APPC1900
                                       GO TO L1;                             APPC1910
                                  END;                                       APPC1920
                  J = J + 1;          /* INCREMENT STATEMENT COUNTER */      APPC1930
                  PUT EDIT( J,CARD ) ( COL(44),F(3),COL(50),A(80) );         APPC1940
                  I = 1;    /*  RESET  TEXT  POINTER  */                    APPC1950
   END;                                                                      APPC1960
                                                                             APPC1970
        /*  THE MAIN PART OF THE PROGRAM FOLLOWS IMMEDIATELY.  */            APPC1980
                                                                             APPC1990
ON ENDFILE( SYSIN )  GO TO FINIS;                                            APPC2000
PUT EDIT( 'RUN OF THE BAPSIM  ANALYZER ' ) (COL(60),A);   /* HEADING */     APPC2010
PUT SKIP(5);                                                                 APPC2020
SIGNAL CONDITION( EOC );    /* GET THE FIRST CARD */                         APPC2030
                                                                             APPC2040
                                                                             APPC2050
IF PROGRAM THEN PUT EDIT('NORMAL ANALYZER EXIT')(SKIP(2),COL(10),A);         APPC2060
           ELSE PUT EDIT('NO PROGRAM SUPPLIED')(SKIP(2),COL(10),A);          APPC2070
                                                                             APPC2080
                                                                             APPC2090
GO TO DONE;                                                                  APPC2100
                                                                             APPC2110
                                                                             APPC2120
                                                                             APPC2130
                                                                             APPC2140
```

```
        /* THE PROCEDURES APPEAR BELOW - PRIMITIVE PROCEDURES FIRST */ APPC2150
                                                                       APPC2160
                                                                       APPC2170
LITERAL: PROC( S )      RETURNS(  BIT(1)  );                           APPC2180
         DCL  S  CHAR(*);                                              APPC2190
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                      APPC2200
         DO WHILE( C(I)=' ' );       I = I + 1;                        APPC2210
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                      APPC2220
         END;                                                          APPC2230
         IF  I+LENGTH(S)>81  THEN  RETURN( '0'B );                     APPC2240
         IF  SUBSTR(CARD,I,LENGTH(S))=S  THEN  DO;                     APPC2250
         I = I + LENGTH(S); RETURN ('1'B );     END;                   APPC2260
         RETURN( '0'B );                                               APPC2270
END LITERAL;                                                           APPC2280
                                                                       APPC2290
                                                                       APPC2300
     ID: PROC           RETURNS(  BIT(1)  );                          APPC2310
        DCL       J          FIXED BINARY(31);                        APPC2320
        IF  I>80  THEN  SIGNAL CONDITION( EOC );                       APPC2330
         DO WHILE( C(I)=' ' );  I = I + 1;                             APPC2340
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                      APPC2350
         END;                                                          APPC2360
         IF  C(I)>'Z' | C(I)<'A'  THEN  RETURN( '0'B );                APPC2370
         DO J=I+1 BY 1 WHILE( C(J)>='A' );  END;                       APPC2380
         SYMBOL = SUBSTR( CARD,I,J-I );  I = J;                        APPC2390
IF LENGTH(SYMBOL)>8 THEN SYMBOL=SUBSTR(SYMBOL,1,4)||                   APPC2400
                                SUBSTR(SYMBOL,LENGTH(SYMBOL)-3,4);     APPC2410
         RETURN( '1'B );                                               APPC2420
     END ID;                                                           APPC2430
                                                                       APPC2440
                                                                       APPC2450
    INT: PROC           RETURNS(  BIT(1)  );                           APPC2460
        DCL       J          FIXED BINARY(31);                        APPC2470
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                      APPC2480
         DO WHILE( C(I)=' ' );  I = I + 1;                             APPC2490
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                      APPC2500
         END;                                                          APPC2510
         IF  C(I)>='0'  THEN  DO;                                      APPC2520
```

```
         DO J=I+1 BY 1 WHILE( C(J)>='0' );  END;                          APPC2530
         SYMBOL = SUBSTR( CARD,I,J-I );  I = J;                           APPC2540
         RETURN( '1'B );       END;                                       APPC2550
         RETURN( '0'B );                                                  APPC2560
    END INT;                                                              APPC2570
                                                                          APPC2580
                                                                          APPC2590
  ERROR: PROC;                                                            APPC2600
         PUT EDIT( '*** ERROR AT $ ***','$' )(COL(1),A,COL(I+49),A);      APPC2610
         PUT EDIT( 'RECOVERY NOT POSSIBLE  --  COMPILATION ABORTED' )     APPC2620
                ( SKIP(2),COL(1),A );                                     APPC2630
         CLOSE FILE( SYSPRINT );                                          APPC2640
         STOP;                                                            APPC2650
  END ERROR;                                                              APPC2660
                                                                          APPC2670
                                                                          APPC2680
                                                                          APPC2690
                                                                          APPC2700
       /*  THE NON-PRIMITIVE PROCEDURES APPEAR NEXT  */                   APPC2710
                                                                          APPC2720
                                                                          APPC2730
PROGRAM: PROC                          RETURNS ( BIT(1) );                APPC2740
       IF  ¬SIMULATION_BLOCK  THEN  RETURN('0'B);                         APPC2750
       RETURN ('1'B);                                                     APPC2760
END PROGRAM;                                                              APPC2770
                                                                          APPC2780
SIMULATION_BLOCK: PROC                 RETURNS( BIT(1) );                 APPC2790
       IF  ¬LITERAL('SIMULATION')  THEN  RETURN('0'B);                    APPC2800
       IF  ¬STRUCTURE_BLOCK  THEN  CALL ERROR;                            APPC2810
       IF  ¬BEHAVIOR_BLOCK  THEN  CALL ERROR;                             APPC2820
       IF  ¬IN_OUT_BLOCK  THEN  CALL ERROR;                               APPC2830
       IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                           APPC2840
       IF  ¬LITERAL( 'SIMULATION' )  THEN  CALL ERROR;                    APPC2850
       RETURN( '1'B);                                                     APPC2860
END SIMULATION_BLOCK;                                                     APPC2870
                                                                          APPC2880
STRUCTURE_BLOCK:PROC                   RETURNS( BIT(1) );                 APPC2890
       IF  ¬LITERAL('DECLARE')  THEN  RETURN( '0'B);                      APPC2900
```

```
        IF  ¬DECLARATION_STMT  THEN  CALL ERROR;                    APPC2910
        DO   WHILE(LITERAL(';') );                                  APPC2920
             IF  ¬DECLARATION_STMT  THEN  CALL ERROR;               APPC2930
             END;                                                   APPC2940
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                    APPC2950
        IF  ¬LITERAL( 'DECLARE' )  THEN  CALL ERROR;                APPC2960
        RETURN( '1'B);                                              APPC2970
END STRUCTURE_BLOCK;                                                APPC2980
                                                                    APPC2990
BEHAVIOR_BLOCK: PROC                    RETURNS( BIT(1) );          APPC3000
        IF  ¬FETCH_BLOCK  THEN  RETURN( '0'B );                     APPC3010
        IF  ¬DECODE_BLOCK  THEN  CALL ERROR;                        APPC3020
        IF  ¬EXECUTE_BLOCK  THEN  CALL ERROR;                       APPC3030
        RETURN( '1'B );                                             APPC3040
END BEHAVIOR_BLOCK;                                                 APPC3050
                                                                    APPC3060
FETCH_BLOCK: PROC                       RETURNS( BIT(1) );          APPC3070
        IF  ¬LITERAL('FETCH')  THEN  RETURN( '0'B );                APPC3080
        IF  ¬SIMPLE_SEQUENCE  THEN  CALL ERROR;                     APPC3090
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                    APPC3100
        IF  ¬LITERAL( 'FETCH' )  THEN  CALL ERROR;                  APPC3110
        RETURN( '1'B );                                             APPC3120
END FETCH_BLOCK;                                                    APPC3130
                                                                    APPC3140
SIMPLE_SEQUENCE: PROC                   RETURNS( BIT(1) );          APPC3150
        IF  ¬SIMPLE_STMT  THEN  RETURN( '0'B );                     APPC3160
        DO WHILE( LITERAL(',') );                                   APPC3170
             IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                    APPC3180
             END;                                                   APPC3190
        RETURN( '1'B );                                             APPC3200
END SIMPLE_SEQUENCE;                                                APPC3210
                                                                    APPC3220
DECODE_BLOCK: PROC                      RETURNS( BIT(1) );          APPC3230
        IF  ¬LITERAL('DECODE')  THEN  RETURN( '0'B );               APPC3240
        IF  ¬SIMPLE_SEQUENCE  THEN  CALL ERROR;                     APPC3250
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                    APPC3260
        IF  ¬LITERAL( 'DECODE' )  THEN  CALL ERROR;                 APPC3270
        RETURN( '1'B );                                             APPC3280
```

```
END DECODE_BLOCK;                                                    APPC3290
                                                                     APPC3300
EXECUTE_BLOCK: PROC                        RETURNS( BIT(1) );        APPC3310
        IF  ¬LITERAL( 'EXECUTE' )  THEN  RETURN( '0'B);              APPC3320
        IF  ¬COMPOUND_STMT  THEN  CALL ERROR;                        APPC3330
        DO WHILE( LITERAL(';') );                                    APPC3340
             IF  ¬COMPOUND_STMT  THEN  CALL ERROR;                   APPC3350
             END;                                                    APPC3360
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                     APPC3370
        IF  ¬LITERAL( 'EXECUTE' )  THEN  CALL ERROR;                 APPC3380
        RETURN('1'B);                                                APPC3390
END EXECUTE_BLOCK;                                                   APPC3400
                                                                     APPC3410
IN_OUT_BLOCK: PROC                         RETURNS( BIT(1) );        APPC3420
        IF  ¬INITIALIZATION_STMT  THEN  RETURN( '0'B);               APPC3430
        IF  ¬MONITOR_STMT  THEN  CALL ERROR;                         APPC3440
        RETURN( '1'B);                                               APPC3450
END IN_OUT_BLOCK;                                                    APPC3460
                                                                     APPC3470
INITIALIZATION_STMT: PROC                  RETURNS( BIT(1) );        APPC3480
        IF  ¬LITERAL('INITIALIZE')  THEN  RETURN( '0'B);             APPC3490
        IF  ¬ID  THEN  CALL ERROR;                                   APPC3500
        DO WHILE(LITERAL(',') );                                     APPC3510
             IF  ¬ID  THEN  CALL ERROR;                              APPC3520
             END;                                                    APPC3530
        RETURN('1'B);                                                APPC3540
END INITIALIZATION_STMT;                                             APPC3550
                                                                     APPC3560
MONITOR_STMT: PROC                         RETURNS(BIT(1) );         APPC3570
        IF  ¬LITERAL( 'MONITOR')  THEN  RETURN('0'B);                APPC3580
        IF  ¬ID  THEN  CALL ERROR;                                   APPC3590
        DO WHILE(LITERAL(',') );                                     APPC3600
             IF  ¬ID  THEN  CALL ERROR;                              APPC3610
             END;                                                    APPC3620
        RETURN('1'B);                                                APPC3630
END MONITOR_STMT;                                                    APPC3640
                                                                     APPC3650
                                                                     APPC3660
```

```
DECLARATION_STMT:  PROC                    RETURNS( BIT(1) );          APPC3670
        IF  REGISTER_DCL      THEN  GO TO L1;                          APPC3680
        IF  SUBREGISTER_DCL   THEN  GO TO L1;                          APPC3690
        IF  MEMORY_DCL        THEN  GO TO L1;                          APPC3700
        IF  TERMINAL_DCL      THEN  GO TO L1;                          APPC3710
        IF  CONSTANT_DCL      THEN  GO TO L1;                          APPC3720
        IF  OPERATION_DCL     THEN  GO TO L1;                          APPC3730
        RETURN( '0'B );                                                APPC3740
    L1: RETURN( '1'B );                                                APPC3750
END DECLARATION_STMT;                                                  APPC3760
                                                                       APPC3770
REGISTER_DCL:  PROC                        RETURNS( BIT(1) );          APPC3780
        IF  ¬LITERAL('REGISTER')  THEN  RETURN( '0'B );                APPC3790
        IF  ¬REGISTER_ID  THEN  CALL ERROR;                            APPC3800
        DO WHILE( LITERAL(',') );                                      APPC3810
             IF  ¬REGISTER_ID  THEN  CALL ERROR;                       APPC3820
             END;                                                      APPC3830
        RETURN( '1'B );                                                APPC3840
END REGISTER_DCL;                                                      APPC3850
                                                                       APPC3860
REGISTER_ID:  PROC                         RETURNS( BIT(1) );          APPC3870
        IF  ¬ID  THEN  RETURN( '0'B );                                 APPC3880
        IF  ¬LITERAL( '(' )  THEN  DO;                                 APPC3890
                  RETURN( '1'B );  END;                                APPC3900
        IF  ¬INT  THEN  CALL ERROR;                                    APPC3910
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                         APPC3920
        IF  ¬INT  THEN  CALL ERROR;                                    APPC3930
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                         APPC3940
        RETURN( '1'B );                                                APPC3950
END REGISTER_ID;                                                       APPC3960
                                                                       APPC3970
SUBREGISTER_DCL:  PROC                     RETURNS( BIT(1) );          APPC3980
        IF  ¬LITERAL('SUBREGISTER')  THEN  RETURN( '0'B );             APPC3990
        IF  ¬SREXP  THEN  CALL ERROR;                                  APPC4000
        DO WHILE( LITERAL(',') );                                      APPC4010
             IF  ¬SREXP  THEN  CALL ERROR;                             APPC4020
             END;                                                      APPC4030
        RETURN( '1'B );                                                APPC4040
```

```
END SUBREGISTER_DCL;                                                    APPC4050
                                                                        APPC4060
SREXP:  PROC                              RETURNS( BIT(1) );            APPC4070
        IF  ¬ID  THEN  RETURN( '0'B );                                  APPC4080
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                          APPC4090
        IF  ¬ID  THEN  CALL ERROR;                                      APPC4100
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPC4110
        IF  ¬LITERAL( '=' )  THEN  CALL ERROR;                          APPC4120
        IF  ¬ID  THEN  CALL ERROR;                                      APPC4130
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                          APPC4140
        IF  ¬INT  THEN  CALL ERROR;                                     APPC4150
        IF  LITERAL( ')' )  THEN  DO;  RETURN( '1'B );  END;            APPC4160
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                          APPC4170
        IF  ¬INT  THEN  CALL ERROR;                                     APPC4180
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPC4190
        RETURN( '1'B );                                                 APPC4200
END SREXP;                                                              APPC4210
                                                                        APPC4220
MEMORY_DCL:  PROC                         RETURNS( BIT(1) );            APPC4230
        IF  ¬LITERAL('MEMORY')  THEN  RETURN( '0'B );                   APPC4240
        IF  ¬MEMEXP  THEN  CALL ERROR;                                  APPC4250
        DO WHILE( LITERAL(',') );                                       APPC4260
             IF  ¬MEMEXP  THEN  CALL ERROR;                             APPC4270
             END;                                                       APPC4280
        RETURN( '1'B );                                                 APPC4290
END MEMORY_DCL;                                                         APPC4300
                                                                        APPC4310
MEMEXP:  PROC                             RETURNS( BIT(1) );            APPC4320
        IF  ¬MEMLHS  THEN  RETURN( '0'B );                              APPC4330
        IF  ¬LITERAL( '=' )  THEN  CALL ERROR;                          APPC4340
        IF  ¬MEMRHS  THEN  CALL ERROR;                                  APPC4350
        RETURN( '1'B );                                                 APPC4360
END MEMEXP;                                                             APPC4370
                                                                        APPC4380
MEMLHS:  PROC                             RETURNS( BIT(1) );            APPC4390
        IF  ¬ID  THEN  RETURN( '0'B );                                  APPC4400
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                          APPC4410
        IF  ¬ID  THEN  CALL ERROR;                                      APPC4420
```

```
        IF  LITERAL( ')' )  THEN  RETURN( '1'B );                    APPC4430
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                       APPC4440
        IF  ¬ID  THEN  CALL ERROR;                                   APPC4450
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                       APPC4460
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                       APPC4470
        RETURN( '1'B );                                              APPC4480
END MEMLHS;                                                          APPC4490
                                                                     APPC4500
MEMRHS:  PROC                              RETURNS( BIT(1) );        APPC4510
        IF  ¬ID  THEN  RETURN( '0'B );                               APPC4520
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                       APPC4530
        IF  ¬INT  THEN  CALL ERROR;                                  APPC4540
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                       APPC4550
        IF  ¬INT  THEN  CALL ERROR;                                  APPC4560
        IF  ¬LITERAL( ',' )  THEN  CALL ERROR;                       APPC4570
        IF  ¬INT  THEN  CALL ERROR;                                  APPC4580
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                       APPC4590
        IF  ¬INT  THEN  CALL ERROR;                                  APPC4600
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                       APPC4610
        RETURN( '1'B );                                              APPC4620
END MEMRHS;                                                          APPC4630
                                                                     APPC4640
TERMINAL_DCL:  PROC                        RETURNS( BIT(1) );        APPC4650
        IF  ¬LITERAL('TERMINAL')  THEN  RETURN( '0'B );              APPC4660
        IF  ¬REGISTER_ID  THEN  CALL ERROR;                          APPC4670
        DO WHILE( LITERAL( ',' ) );                                  APPC4680
             IF  ¬REGISTER_ID  THEN  CALL ERROR;                     APPC4690
             END;                                                    APPC4700
        RETURN( '1'B );                                              APPC4710
END TERMINAL_DCL;                                                    APPC4720
                                                                     APPC4730
CONSTANT_DCL:  PROC                        RETURNS( BIT(1) );        APPC4740
        IF  ¬LITERAL('CONSTANT')  THEN  RETURN( '0'B );              APPC4750
        IF  ¬CONSEXP  THEN  CALL ERROR;                              APPC4760
        DO WHILE( LITERAL(',') );                                    APPC4770
             IF  ¬CONSEXP  THEN  CALL ERROR;                         APPC4780
             END;                                                    APPC4790
        RETURN( '1'B );                                              APPC4800
```

```
END CONSTANT_DCL;                                                    APPC4810
                                                                     APPC4820
CONSEXP:  PROC                              RETURNS( BIT(1) );       APPC4830
        IF  ¬ID  THEN  RETURN( '0'B );                               APPC4840
        IF  ¬LITERAL( '=' )  THEN  CALL ERROR;                       APPC4850
        IF  ¬INT  THEN  CALL ERROR;                                  APPC4860
        RETURN( '1'B );                                              APPC4870
END CONSEXP;                                                         APPC4880
                                                                     APPC4890
OPERATION_DCL:  PROC                        RETURNS( BIT(1) );       APPC4900
        IF  ¬LITERAL('OPERATION')  THEN  RETURN( '0'B );             APPC4910
        IF  ¬ID  THEN  CALL ERROR;                                   APPC4920
        DO WHILE( LITERAL(',') );                                    APPC4930
             IF  ¬ID  THEN  CALL ERROR;                              APPC4940
             END;                                                    APPC4950
        RETURN( '1'B );                                              APPC4960
END OPERATION_DCL;                                                   APPC4970
                                                                     APPC4980
COMPOUND_STMT:  PROC                        RETURNS( BIT(1) );       APPC4990
        IF  ¬ID  THEN  RETURN( '0'B );                               APPC5000
        IF  ¬LITERAL( ':' )  THEN  CALL ERROR;                       APPC5010
        IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                          APPC5020
        DO WHILE( LITERAL(',') );                                    APPC5030
             IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                     APPC5040
             END;                                                    APPC5050
        RETURN( '1'B );                                              APPC5060
END COMPOUND_STMT;                                                   APPC5070
                                                                     APPC5080
SIMPLE_STMT:  PROC          RETURNS( BIT(1) )   RECURSIVE;           APPC5090
        IF  DO_STMT  THEN  GO TO L1;                                 APPC5100
        IF  IF_STMT  THEN  GO TO L1;                                 APPC5110
        IF  GO_TO_STMT  THEN  GO TO L1;                              APPC5120
        IF  TRANSFER_STMT  THEN  GO TO L1;                           APPC5130
        IF  TERMINAL_STMT  THEN  GO TO L1;                           APPC5140
        RETURN( '0'B );                                              APPC5150
   L1:  IF  ¬LITERAL('<')  THEN  GO TO L2;                           APPC5160
        IF  ¬INT  THEN  CALL  ERROR;                                 APPC5170
        IF  ¬LITERAL('>')  THEN  CALL  ERROR;                        APPC5180
```

```
    L2: RETURN( '1'B );                                                    APPC5190
END SIMPLE_STMT;                                                           APPC5200
                                                                           APPC5210
DO_STMT:  PROC                RETURNS( BIT(1) )   RECURSIVE;               APPC5220
        IF  ¬LITERAL('DO')  THEN  RETURN( '0'B );                          APPC5230
        IF  ¬ID  THEN  CALL ERROR;                                         APPC5240
        RETURN( '1'B );                                                    APPC5250
END DO_STMT;                                                               APPC5260
                                                                           APPC5270
IF_STMT:  PROC                RETURNS( BIT(1) )   RECURSIVE;               APPC5280
        IF  ¬LITERAL('IF')  THEN  RETURN( '0'B );                          APPC5290
        IF  ¬CONDITION  THEN  CALL ERROR;                                  APPC5300
        IF  ¬LITERAL('THEN')  THEN  CALL ERROR;                            APPC5310
        IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                                APPC5320
        RETURN( '1'B );                                                    APPC5330
END IF_STMT;                                                               APPC5340
                                                                           APPC5350
CONDITION:  PROC                          RETURNS( BIT(1) );               APPC5360
        IF  ¬LITERAL( '(' )  THEN  RETURN( '0'B );                         APPC5370
        IF  ¬BOOLEAN_TERM  THEN  CALL ERROR;                               APPC5380
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                             APPC5390
        RETURN( '1'B );                                                    APPC5400
END CONDITION;                                                             APPC5410
                                                                           APPC5420
BOOLEAN_TERM:  PROC           RETURNS( BIT(1) )   RECURSIVE;               APPC5430
        IF  ¬BOOLEAN_FACTOR  THEN  RETURN( '0'B );                         APPC5440
        DO WHILE( LITERAL('.OR.') );                                       APPC5450
             IF  ¬BOOLEAN_FACTOR  THEN  CALL ERROR;                        APPC5460
             END;                                                          APPC5470
        RETURN( '1'B );                                                    APPC5480
END BOOLEAN_TERM;                                                          APPC5490
                                                                           APPC5500
BOOLEAN_FACTOR:  PROC         RETURNS( BIT(1) )   RECURSIVE;               APPC5510
        IF  ¬BOOLEAN_SEC  THEN  RETURN( '0'B );                            APPC5520
        DO WHILE( LITERAL('.AND.') );                                      APPC5530
             IF  ¬BOOLEAN_SEC  THEN  CALL ERROR;                           APPC5540
             END;                                                          APPC5550
        RETURN( '1'B );                                                    APPC5560
```

```
END BOOLEAN_FACTOR;                                                    APPC5570
                                                                       APPC5580
BOOLEAN_SEC:  PROC          RETURNS( BIT(1) )   RECURSIVE;             APPC5590
        IF  LITERAL('.NOT.')  THEN  ;                                  APPC5600
        IF  BOOLEAN_PRIM  THEN  GO TO L1;                              APPC5610
        RETURN( '0'B );                                                APPC5620
    L1: RETURN( '1'B );                                                APPC5630
END BOOLEAN_SEC;                                                       APPC5640
                                                                       APPC5650
BOOLEAN_PRIM:  PROC         RETURNS( BIT(1) )   RECURSIVE;             APPC5660
        IF  LOGICAL_VALUE  THEN  RETURN( '1'B );                       APPC5670
        IF  RELATION  THEN  RETURN( '1'B );                            APPC5680
        IF  ¬LITERAL( '(' )  THEN  RETURN( '0'B );                     APPC5690
        IF  ¬BOOLEAN_TERM  THEN  CALL ERROR;                           APPC5700
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                         APPC5710
        RETURN( '1'B );                                                APPC5720
END BOOLEAN_PRIM;                                                      APPC5730
                                                                       APPC5740
RELATION:  PROC             RETURNS( BIT(1) )   RECURSIVE;             APPC5750
        IF  ¬SAE  THEN  RETURN( '0'B );                                APPC5760
        IF  ¬REL_OP  THEN  RETURN( '1'B );                             APPC5770
        IF  ¬SAE  THEN  CALL ERROR;                                    APPC5780
        RETURN( '1'B );                                                APPC5790
END RELATION;                                                          APPC5800
                                                                       APPC5810
REL_OP:  PROC               RETURNS( BIT(1) )   RECURSIVE;             APPC5820
        IF  LITERAL('.EQ.')  THEN  GO TO L1;                           APPC5830
        IF  LITERAL('.NE.')  THEN  GO TO L1;                           APPC5840
        IF  LITERAL('.LT.')  THEN  GO TO L1;                           APPC5850
        IF  LITERAL('.GT.')  THEN  GO TO L1;                           APPC5860
        IF  LITERAL('.LE.')  THEN  GO TO L1;                           APPC5870
        IF  LITERAL('.GE.')  THEN  GO TO L1;                           APPC5880
        RETURN( '0'B );                                                APPC5890
    L1: RETURN( '1'B );                                                APPC5900
END REL_OP;                                                            APPC5910
                                                                       APPC5920
SAE:  PROC                  RETURNS( BIT(1) )   RECURSIVE;             APPC5930
        IF  INT  THEN  GO TO L1;                                       APPC5940
```

```
        IF  DEST  THEN  GO TO L1;                                       APPC5950
        RETURN( '0'B );                                                 APPC5960
    L1: RETURN( '1'B );                                                 APPC5970
END SAE;                                                                APPC5980
                                                                        APPC5990
LOGICAL_VALUE:  PROC                        RETURNS( BIT(1) );          APPC6000
        IF  LITERAL('.TRUE.')  THEN  GO TO L1;                          APPC6010
        IF  LITERAL('.FALSE.')  THEN  GO TO L1;                         APPC6020
        RETURN( '0'B );                                                 APPC6030
    L1: RETURN( '1'B );                                                 APPC6040
END LOGICAL_VALUE;                                                      APPC6050
                                                                        APPC6060
GO_TO_STMT:  PROC            RETURNS( BIT(1) )   RECURSIVE;             APPC6070
        IF  ¬LITERAL( 'GO' )  THEN  RETURN( '0'B );                     APPC6080
        IF  ¬LITERAL( 'TO' )  THEN  CALL ERROR;                         APPC6090
        IF  ¬ID  THEN  CALL ERROR;                                      APPC6100
        RETURN( '1'B );                                                 APPC6110
END GO_TO_STMT;                                                         APPC6120
                                                                        APPC6130
TRANSFER_STMT: PROC                         RETURNS( BIT(1) );          APPC6140
        DCL   BACKUP          FIXED BINARY(31);                         APPC6150
        BACKUP = I;           /*  SAVE PTR TO TEXT POSITION  */         APPC6160
        IF  ¬DEST  THEN  RETURN( '0'B );                                APPC6170
        IF  ¬LITERAL( '<-' )  THEN  DO;                                 APPC6180
                I = BACKUP;           /*  BACKUP  TEXT  PTR  */         APPC6190
                RETURN( '0'B );   END;                                  APPC6200
        IF  INT  THEN  GO TO DONE;                                      APPC6210
        IF  UNARY_EXP  THEN  GO TO DONE;                                APPC6220
        IF  BINARY_EXP  THEN  GO TO DONE;                               APPC6230
        CALL ERROR;                                                     APPC6240
  DONE: RETURN( '1'B );                                                 APPC6250
END TRANSFER_STMT;                                                      APPC6260
                                                                        APPC6270
  DEST: PROC                                RETURNS( BIT(1) );          APPC6280
        IF  ¬ID  THEN  RETURN( '0'B );                                  APPC6290
        IF  ¬LITERAL( '(' )  THEN  GO TO L1;                            APPC6300
        IF  ID  THEN  DO;                                               APPC6310
                IF  LITERAL( ')' )  THEN  DO;                           APPC6320
```

```
                    GO TO L1;                END;                    APPC6330
                                          ELSE  CALL ERROR;         APPC6340
                END;                                                APPC6350
        IF  ¬INT  THEN  CALL ERROR;                                 APPC6360
        IF  LITERAL(')')  THEN  GO TO L1;                           APPC6370
        IF  ¬LITERAL('-')  THEN  CALL ERROR;                        APPC6380
        IF  ¬INT  THEN  CALL ERROR;                                 APPC6390
        IF  ¬LITERAL(')')  THEN  CALL ERROR;                        APPC6400
    L1: RETURN( '1'B );                                             APPC6410
END DEST;                                                           APPC6420
                                                                    APPC6430
UNARY_EXP: PROC                          RETURNS( BIT(1) );         APPC6440
        IF  ¬UNARY_OP  THEN  RETURN( '0'B );                        APPC6450
        IF  ¬UNARY_SOURCE  THEN  CALL ERROR;                        APPC6460
        RETURN( '1'B );                                             APPC6470
END UNARY_EXP;                                                      APPC6480
                                                                    APPC6490
UNARY_OP: PROC                           RETURNS( BIT(1) );         APPC6500
        IF  LITERAL('.AND.')  THEN GO TO L1;                        APPC6510
        IF  LITERAL('.OR.')   THEN GO TO L1;                        APPC6520
        IF  LITERAL('.NOT.')  THEN GO TO L1;                        APPC6530
        IF  LITERAL('.SHL.')  THEN GO TO L1;                        APPC6540
        IF  LITERAL('.SHR.')  THEN GO TO L1;                        APPC6550
        IF  LITERAL('.CIRL.') THEN GO TO L1;                        APPC6560
        IF  LITERAL('.CIRR.') THEN GO TO L1;                        APPC6570
        RETURN( '0'B );                                             APPC6580
    L1: RETURN( '1'B );                                             APPC6590
END UNARY_OP;                                                       APPC6600
                                                                    APPC6610
UNARY_SOURCE: PROC                       RETURNS( BIT(1) );         APPC6620
        IF  ¬ID  THEN  RETURN( '0'B );                              APPC6630
        IF  ¬LITERAL( '(' )  THEN  GO TO L1;                        APPC6640
        IF  ID  THEN  DO;                                           APPC6650
                IF  LITERAL( ')' )  THEN  DO;                       APPC6660
                    GO TO L1;                END;                   APPC6670
                                          ELSE CALL ERROR;          APPC6680
                END;                                                APPC6690
        IF  ¬INT  THEN  CALL ERROR;                                 APPC6700
```

```
        IF  LITERAL(')')  THEN  GO TO L1;                          APPC6710
        IF  ¬LITERAL('-')  THEN  CALL ERROR;                       APPC6720
        IF  ¬INT  THEN  CALL ERROR;                                APPC6730
        IF  ¬LITERAL(')')  THEN  CALL ERROR;                       APPC6740
    L1: RETURN( '1'B );                                            APPC6750
END UNARY_SOURCE;                                                  APPC6760
                                                                   APPC6770
BINARY_EXP: PROC                          RETURNS( BIT(1) );       APPC6780
        IF  ¬OP1  THEN  RETURN( '0'B );                            APPC6790
        IF  ¬BINARY_OP  THEN  GO TO L1;                            APPC6800
        IF  OP2  THEN  GO TO L1;                                   APPC6810
        IF  INT  THEN  GO TO L1;                                   APPC6820
        CALL ERROR;                                                APPC6830
    L1: RETURN( '1'B );                                            APPC6840
END BINARY_EXP;                                                    APPC6850
                                                                   APPC6860
BINARY_OP: PROC                           RETURNS( BIT(1) );       APPC6870
        IF  LITERAL('.ADD.')  THEN  GO TO L1;                      APPC6880
        IF  LITERAL('.SUB.')  THEN  GO TO L1;                      APPC6890
        IF  LITERAL('.OR.')   THEN  GO TO L1;                      APPC6900
        IF  LITERAL('.AND.')  THEN  GO TO L1;                      APPC6910
        IF  LITERAL('.XOR.')  THEN  GO TO L1;                      APPC6920
        IF  LITERAL('.SHL.')  THEN  GO TO L1;                      APPC6930
        IF  LITERAL('.SHR.')  THEN  GO TO L1;                      APPC6940
        IF  LITERAL('.CNT.')  THEN  GO TO L1;                      APPC6950
        RETURN( '0'B );                                            APPC6960
    L1: RETURN( '1'B );                                            APPC6970
END BINARY_OP;                                                     APPC6980
                                                                   APPC6990
   OP1: PROC                              RETURNS( BIT(1) );       APPC7000
        IF  ¬ID  THEN  RETURN( '0'B );                             APPC7010
        IF  ¬LITERAL( '(' )  THEN  GO TO L1;                       APPC7020
        IF  ID  THEN  DO;                                          APPC7030
                IF  LITERAL( ')' )  THEN  DO;                      APPC7040
                    GO TO L1;                 END;                 APPC7050
                                        ELSE  CALL ERROR;          APPC7060
                END;                                               APPC7070
        IF  ¬INT  THEN  CALL ERROR;                                APPC7080
```

```
        IF  LITERAL(')')  THEN  GO TO L1;                          APPC7090
        IF  ¬LITERAL('-')  THEN  CALL ERROR;                       APPC7100
        IF  ¬INT  THEN  CALL ERROR;                                APPC7110
        IF  ¬LITERAL(')')  THEN  CALL ERROR;                       APPC7120
    L1: RETURN( '1'B );                                            APPC7130
END OP1;                                                           APPC7140
                                                                   APPC7150
   OP2: PROC                              RETURNS( BIT(1) );       APPC7160
        IF  ¬ID  THEN  RETURN( '0'B );                             APPC7170
        IF  ¬LITERAL( '(' )  THEN  GO TO L1;                       APPC7180
        IF  ID  THEN  DO;                                          APPC7190
                IF  LITERAL( ')' )  THEN  DO;                      APPC7200
                     GO TO L1;                 END;                APPC7210
                                  ELSE  CALL ERROR;                APPC7220
                END;                                               APPC7230
        IF  ¬INT  THEN  CALL ERROR;                                APPC7240
        IF  LITERAL(')')  THEN  GO TO L1;                          APPC7250
        IF  ¬LITERAL('-')  THEN  CALL ERROR;                       APPC7260
        IF  ¬INT  THEN  CALL ERROR;                                APPC7270
        IF  ¬LITERAL(')')  THEN  CALL ERROR;                       APPC7280
    L1: RETURN( '1'B );                                            APPC7290
END OP2;                                                           APPC7300
                                                                   APPC7310
TERMINAL_STMT:  PROC                   RETURNS( BIT(1) );          APPC7320
        DCL       BACKUP    FIXED BINARY(31);                      APPC7330
        BACKUP = I;          /*  SAVE PTR TO TEXT POSITION  */     APPC7340
        IF  ¬TERMINAL  THEN  RETURN( '0'B );                       APPC7350
        IF  ¬LITERAL( ':=' )  THEN  DO;                            APPC7360
                I = BACKUP;          /*  BACKUP  TEXT  PTR  */     APPC7370
                RETURN( '0'B );   END;                             APPC7380
        IF  ¬LABEL  THEN  CALL ERROR;                              APPC7390
        RETURN( '1'B );                                            APPC7400
END TERMINAL_STMT;                                                 APPC7410
                                                                   APPC7420
TERMINAL:  PROC                        RETURNS( BIT(1) );          APPC7430
        IF  ¬ID  THEN  RETURN( '0'B );                             APPC7440
        IF  ¬LITERAL( '(' )  THEN  GO TO L1;                       APPC7450
        IF  ¬INT  THEN  CALL ERROR;                                APPC7460
```

```
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPC7470
    L1: RETURN( '1'B );                                                 APPC7480
END TERMINAL;                                                           APPC7490
                                                                        APPC7500
LABEL:  PROC                                  RETURNS( BIT(1) );        APPC7510
        IF  ¬TERM  THEN  RETURN( '0'B );                                APPC7520
     L: IF  ¬BOP  THEN  GO TO L1;                                       APPC7530
        IF  ¬TERM  THEN  CALL ERROR;                                    APPC7540
        GO TO L;                                                        APPC7550
    L1: RETURN( '1'B );                                                 APPC7560
END LABEL;                                                              APPC7570
                                                                        APPC7580
TERM:  PROC                                   RETURNS( BIT(1) );        APPC7590
        IF  DEF1  THEN  GO TO L1;                                       APPC7600
        IF  DEF2  THEN  GO TO L1;                                       APPC7610
        RETURN( '0'B );                                                 APPC7620
    L1: RETURN( '1'B );                                                 APPC7630
END TERM;                                                               APPC7640
                                                                        APPC7650
DEF1:  PROC                                   RETURNS( BIT(1) );        APPC7660
        IF  ¬ID  THEN  RETURN( '0'B );                                  APPC7670
        IF  ¬LITERAL( '(' )  THEN  GO TO L1;                            APPC7680
        IF  ¬INT  THEN  CALL ERROR;                                     APPC7690
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPC7700
    L1: RETURN( '1'B );                                                 APPC7710
END DEF1;                                                               APPC7720
                                                                        APPC7730
DEF2:  PROC                                   RETURNS( BIT(1) );        APPC7740
        IF  ¬LITERAL( '(' )  THEN  RETURN( '0'B );                      APPC7750
        IF  ¬ LITERAL( '¬' )  THEN  CALL ERROR;                         APPC7760
        IF  ¬DEF1  THEN  CALL ERROR;                                    APPC7770
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPC7780
        RETURN( '1'B );                                                 APPC7790
END DEF2;                                                               APPC7800
                                                                        APPC7810
BOP:  PROC                                    RETURNS( BIT(1) );        APPC7820
        IF  LITERAL('*')  THEN  GO TO L1;                               APPC7830
        IF  LITERAL('+')  THEN  GO TO L1;                               APPC7840
```

```
        RETURN( '0'B );                                                  APPC7850
    L1: RETURN( '1'B );                                                  APPC7860
END BOP;                                                                 APPC7870
                                                                         APPC7880
                                                                         APPC7890
                                                                         APPC7900
        /*  THIS IS THE END OF THE INTERNAL PROCEDURES  */               APPC7910
                                                                         APPC7920
                                                                         APPC7930
                                                                         APPC7940
                                                                         APPC7950
FINIS: PUT EDIT('END OF FILE SENSED ON SYSIN')(SKIP(2),COL(10),A);       APPC7960
  DONE:                                                                  APPC7970
        END COMPILE;                                                     APPC7980
```

Appendix 4. The BAPSIM Translator

```
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPD1002
        /*                                                               */APPD1004
        /*       THIS  IS  THE  'BAPSIM'  TRANSLATOR  IN  PL/1           */APPD1006
        /*                                                               */APPD1008
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPD1010
                                                                          APPD1012
                                                                          APPD1014
(SIZE,SUBSCRIPTRANGE,STRINGRANGE):    /*     CONDITION  ENABLING       */APPD1016
COMPILE:PROC  OPTIONS(MAIN);                                              APPD1018
                                                                          APPD1020
                                                                          APPD1022
DECLARE                                                                   APPD1024
        CARD  CHAR(80),  C(80)  CHAR(1)  DEF  CARD,                       APPD1026
        I  FIXED BINARY(31),          /*   TEXT  POINTER   */            APPD1028
        J  FIXED BINARY(31)  INITIAL(0),   /*  STATEMENT  COUNTER  */     APPD1030
        SYMBOL  CHAR(32) VARYING,                                         APPD1032
        LINE  CHAR(80),      /*  THE OUTPUT RECORD  */                    APPD1034
        TEMP  CHAR(80) VARYING,       /*  A TEMPORARY STRING  */          APPD1036
        IO  FIXED BINARY(31)  INITIAL(0),       /*  IO  COUNTER  */       APPD1038
        TYPE  FIXED BINARY(31),       /* STORES OPERATOR CODE */          APPD1040
        (S0,S1,S2)            CHAR(50) VARYING,                           APPD1042
        OPTABLE(12)           CHAR(8)   VARYING,                          APPD1044
        OPTABLE_PTR           FIXED BINARY(15)    INITIAL(0),             APPD1046
        #PROC     BIT(1)      INITIAL('0'B),                              APPD1048
                                                                          APPD1050
                                                                          APPD1052
        /*  THE  PRIMITIVE PROCEDURES ARE DECLARED NEXT  */               APPD1054
                                                                          APPD1056
                                                                          APPD1058
        LITERAL               ENTRY( CHAR(*) )    RETURNS( BIT(1) ),      APPD1060
        ID                    ENTRY               RETURNS( BIT(1) ),      APPD1062
        INT                   ENTRY               RETURNS( BIT(1) ),      APPD1064
        ERROR                 ENTRY,                                      APPD1066
        STAR       ENTRY                  RETURNS( CHAR(32) VAR ),        APPD1068
        OUT        ENTRY( CHAR(*) ),                                      APPD1070
                                                                          APPD1072
                                                                          APPD1074
        /*  THE DEFINED PROCEDURES ARE DECLARED NEXT  */                  APPD1076
```

```
                                                                    APPD1078
PROGRAM                 ENTRY   RETURNS( BIT(1) ),                  APPD1080
SIMULATION_BLOCK        ENTRY   RETURNS( BIT(1) ),                  APPD1082
STRUCTURE_BLOCK         ENTRY   RETURNS( BIT(1) ),                  APPD1084
BEHAVIOR_BLOCK          ENTRY   RETURNS( BIT(1) ),                  APPD1086
FETCH_BLOCK             ENTRY   RETURNS( BIT(1) ),                  APPD1088
SIMPLE_SEQUENCE         ENTRY   RETURNS( BIT(1) ),                  APPD1090
DECODE_BLOCK            ENTRY   RETURNS( BIT(1) ),                  APPD1092
EXECUTE_BLOCK           ENTRY   RETURNS( BIT(1) ),                  APPD1094
IN_OUT_BLOCK            ENTRY   RETURNS( BIT(1) ),                  APPD1096
INITIALIZATION_STMT     ENTRY   RETURNS( BIT(1) ),                  APPD1098
MONITOR_STMT            ENTRY   RETURNS( BIT(1) ),                  APPD1100
DECLARATION_STMT        ENTRY   RETURNS( BIT(1) ),                  APPD1102
REGISTER_DCL            ENTRY   RETURNS( BIT(1) ),                  APPD1104
REGISTER_ID             ENTRY   RETURNS( BIT(1) ),                  APPD1106
SUBREGISTER_DCL         ENTRY   RETURNS( BIT(1) ),                  APPD1108
SREXP                   ENTRY   RETURNS( BIT(1) ),                  APPD1110
MEMORY_DCL              ENTRY   RETURNS( BIT(1) ),                  APPD1112
MEMEXP                  ENTRY   RETURNS( BIT(1) ),                  APPD1114
MEMLHS                  ENTRY   RETURNS( BIT(1) ),                  APPD1116
MEMRHS                  ENTRY   RETURNS( BIT(1) ),                  APPD1118
TERMINAL_DCL            ENTRY   RETURNS( BIT(1) ),                  APPD1120
CONSTANT_DCL            ENTRY   RETURNS( BIT(1) ),                  APPD1122
CONSEXP                 ENTRY   RETURNS( BIT(1) ),                  APPD1124
OPERATION_DCL           ENTRY   RETURNS( BIT(1) ),                  APPD1126
COMPOUND_STMT           ENTRY   RETURNS( BIT(1) ),                  APPD1128
SIMPLE_STMT             ENTRY   RETURNS( BIT(1) ),                  APPD1130
DO_STMT                 ENTRY   RETURNS( BIT(1) ),                  APPD1132
IF_STMT                 ENTRY   RETURNS( BIT(1) ),                  APPD1134
CONDITION               ENTRY   RETURNS( BIT(1) ),                  APPD1136
BOOLEAN_TERM            ENTRY   RETURNS( BIT(1) ),                  APPD1138
BOOLEAN_FACTOR          ENTRY   RETURNS( BIT(1) ),                  APPD1140
BOOLEAN_SEC             ENTRY   RETURNS( BIT(1) ),                  APPD1142
BOOLEAN_PRIM            ENTRY   RETURNS( BIT(1) ),                  APPD1144
RELATION                ENTRY   RETURNS( BIT(1) ),                  APPD1146
REL_OP                  ENTRY   RETURNS( BIT(1) ),                  APPD1148
SAE                     ENTRY   RETURNS( BIT(1) ),                  APPD1150
LOGICAL_VALUE           ENTRY   RETURNS( BIT(1) ),                  APPD1152
```

```
        GO_TO_STMT              ENTRY     RETURNS( BIT(1) ),                  APPD1154
        TRANSFER_STMT           ENTRY     RETURNS( BIT(1) ),                  APPD1156
        DEST                    ENTRY     RETURNS( BIT(1) ),                  APPD1158
        UNARY_EXP               ENTRY     RETURNS( BIT(1) ),                  APPD1160
        UNARY_OP                ENTRY     RETURNS( BIT(1) ),                  APPD1162
        UNARY_SOURCE            ENTRY     RETURNS( BIT(1) ),                  APPD1164
        BINARY_EXP              ENTRY     RETURNS( BIT(1) ),                  APPD1166
        BINARY_OP               ENTRY     RETURNS( BIT(1) ),                  APPD1168
        OP1                     ENTRY     RETURNS( BIT(1) ),                  APPD1170
        OP2                     ENTRY     RETURNS( BIT(1) ),                  APPD1172
        TERMINAL_STMT           ENTRY     RETURNS( BIT(1) ),                  APPD1174
        TERMINAL                ENTRY     RETURNS( BIT(1) ),                  APPD1176
        LABEL                   ENTRY     RETURNS( BIT(1) ),                  APPD1178
        TERM                    ENTRY     RETURNS( BIT(1) ),                  APPD1180
        DEF1                    ENTRY     RETURNS( BIT(1) ),                  APPD1182
        DEF2                    ENTRY     RETURNS( BIT(1) ),                  APPD1184
        BOP                     ENTRY     RETURNS( BIT(1) ),                  APPD1186
        DUMMY     FIXED BINARY(15);   /* HAS THE ';' TO END DCL'S */          APPD1188
DECLARE ASSM  FILE;                                                           APPD1190
        /*  THIS IS THE END OF THE DECLARATIONS  */                           APPD1192
                                                                              APPD1194
                                                                              APPD1196
ON CONDITION(EOC)              /*  END-OF-CARD CONDITION  */                  APPD1198
   BEGIN;     L1: GET EDIT( CARD )  ( A(80) );                               APPD1200
                  IF C(1)='*' THEN DO; PUT EDIT(CARD)(COL(50),A(80));         APPD1202
                                       GO TO L1;                              APPD1204
                                    END;                                      APPD1206
                  J = J + 1;          /* INCREMENT STATEMENT COUNTER */       APPD1208
                  PUT EDIT( J,CARD ) ( COL(44),F(3),COL(50),A(80) );          APPD1210
                  I = 1;    /*  RESET  TEXT  POINTER  */                       APPD1212
   END;                                                                       APPD1214
                                                                              APPD1216
        /*  THE MAIN PART OF THE PROGRAM FOLLOWS IMMEDIATELY.  */             APPD1218
                                                                              APPD1220
ON ENDFILE( SYSIN )  GO TO FINIS;                                             APPD1222
PUT EDIT( 'RUN OF THE BAPSIM TRANSLATOR' ) (COL(60),A);   /* HEADING */       APPD1224
PUT EDIT('*** GENERATED  CODE ***','*** BAPSIM  SOURCE  CODE ***')            APPD1226
        (SKIP(4),COL(1),A,COL(50),A);                                         APPD1228
```

```
PUT SKIP(5);                                                          APPD1230
SIGNAL CONDITION( EOC );    /* GET THE FIRST CARD */                  APPD1232
OPEN  FILE(ASSM)  RECORD  OUTPUT;                                     APPD1234
                                                                      APPD1236
                                                                      APPD1238
IF PROGRAM THEN PUT EDIT('NORMAL COMPILER EXIT')(SKIP(2),COL(10),A);  APPD1240
           ELSE PUT EDIT('NO PROGRAM SUPPLIED')(SKIP(2),COL(10),A);   APPD1242
                                                                      APPD1244
                                                                      APPD1246
        PUT  FILE(SYSPRINT)  EDIT     /*  I/O COUNT FOR DEBUG  */     APPD1248
        ( IO,'  SEMANTIC-ACTION RECORDS WERE GENERATED.' )              APPD1250
        ( SKIP(2),COL(10),F(4),A(41) );                               APPD1252
        GO TO DONE;                                                   APPD1254
                                                                      APPD1256
                                                                      APPD1258
                                                                      APPD1260
                                                                      APPD1262
        /* THE PROCEDURES APPEAR BELOW - PRIMITIVE PROCEDURES FIRST */ APPD1264
                                                                      APPD1266
                                                                      APPD1268
LITERAL: PROC( S )     RETURNS(  BIT(1)  );                           APPD1270
         DCL  S  CHAR(*);                                             APPD1272
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                     APPD1274
         DO WHILE( C(I)=' ' );       I = I + 1;                       APPD1276
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                     APPD1278
         END;                                                         APPD1280
         IF  I+LENGTH(S)>81  THEN  RETURN( '0'B );                    APPD1282
         IF  SUBSTR(CARD,I,LENGTH(S))=S  THEN  DO;                    APPD1284
         I = I + LENGTH(S); RETURN ('1'B );     END;                  APPD1286
         RETURN( '0'B );                                              APPD1288
END LITERAL;                                                          APPD1290
                                                                      APPD1292
                                                                      APPD1294
     ID: PROC          RETURNS(  BIT(1)  );                           APPD1296
        DCL       J          FIXED BINARY(31);                       APPD1298
        IF  I>80  THEN  SIGNAL CONDITION( EOC );                      APPD1300
         DO WHILE( C(I)=' ' );  I = I + 1;                            APPD1302
         IF  I>80  THEN  SIGNAL CONDITION( EOC );                     APPD1304
```

```
        END;                                                              APPD1306
        IF  C(I)>'Z' | C(I)<'A'  THEN  RETURN( '0'B );                    APPD1308
        DO J=I+1 BY 1 WHILE( C(J)>='A' );  END;                           APPD131C
        SYMBOL = SUBSTR( CARD,I,J-I );  I = J;                            APPD1312
IF LENGTH(SYMBOL)>8 THEN SYMBOL=SUBSTR(SYMBOL,1,4)||                      APPD1314
                                SUBSTR(SYMBOL,LENGTH(SYMBOL)-3,4);        APPD1316
        RETURN( '1'B );                                                   APPD1318
    END ID;                                                               APPD1320
                                                                          APPD1322
                                                                          APPD1324
   INT: PROC          RETURNS(  BIT(1)  );                               APPD1326
       DCL      J          FIXED BINARY(31);                             APPD1328
        IF  I>80  THEN  SIGNAL CONDITION( EOC );                          APPD1330
        DO WHILE( C(I)=' ' );  I = I + 1;                                 APPD1332
        IF  I>80  THEN  SIGNAL CONDITION( EOC );                          APPD1334
        END;                                                              APPD1336
        IF  C(I)>='0'  THEN  DO;                                          APPD1338
        DO J=I+1 BY 1 WHILE( C(J)>='0' );  END;                           APPD1340
        SYMBOL = SUBSTR( CARD,I,J-I );  I = J;                            APPD1342
        RETURN( '1'B );       END;                                        APPD1344
        RETURN( '0'B );                                                   APPD1346
   END INT;                                                               APPD1348
                                                                          APPD1350
                                                                          APPD1352
 ERROR: PROC;                                                             APPD1354
        PUT EDIT( '*** ERROR AT $ ***','$' )(COL(1),A,COL(I+49),A);       APPD1356
        PUT EDIT( 'RECOVERY NOT POSSIBLE  --  COMPILATION ABORTED' )      APPD1358
              ( SKIP(2),COL(1),A );                                       APPD1360
        CLOSE FILE( SYSPRINT );                                           APPD1362
        CLOSE  FILE( ASSM );                                              APPD1364
        STOP;                                                             APPD1366
 END ERROR;                                                               APPD1368
                                                                          APPD1370
                                                                          APPD1372
  STAR: PROC          RETURNS(  CHAR(32) VARYING  );                      APPD1374
        RETURN( SYMBOL );                                                 APPD1376
  END STAR;                                                               APPD1378
                                                                          APPD1380
```

```
                                                                        APPD1382
    OUT: PROC( S );                                                     APPD1384
         DCL  S  CHAR(*);                                               APPD1386
         DCL      KARD      CHARACTER(80);                              APPD1388
         KARD = S;                                                      APPD1390
         WRITE  FILE(ASSM)  FROM(KARD);                                 APPD1392
         PUT EDIT( S )  ( COL(1),A );                                   APPD1394
         IO = IO + 1;          /* I/O COUNTER FOR DEBUG */              APPD1396
    END OUT;                                                            APPD1398
                                                                        APPD1400
                                                                        APPD1402
                                                                        APPD1404
                                                                        APPD1406
        /*  THE NON-PRIMITIVE PROCEDURES APPEAR NEXT  */                APPD1408
                                                                        APPD1410
                                                                        APPD1412
PROGRAM: PROC                              RETURNS ( BIT(1) );          APPD1414
        IF  ¬SIMULATION_BLOCK  THEN  RETURN('0'B);                      APPD1416
        RETURN ('1'B);                                                  APPD1418
END PROGRAM;                                                            APPD1420
                                                                        APPD1422
SIMULATION_BLOCK: PROC                     RETURNS( BIT(1) );           APPD1424
        IF  ¬LITERAL('SIMULATION')  THEN  RETURN('0'B);                 APPD1426
        LINE = ' (SIZE,SUBSCRIPTRANGE,STRINGRANGE):'   ;                APPD1428
        CALL OUT(LINE);                                                 APPD1430
        LINE=' B#PS#M: PROC OPTIONS(MAIN);'  ;  CALL OUT(LINE);         APPD1432
        IF  ¬STRUCTURE_BLOCK  THEN  CALL ERROR;                         APPD1434
        IF  ¬BEHAVIOR_BLOCK  THEN  CALL ERROR;                          APPD1436
        IF  ¬IN_OUT_BLOCK  THEN  CALL ERROR;                            APPD1438
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                        APPD1440
        IF  ¬LITERAL( 'SIMULATION' )  THEN  CALL ERROR;                 APPD1442
        LINE = ' STOP: C#CLE = 9999; GO TO O#T;' ;  CALL OUT(LINE);     APPD1444
        LINE = ' O#NE: PUT FILE(SYSPRINT) EDIT'   ;                     APPD1446
        CALL OUT(LINE);                                                 APPD1448
        LINE=' ( ''NORMAL SIMULATOR EXIT -- SUCCESSFUL RUN'' )'   ;     APPD1450
        CALL OUT(LINE);                                                 APPD1452
        LINE = ' (SKIP(5),COL(10),A);'   ;                              APPD1454
        CALL OUT(LINE);                                                 APPD1456
```

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        LINE=' END B#PS#M;'   ;                          CALL OUT(LINE);        APPD1458
        RETURN( '1'B);                                                          APPD1460
END SIMULATION_BLOCK;                                                           APPD1462
                                                                                APPD1464
STRUCTURE_BLOCK:PROC                      RETURNS( BIT(1) );                    APPD1466
        IF  ¬LITERAL('DECLARE')  THEN  RETURN( '0'B);                           APPD1468
        IF  ¬DECLARATION_STMT  THEN  CALL ERROR;                                APPD1470
        DO   WHILE(LITERAL(';') );                                              APPD1472
             IF  ¬DECLARATION_STMT  THEN  CALL ERROR;                           APPD1474
             END;                                                               APPD1476
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                                APPD1478
        IF  ¬LITERAL( 'DECLARE' )  THEN  CALL ERROR;                            APPD1480
        LINE = ' %INCLUDE  DCLS;                    /* * * * * * * * * * */';APPD1482
        CALL OUT(LINE);                                                         APPD1484
        RETURN( '1'B);                                                          APPD1486
END STRUCTURE_BLOCK;                                                            APPD1488
                                                                                APPD1490
BEHAVIOR_BLOCK: PROC                      RETURNS( BIT(1) );                    APPD1492
        IF  ¬FETCH_BLOCK  THEN  RETURN( '0'B );                                 APPD1494
        IF  ¬DECODE_BLOCK  THEN  CALL ERROR;                                    APPD1496
        IF  ¬EXECUTE_BLOCK  THEN  CALL ERROR;                                   APPD1498
        RETURN( '1'B );                                                         APPD1500
END BEHAVIOR_BLOCK;                                                             APPD1502
                                                                                APPD1504
FETCH_BLOCK: PROC                         RETURNS( BIT(1) );                    APPD1506
        IF  ¬LITERAL('FETCH')  THEN  RETURN( '0'B );                            APPD1508
        LINE = ' F#TCH:'   ;                             CALL OUT(LINE);        APPD1510
        IF  ¬SIMPLE_SEQUENCE  THEN  CALL ERROR;                                 APPD1512
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                                APPD1514
        IF  ¬LITERAL( 'FETCH' )  THEN  CALL ERROR;                              APPD1516
        LINE = ' GO TO D#COD#;'   ;                      CALL OUT(LINE);        APPD1518
        RETURN( '1'B );                                                         APPD1520
END FETCH_BLOCK;                                                                APPD1522
                                                                                APPD1524
SIMPLE_SEQUENCE: PROC                     RETURNS( BIT(1) );                    APPD1526
        IF  ¬SIMPLE_STMT  THEN  RETURN( '0'B );                                 APPD1528
        DO WHILE( LITERAL(',') );                                               APPD1530
             IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                                APPD1532
```

```
            END;                                                          APPD1534
        RETURN( '1'B );                                                   APPD1536
END SIMPLE_SEQUENCE;                                                      APPD1538
                                                                          APPD1540
DECODE_BLOCK: PROC                      RETURNS( BIT(1) );                APPD1542
        IF  ¬LITERAL('DECODE')  THEN  RETURN( '0'B );                     APPD1544
        LINE = ' D#COD#:'    ;                      CALL OUT(LINE);       APPD1546
        IF  ¬SIMPLE_SEQUENCE  THEN  CALL ERROR;                           APPD1548
        IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                          APPD1550
        IF  ¬LITERAL( 'DECODE' )  THEN  CALL ERROR;                       APPD1552
        LINE = ' %INCLUDE ENDCODE;                 /* * * * * * * * * * */';APPD1554
        CALL OUT(LINE);                                                   APPD1556
        RETURN( '1'B );                                                   APPD1558
END DECODE_BLOCK;                                                         APPD1560
                                                                          APPD1562
EXECUTE_BLOCK: PROC                     RETURNS( BIT(1) );                APPD1564
        IF  ¬LITERAL( 'EXECUTE')  THEN  RETURN( '0'B);                    APPD1566
        LINE=' EX#CUTE:' ;                         CALL OUT(LINE);        APPD1568
        IF  ¬COMPOUND_STMT  THEN  CALL ERROR;                             APPD1570
        IF  #PROC  THEN  DO;                                              APPD1572
                    LINE = ' END;'    ;                                   APPD1574
                    CALL OUT(LINE);                                       APPD1576
                    #PROC = '0'B;                                         APPD1578
                      END;                                                APPD1580
                ELSE  DO;                                                 APPD1582
                    LINE = ' GO TO O#T;'    ;                             APPD1584
                    CALL OUT(LINE);                                       APPD1586
                      END;                                                APPD1588
        DO WHILE( LITERAL(';') );                                         APPD1590
             IF  ¬COMPOUND_STMT  THEN  CALL ERROR;                        APPD1592
             IF  #PROC  THEN  DO;                                         APPD1594
                    LINE = ' END;'    ;                                   APPD1596
                    CALL OUT(LINE);                                       APPD1598
                    #PROC = '0'B;                                         APPD1600
                          END;                                            APPD1602
                     ELSE  DO;                                            APPD1604
                    LINE = ' GO TO O#T;'    ;                             APPD1606
                    CALL OUT(LINE);                                       APPD1608
```

```
                              END;                                                    APPD1610
                    END;                                                              APPD1612
          IF  ¬LITERAL( 'END' )  THEN  CALL ERROR;                                    APPD1614
          IF  ¬LITERAL( 'EXECUTE' )  THEN  CALL ERROR;                                APPD1616
          LINE = ' %INCLUDE PRIMPROC;              /* * * * * * * * * */';           APPD1618
          CALL OUT(LINE);                                                             APPD1620
          RETURN('1'B);                                                               APPD1622
END EXECUTE_BLOCK;                                                                    APPD1624
                                                                                      APPD1626
IN_OUT_BLOCK: PROC                        RETURNS( BIT(1) );                          APPD1628
          IF  ¬INITIALIZATION_STMT  THEN  RETURN( '0'B);                              APPD1630
          IF  ¬MONITOR_STMT  THEN  CALL ERROR;                                        APPD1632
          RETURN( '1'B);                                                              APPD1634
END IN_OUT_BLOCK;                                                                     APPD1636
                                                                                      APPD1638
INITIALIZATION_STMT: PROC                 RETURNS( BIT(1) );                          APPD1640
          IF  ¬LITERAL('INITIALIZE')  THEN  RETURN( '0'B);                            APPD1642
          LINE = ' INITI#L:'      ;                    CALL OUT(LINE);                APPD1644
          LINE = ' PUT FILE(SYSPRINT) EDIT'    ;    CALL OUT(LINE);                   APPD1646
          LINE = ' (''INITIALIZATION DATA IS ECHO-CHECKED BELOW'')'    ;              APPD1648
          CALL OUT(LINE);                                                             APPD1650
          LINE = ' (PAGE,LINE(2),COL(40),A);'    ; CALL OUT(LINE);                    APPD1652
          LINE = ' GET FILE(SYSIN) LIST(CH#CK);'    ;                                 APPD1654
          CALL OUT(LINE);                                                             APPD1656
          LINE = ' PUT FILE(SYSPRINT) LIST(CH#CK) SKIP;'    ;                         APPD1658
          CALL OUT(LINE);                                                             APPD1660
          IF  ¬ID  THEN  CALL ERROR;                                                  APPD1662
          LINE=' GET FILE(SYSIN) DATA('||STAR||');' ;                                 APPD1664
          CALL OUT(LINE);                                                             APPD1666
          LINE = ' PUT FILE(SYSPRINT) DATA('||STAR||') SKIP;'    ;                    APPD1668
          CALL OUT(LINE);                                                             APPD1670
          DO WHILE(LITERAL(',') );                                                    APPD1672
               IF  ¬ID  THEN  CALL ERROR;                                             APPD1674
               LINE=' GET FILE(SYSIN) DATA('||STAR||');' ;                            APPD1676
               CALL OUT(LINE);                                                        APPD1678
               LINE = ' PUT FILE(SYSPRINT) DATA('||STAR||') SKIP;'    ;               APPD1680
               CALL OUT(LINE);                                                        APPD1682
               END;                                                                   APPD1684
```

```
        LINE = ' GO TO HE#D;'    ;                    CALL OUT(LINE);          APPD1686
        RETURN('1'B);                                                          APPD1688
END INITIALIZATION_STMT;                                                       APPD1690
                                                                               APPD1692
MONITOR_STMT: PROC                          RETURNS(BIT(1) );                  APPD1694
        IF  ¬LITERAL( 'MONITOR')  THEN  RETURN('0'B);                          APPD1696
        LINE = ' O#T:'    ;                          CALL OUT(LINE);           APPD1698
        LINE = ' PUT FILE(SYSPRINT) EDIT'   ;        CALL OUT(LINE);           APPD1700
        LINE = ' (''CYCLE = '',C#CLE)'    ;          CALL OUT(LINE);           APPD1702
        LINE = ' (SKIP(5),A,P''9999'');'    ;        CALL OUT(LINE);           APPD1704
        LINE = ' IF  T#ME ¬= 0  THEN'    ;           CALL OUT(LINE);           APPD1706
        LINE = ' PUT FILE(SYSPRINT) EDIT'   ;        CALL OUT(LINE);           APPD1708
        LINE = ' (''TIME = '',T#ME)'    ;            CALL OUT(LINE);           APPD1710
        LINE = ' (SKIP,A,P''9999999'');'    ;        CALL OUT(LINE);           APPD1712
        IF  ¬ID  THEN  CALL ERROR;                                             APPD1714
        LINE =' PUT FILE(SYSPRINT) DATA('||STAR||') SKIP;'    ;                APPD1716
        CALL OUT(LINE);                                                        APPD1718
        DO WHILE(LITERAL(',') );                                               APPD1720
             IF  ¬ID  THEN  CALL ERROR;                                        APPD1722
             LINE=' PUT FILE(SYSPRINT) DATA('||STAR||') SKIP;'    ;           APPD1724
             CALL OUT (LINE);                                                  APPD1726
             END;                                                              APPD1728
        LINE = ' GO TO #NCR;'    ;                   CALL OUT(LINE);           APPD1730
        RETURN('1'B);                                                          APPD1732
END MONITOR_STMT;                                                              APPD1734
                                                                               APPD1736
                                                                               APPD1738
DECLARATION_STMT:  PROC                     RETURNS( BIT(1) );                 APPD1740
        IF  REGISTER_DCL      THEN  GO TO L1;                                  APPD1742
        IF  SUBREGISTER_DCL   THEN  GO TO L1;                                  APPD1744
        IF  MEMORY_DCL        THEN  GO TO L1;                                  APPD1746
        IF  TERMINAL_DCL      THEN  GO TO L1;                                  APPD1748
        IF  CONSTANT_DCL      THEN  GO TO L1;                                  APPD1750
        IF  OPERATION_DCL     THEN  GO TO L1;                                  APPD1752
        RETURN( '0'B );                                                        APPD1754
    L1: RETURN( '1'B );                                                        APPD1756
END DECLARATION_STMT;                                                          APPD1758
                                                                               APPD1760
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REGISTER_DCL:  PROC                          RETURNS( BIT(1) );                  APPD1762
        IF  ¬LITERAL('REGISTER')  THEN  RETURN( '0'B );                          APPD1764
        IF  ¬REGISTER_ID  THEN  CALL ERROR;                                      APPD1766
        DO WHILE( LITERAL(',') );                                                APPD1768
             IF  ¬REGISTER_ID  THEN  CALL ERROR;                                 APPD1770
             END;                                                                APPD1772
        RETURN( '1'B );                                                          APPD1774
END REGISTER_DCL;                                                                APPD1776
                                                                                 APPD1778
REGISTER_ID:  PROC                           RETURNS( BIT(1) );                  APPD1780
        DCL         (LENGTH,I1,I2)  FIXED DECIMAL(2),                            APPD1782
                    TEMP            CHAR(5),                                     APPD1784
                    R  CHAR(8) VARYING,                                          APPD1786
                    L  CHAR(2) VARYING;                                          APPD1788
        IF  ¬ID  THEN  RETURN( '0'B );                                           APPD1790
        R = STAR;                                                                APPD1792
        IF  ¬LITERAL( '(' )  THEN  DO;                                           APPD1794
                    LINE = ' DCL  '||R||'  BIT(1);'  ;                           APPD1796
                    CALL OUT(LINE);                                              APPD1798
                    RETURN( '1'B );  END;                                        APPD1800
                                                                                 APPD1802
        IF  ¬INT  THEN  CALL ERROR;                                              APPD1804
        I1 = STAR;              /*  CONVERSION PERFORMED HERE  */                APPD1806
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                                   APPD1808
        IF  ¬INT  THEN  CALL ERROR;                                              APPD1810
        I2 = STAR;              /*  CONVERSION PERFORMED HERE  */                APPD1812
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                                   APPD1814
        LENGTH = I2 - I1 + 1;                                                    APPD1816
        TEMP = LENGTH;                                                           APPD1818
        IF  LENGTH<=9  THEN  L = SUBSTR(TEMP,5,1);                               APPD1820
        IF  LENGTH >9  THEN  L = SUBSTR(TEMP,4,2);                               APPD1822
        LINE = ' DCL  '||R||'  BIT('||L||');'  ;                                 APPD1824
        CALL OUT(LINE);                                                          APPD1826
        LENGTH = LENGTH - 1;                                                     APPD1828
        TEMP = LENGTH;                                                           APPD1830
        IF  LENGTH<=9  THEN  L = SUBSTR(TEMP,5,1);                               APPD1832
        IF  LENGTH >9  THEN  L = SUBSTR(TEMP,4,2);                               APPD1834
        LINE = ' DCL  $'||R||'(0:'||L||')  BIT(1)  DEF  '||R||';'  ;             APPD1836
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        CALL OUT(LINE);                                                  APPD1838
        RETURN( '1'B );                                                  APPD1840
END REGISTER_ID;                                                         APPD1842
                                                                         APPD1844
SUBREGISTER_DCL:  PROC                    RETURNS( BIT(1) );             APPD1846
        IF  ¬LITERAL('SUBREGISTER')  THEN  RETURN( '0'B );               APPD1848
        IF  ¬SREXP  THEN  CALL ERROR;                                    APPD1850
        DO WHILE( LITERAL(',') );                                        APPD1852
             IF  ¬SREXP  THEN  CALL ERROR;                               APPD1854
             END;                                                        APPD1856
        RETURN( '1'B );                                                  APPD1858
END SUBREGISTER_DCL;                                                     APPD1860
                                                                         APPD1862
SREXP:  PROC                              RETURNS( BIT(1) );             APPD1864
        DCL         (R1,R2)    CHAR(8)    VARYING,                       APPD1866
                    BEGIN      CHAR(2)    VARYING,                       APPD1868
                    L          CHAR(2)    VARYING,                       APPD1870
                    TEMP       CHAR(5),                                  APPD1872
                    (LENGTH,I1,I2)        FIXED DECIMAL(2);              APPD1874
        IF  ¬ID  THEN  RETURN( '0'B );                                   APPD1876
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                           APPD1878
        IF  ¬ID  THEN  CALL ERROR;                                       APPD1880
        R2 = STAR;                                                       APPD1882
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                           APPD1884
        IF  ¬LITERAL( '=' )  THEN  CALL ERROR;                           APPD1886
        IF  ¬ID  THEN  CALL ERROR;                                       APPD1888
        R1 = STAR;                                                       APPD1890
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                           APPD1892
        IF  ¬INT  THEN  CALL ERROR;                                      APPD1894
        BEGIN = STAR;                                                    APPD1896
        I1 = BEGIN;             /*  CONVERSION PERFORMED HERE  */       APPD1898
        IF  LITERAL( ')' )  THEN  DO;  L = '1';  GO TO L1;  END;         APPD1900
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                           APPD1902
        IF  ¬INT  THEN  CALL ERROR;                                      APPD1904
        I2 = STAR;              /*  CONVERSION PERFORMED HERE  */       APPD1906
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                           APPD1908
        LENGTH = I2 - I1 + 1;                                            APPD1910
        TEMP = LENGTH;                                                   APPD1912
```

```
        IF  LENGTH<=9  THEN  L = SUBSTR(TEMP,5,1);                          APPD1914
        IF  LENGTH >9  THEN  L = SUBSTR(TEMP,4,2);                          APPD1916
    L1: I1 = I1 + 1;                                                        APPD1918
        TEMP = I1;                                                          APPD1920
        IF  I1<=9  THEN  BEGIN = SUBSTR(TEMP,5,1);                          APPD1922
        IF  I1 >9  THEN  BEGIN = SUBSTR(TEMP,4,2);                          APPD1924
        LINE = ' DCL  '||R2||'  BIT('||L||')  DEF  '||R1||                  APPD1926
               '  POSITION('||BEGIN||');'  ;                                APPD1928
        CALL OUT(LINE);                                                     APPD1930
        /*  INDIVIDUAL BITS OF A SUBREGISTER MAY NOT BE ACCESSED  */        APPD1932
        RETURN( '1'B );                                                     APPD1934
END SREXP;                                                                  APPD1936
                                                                            APPD1938
MEMORY_DCL:  PROC                          RETURNS( BIT(1) );               APPD1940
        IF  ¬LITERAL('MEMORY')  THEN  RETURN( '0'B );                       APPD1942
        IF  ¬MEMEXP  THEN  CALL ERROR;                                      APPD1944
        DO WHILE( LITERAL(',') );                                           APPD1946
             IF  ¬MEMEXP  THEN  CALL ERROR;                                 APPD1948
             END;                                                           APPD1950
        RETURN( '1'B );                                                     APPD1952
END MEMORY_DCL;                                                             APPD1954
                                                                            APPD1956
MEMEXP:  PROC                              RETURNS( BIT(1) );               APPD1958
        IF  ¬MEMLHS  THEN  RETURN( '0'B );                                  APPD1960
        IF  ¬LITERAL( '=' )  THEN  CALL ERROR;                              APPD1962
        IF  ¬MEMRHS  THEN  CALL ERROR;                                      APPD1964
        RETURN( '1'B );                                                     APPD1966
END MEMEXP;                                                                 APPD1968
                                                                            APPD1970
MEMLHS:  PROC                              RETURNS( BIT(1) );               APPD1972
        IF  ¬ID  THEN  RETURN( '0'B );                                      APPD1974
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                              APPD1976
        IF  ¬ID  THEN  CALL ERROR;                                          APPD1978
        IF  LITERAL( ')' )  THEN  RETURN( '1'B );                           APPD1980
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                              APPD1982
        IF  ¬ID  THEN  CALL ERROR;                                          APPD1984
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                              APPD1986
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                              APPD1988
```

```
        RETURN( '1'B );                                                    APPD1990
END MEMLHS;                                                                APPD1992
                                                                           APPD1994
MEMRHS:  PROC                              RETURNS( BIT(1) );              APPD1996
        DCL         (I1,I2,I3,I4)          FIXED DECIMAL(3),               APPD1998
                    (LENGTH1,LENGTH2)      FIXED DECIMAL(3),               APPD2000
                    R                      CHAR(8)  VARYING,               APPD2002
                    TEMP                   CHAR(6),                        APPD2004
                    (L1,L2)                CHAR(3)  VARYING;               APPD2006
        IF  ¬IO  THEN  RETURN( '0'B );                                     APPD2008
        R = STAR;                                                          APPD2010
        IF  ¬LITERAL( '(' )  THEN  CALL ERROR;                             APPD2012
        IF  ¬INT  THEN  CALL ERROR;                                        APPD2014
        I1 = STAR;              /*  CONVERSION PERFORMED HERE  */          APPD2016
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                             APPD2018
        IF  ¬INT  THEN  CALL ERROR;                                        APPD2020
        I2 = STAR;              /*  CONVERSION PERFORMED HERE  */          APPD2022
        LENGTH1 = I2 - I1     ;                                            APPD2024
        TEMP = LENGTH1;                                                    APPD2026
        IF  LENGTH1<=9  THEN  L1 = SUBSTR(TEMP,6,1);                       APPD2028
        IF  LENGTH1>99  THEN  L1 = SUBSTR(TEMP,4,3);                       APPD2030
        IF  LENGTH1 >9   &   LENGTH1<=99  THEN  L1 = SUBSTR(TEMP,5,2);     APPD2032
        IF  ¬LITERAL( ',' )  THEN  CALL ERROR;                             APPD2034
        IF  ¬INT  THEN  CALL ERROR;                                        APPD2036
        I3 = STAR;              /*  CONVERSION PERFORMED HERE  */          APPD2038
        IF  ¬LITERAL( '-' )  THEN  CALL ERROR;                             APPD2040
        IF  ¬INT  THEN  CALL ERROR;                                        APPD2042
        I4 = STAR;              /*  CONVERSION PERFORMED HERE  */          APPD2044
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                             APPD2046
        LENGTH2 = I4 - I3 + 1;                                             APPD2048
        TEMP = LENGTH2;                                                    APPD2050
        IF  LENGTH2<=9  THEN  L2 = SUBSTR(TEMP,6,1);                       APPD2052
        IF  LENGTH2>99  THEN  L2 = SUBSTR(TEMP,4,3);                       APPD2054
        IF  LENGTH2 >9   &   LENGTH2<=99  THEN  L2 = SUBSTR(TEMP,5,2);     APPD2056
        LINE = ' DCL  '||R||'(0:'||L1||')  BIT('||L2||') '  ;              APPD2058
        CALL OUT(LINE);                                                    APPD2060
        LENGTH1 = LENGTH1 + 1;                                             APPD2062
        TEMP = LENGTH1;                                                    APPD2064
```

```
        LINE = ' INITIAL(  ('||TEMP||') ('||L2||') ''0''B  );'   ;      APPD2066
        CALL OUT(LINE);                                                 APPD2068
        RETURN( '1'B );                                                 APPD2070
END MEMRHS;                                                             APPD2072
                                                                        APPD2074
TERMINAL_DCL:  PROC                        RETURNS( BIT(1) );           APPD2076
        IF  ¬LITERAL('TERMINAL')  THEN  RETURN( '0'B );                 APPD2078
        IF  ¬REGISTER_ID  THEN  CALL ERROR;                             APPD2080
        DO WHILE( LITERAL( ',' ) );                                     APPD2082
             IF  ¬REGISTER_ID  THEN  CALL ERROR;                        APPD2084
             END;                                                       APPD2086
        RETURN( '1'B );                                                 APPD2088
END TERMINAL_DCL;                                                       APPD2090
                                                                        APPD2092
CONSTANT_DCL:  PROC                        RETURNS( BIT(1) );           APPD2094
        IF  ¬LITERAL('CONSTANT')  THEN  RETURN( '0'B );                 APPD2096
        IF  ¬CONSEXP  THEN  CALL ERROR;                                 APPD2098
        DO WHILE( LITERAL(',') );                                       APPD2100
             IF  ¬CONSEXP  THEN  CALL ERROR;                            APPD2102
             END;                                                       APPD2104
        RETURN( '1'B );                                                 APPD2106
END CONSTANT_DCL;                                                       APPD2108
                                                                        APPD2110
CONSEXP:  PROC                             RETURNS( BIT(1) );           APPD2112
        DCL       R          CHAR(8)  VARYING;                          APPD2114
        IF  ¬ID  THEN  RETURN( '0'B );                                  APPD2116
        R = STAR;                                                       APPD2118
        IF  ¬LITERAL( '=' )  THEN  CALL ERROR;                          APPD2120
        IF  ¬INT  THEN  CALL ERROR;                                     APPD2122
        LINE = ' DCL  '||R||'  FIX BIN(31) INITIAL('||STAR||');'   ;    APPD2124
        CALL OUT(LINE);                                                 APPD2126
        RETURN( '1'B );                                                 APPD2128
END CONSEXP;                                                            APPD2130
                                                                        APPD2132
                                                                        APPD2134
                                                                        APPD2136
OPERATION_DCL:  PROC                       RETURNS( BIT(1) );           APPD2138
        IF  ¬LITERAL('OPERATION')  THEN  RETURN( '0'B );                APPD2140
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        IF  ¬ID  THEN  CALL ERROR;                                          APPD2142
        OPTABLE_PTR = OPTABLE_PTR + 1;                                      APPD2144
        OPTABLE( OPTABLE_PTR ) = STAR;                                      APPD2146
        DO WHILE( LITERAL(',') );                                           APPD2148
             IF  ¬ID  THEN  CALL ERROR;                                     APPD2150
             OPTABLE_PTR = OPTABLE_PTR + 1;                                 APPD2152
             OPTABLE( OPTABLE_PTR ) = STAR;                                 APPD2154
             END;                                                           APPD2156
        RETURN( '1'B );                                                     APPD2158
END OPERATION_DCL;                                                          APPD2160
                                                                            APPD2162
COMPOUND_STMT:  PROC                    RETURNS( BIT(1) );                  APPD2164
        DCL       INDEX     FIXED BINARY(15),                               APPD2166
                  R         CHAR(8)   VARYING;                              APPD2168
        IF  ¬ID  THEN  RETURN( '0'B );                                      APPD2170
        R = STAR;                                                           APPD2172
        DO  INDEX = OPTABLE_PTR  TO  1  BY  -1;                             APPD2174
             IF  OPTABLE(INDEX) = R  THEN  GO TO L1;                        APPD2176
             END;                                                           APPD2178
        LINE = ' '||R||':'   ;                                              APPD2180
        CALL OUT(LINE);                                                     APPD2182
        GO TO L2;                                                           APPD2184
    L1: LINE = ' '||R||': PROC ;'   ;                                       APPD2186
        CALL OUT(LINE);                                                     APPD2188
        #PROC = '1'B;                                                       APPD2190
    L2: IF  ¬LITERAL( ':' )  THEN  CALL ERROR;                              APPD2192
        IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                                 APPD2194
        DO WHILE( LITERAL(',') );                                           APPD2196
             IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                            APPD2198
             END;                                                           APPD2200
        RETURN( '1'B );                                                     APPD2202
END COMPOUND_STMT;                                                          APPD2204
                                                                            APPD2206
SIMPLE_STMT:  PROC              RETURNS( BIT(1) )   RECURSIVE;              APPD2208
        IF  DO_STMT  THEN  GO TO L1;                                        APPD2210
        IF  IF_STMT  THEN  GO TO L1;                                        APPD2212
        IF  GO_TO_STMT  THEN  GO TO L1;                                     APPD2214
        IF  TRANSFER_STMT  THEN  GO TO L1;                                  APPD2216
```

```
        IF  TERMINAL_STMT  THEN  GO TO L1;                              APPD2218
/*      IF  EXCHANGE_STMT  THEN  GO TO L1;                          */  APPD2220
        RETURN( '0'B );                                                 APPD2222
    L1: IF  ¬LITERAL('<')  THEN  GO TO L2;                              APPD2224
        IF  ¬INT  THEN  CALL  ERROR;                                    APPD2226
        IF  ¬LITERAL('>')  THEN  CALL  ERROR;                           APPD2228
        LINE = ' T#ME = MOD(T#ME + '  ||STAR||  ' , 1048576 );'   ;     APPD2230
        CALL OUT(LINE);                                                 APPD2232
    L2: RETURN( '1'B );                                                 APPD2234
END SIMPLE_STMT;                                                        APPD2236
                                                                        APPD2238
DO_STMT:  PROC                RETURNS( BIT(1) )   RECURSIVE;            APPD2240
        IF  ¬LITERAL('DO')  THEN  RETURN( '0'B );                       APPD2242
        IF  ¬ID  THEN  CALL ERROR;                                      APPD2244
        LINE = ' CALL  '||STAR||';'   ;                                 APPD2246
        CALL OUT(LINE);                                                 APPD2248
        RETURN( '1'B );                                                 APPD2250
END DO_STMT;                                                            APPD2252
                                                                        APPD2254
IF_STMT:  PROC                RETURNS( BIT(1) )   RECURSIVE;            APPD2256
        IF  ¬LITERAL('IF')  THEN  RETURN( '0'B );                       APPD2258
        TEMP = ' IF ( '   ;                                            APPD2260
        IF  ¬CONDITION  THEN  CALL ERROR;                               APPD2262
        IF  ¬LITERAL('THEN')  THEN  CALL ERROR;                         APPD2264
        LINE = TEMP||' )  THEN  '   ;                                   APPD2266
        CALL OUT(LINE);                                                 APPD2268
        IF  ¬SIMPLE_STMT  THEN  CALL ERROR;                             APPD2270
        RETURN( '1'B );                                                 APPD2272
END IF_STMT;                                                            APPD2274
                                                                        APPD2276
CONDITION:  PROC                        RETURNS( BIT(1) );              APPD2278
        IF  ¬LITERAL( '(' )  THEN  RETURN( '0'B );                      APPD2280
        IF  ¬BOOLEAN_TERM  THEN  CALL ERROR;                            APPD2282
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPD2284
        RETURN( '1'B );                                                 APPD2286
END CONDITION;                                                          APPD2288
                                                                        APPD2290
BOOLEAN_TERM:  PROC           RETURNS( BIT(1) )   RECURSIVE;            APPD2292
```

```
        IF  ¬BOOLEAN_FACTOR  THEN  RETURN( '0'B );                    APPD2294
        DO WHILE( LITERAL('.OR.') );                                  APPD2296
             TEMP = TEMP||' | '    ;                                  APPD2298
             IF  ¬BOOLEAN_FACTOR  THEN  CALL ERROR;                   APPD2300
             END;                                                     APPD2302
        RETURN( '1'B );                                               APPD2304
END BOOLEAN_TERM;                                                     APPD2306
                                                                      APPD2308
BOOLEAN_FACTOR:  PROC        RETURNS( BIT(1) )   RECURSIVE;           APPD2310
        IF  ¬BOOLEAN_SEC  THEN  RETURN( '0'B );                       APPD2312
        DO WHILE( LITERAL('.AND.') );                                 APPD2314
             TEMP = TEMP||' & '    ;                                  APPD2316
             IF  ¬BOOLEAN_SEC  THEN  CALL ERROR;                      APPD2318
             END;                                                     APPD2320
        RETURN( '1'B );                                               APPD2322
END BOOLEAN_FACTOR;                                                   APPD2324
                                                                      APPD2326
BOOLEAN_SEC:  PROC           RETURNS( BIT(1) )   RECURSIVE;           APPD2328
        IF  LITERAL('.NOT.')  THEN  TEMP = TEMP||' ¬ '    ;           APPD2330
        IF  BOOLEAN_PRIM  THEN  GO TO L1;                             APPD2332
        RETURN( '0'B );                                               APPD2334
    L1: RETURN( '1'B );                                               APPD2336
END BOOLEAN_SEC;                                                      APPD2338
                                                                      APPD2340
BOOLEAN_PRIM:  PROC          RETURNS( BIT(1) )   RECURSIVE;           APPD2342
        IF  LOGICAL_VALUE  THEN  RETURN( '1'B );                      APPD2344
        IF  RELATION  THEN  RETURN( '1'B );                           APPD2346
        IF  ¬LITERAL( '(' )  THEN  RETURN( '0'B );                    APPD2348
        TEMP = TEMP||' ( '    ;                                       APPD2350
        IF  ¬BOOLEAN_TERM  THEN  CALL ERROR;                          APPD2352
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                        APPD2354
        TEMP = TEMP||' ) '    ;                                       APPD2356
        RETURN( '1'B );                                               APPD2358
END BOOLEAN_PRIM;                                                     APPD2360
                                                                      APPD2362
RELATION:  PROC              RETURNS( BIT(1) )   RECURSIVE;           APPD2364
        IF  ¬SAE  THEN  RETURN( '0'B );                               APPD2366
        TEMP = TEMP||SO;                                              APPD2368
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        IF  ¬REL_OP  THEN  RETURN( '1'B );                          APPD2370
        IF  ¬SAE  THEN  CALL ERROR;                                 APPD2372
        TEMP = TEMP||SO;                                            APPD2374
        RETURN( '1'B );                                             APPD2376
END RELATION;                                                       APPD2378
                                                                    APPD2380
REL_OP:  PROC                  RETURNS( BIT(1) )   RECURSIVE;       APPD2382
        IF  LITERAL('.EQ.')  THEN  DO;                              APPD2384
                TEMP = TEMP||' = '  ;  GO TO L1;  END;              APPD2386
        IF  LITERAL('.NE.')  THEN  DO;                              APPD2388
                TEMP = TEMP||' ¬= '  ;  GO TO L1;  END;            APPD2390
        IF  LITERAL('.LT.')  THEN  DO;                              APPD2392
                TEMP = TEMP||' < '  ;  GO TO L1;  END;              APPD2394
        IF  LITERAL('.GT.')  THEN  DO;                              APPD2396
                TEMP = TEMP||' > '  ;  GO TO L1;  END;              APPD2398
        IF  LITERAL('.LE.')  THEN  DO;                              APPD2400
                TEMP = TEMP||' <= '  ;  GO TO L1;  END;            APPD2402
        IF  LITERAL('.GE.')  THEN  DO;                              APPD2404
                TEMP = TEMP||' >= '  ;  GO TO L1;  END;            APPD2406
        RETURN( '0'B );                                             APPD2408
    L1: RETURN( '1'B );                                             APPD2410
END REL_OP;                                                         APPD2412
                                                                    APPD2414
SAE:  PROC                     RETURNS( BIT(1) )   RECURSIVE;       APPD2416
        SO = ' ';                                                   APPD2418
        IF  INT  THEN  DO;  SO = STAR;  GO TO L1;  END;             APPD2420
        IF  DEST  THEN  GO TO L1;                                   APPD2422
        RETURN( '0'B );                                             APPD2424
    L1: RETURN( '1'B );                                             APPD2426
END SAE;                                                            APPD2428
                                                                    APPD2430
LOGICAL_VALUE:  PROC                        RETURNS( BIT(1) );      APPD2432
        IF  LITERAL('.TRUE.')  THEN  DO;                            APPD2434
                TEMP = TEMP||' ''1''B '  ;  GO TO L1;  END;         APPD2436
        IF  LITERAL('.FALSE.')  THEN  DO;                           APPD2438
                TEMP = TEMP||' ''0''B '  ;  GO TO L1;  END;         APPD2440
        RETURN( '0'B );                                             APPD2442
    L1: RETURN( '1'B );                                             APPD2444
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END LOGICAL_VALUE;                                                          APPD2446
                                                                            APPD2448
GO_TO_STMT:  PROC            RETURNS( BIT(1) )   RECURSIVE;                 APPD2450
        IF  ¬LITERAL( 'GO' )  THEN  RETURN( '0'B );                         APPD2452
        IF  ¬LITERAL( 'TO' )  THEN  CALL ERROR;                             APPD2454
        IF  ¬ID  THEN  CALL ERROR;                                          APPD2456
        LINE = ' GO TO '||STAR||';'   ;          CALL OUT(LINE);            APPD2458
        RETURN( '1'B );                                                     APPD2460
END GO_TO_STMT;                                                             APPD2462
                                                                            APPD2464
TRANSFER_STMT: PROC                    RETURNS( BIT(1) );                   APPD2466
        DCL   BACKUP          FIXED BINARY(31);                             APPD2468
        BACKUP = I;           /*  SAVE PTR TO TEXT POSITION  */             APPD2470
        TYPE = -1;      S0 = ' ';      S1 = ' ';            S2 = ' ';       APPD2472
                                                                            APPD2474
        IF  ¬DEST  THEN  RETURN( '0'B );                                    APPD2476
        IF  ¬LITERAL( '<-' )  THEN  DO;                                     APPD2478
                I = BACKUP;           /*  BACKUP  TEXT  PTR  */             APPD2480
                RETURN( '0'B );   END;                                      APPD2482
        IF  INT  THEN  DO;                                                  APPD2484
          L1: LINE = ' CALL #SET('||S0||','||STAR||');'    ;                APPD2486
                GO TO DONE;                                                 APPD2488
                     END;                                                   APPD2490
                                                                            APPD2492
        IF  UNARY_EXP  THEN  DO;                                            APPD2494
                IF  TYPE = 2  THEN  GO TO L2;                               APPD2496
                IF  TYPE = 3  THEN  GO TO L3;                               APPD2498
                IF  TYPE = 4  THEN  GO TO L4;                               APPD2500
                IF  TYPE = 5  THEN  GO TO L5;                               APPD2502
                IF  TYPE = 6  THEN  GO TO L6;                               APPD2504
                IF  TYPE = 7  THEN  GO TO L7;                               APPD2506
                IF  TYPE = 8  THEN  GO TO L8;                               APPD2508
                CALL ERROR;                                                 APPD2510
                           END;                                             APPD2512
                                                                            APPD2514
        IF  BINARY_EXP  THEN  DO;                                           APPD2516
                IF  TYPE =  0  THEN  GO TO L0;                              APPD2518
                IF  TYPE = 59  THEN  GO TO L9;                              APPD2520
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                IF  TYPE = 60  THEN  GO TO L10;                          APPD2522
                IF  TYPE = 61  THEN  GO TO L11;                          APPD2524
                IF  TYPE = 62  THEN  GO TO L12;                          APPD2526
                IF  TYPE = 63  THEN  GO TO L13;                          APPD2528
                IF  TYPE = 64  THEN  GO TO L14;                          APPD2530
                IF  TYPE = 65  THEN  GO TO L15;                          APPD2532
                IF  TYPE = 66  THEN  GO TO L16;                          APPD2534
                CALL ERROR;                                              APPD2536
                        END;                                             APPD2538
                                                                         APPD2540
    CALL ERROR;                                                          APPD2542
                                                                         APPD2544
 L0: LINE = ' '||S0||' = '||S1||';'   ;                                  APPD2546
    GO TO DONE;                                                          APPD2548
 L2: LINE = ' CALL UA#D('||S0||','||S2||');'   ;                         APPD2550
    GO TO DONE;                                                          APPD2552
 L3: LINE = ' CALL #UOR('||S0||','||S2||');'   ;                         APPD2554
    GO TO DONE;                                                          APPD2556
 L4: LINE = ' '||S0||' = ¬ '||S2||';'   ;                                APPD2558
    GO TO DONE;                                                          APPD2560
 L5: LINE = ' CALL US#L('||S0||','||S2||');'   ;                         APPD2562
    GO TO DONE;                                                          APPD2564
 L6: LINE = ' CALL US#R('||S0||','||S2||');'   ;                         APPD2566
    GO TO DONE;                                                          APPD2568
 L7: LINE = ' CALL CI#L('||S0||','||S2||');'   ;                         APPD2570
    GO TO DONE;                                                          APPD2572
 L8: LINE = ' CALL CI#R('||S0||','||S2||');'   ;                         APPD2574
    GO TO DONE;                                                          APPD2576
                                                                         APPD2578
 L9: LINE = ' CALL #ADD('||S0||','||S1||','||S2||');'   ;                APPD2580
    GO TO DONE;                                                          APPD2582
L10: LINE = ' CALL #SUB('||S0||','||S1||','||S2||');'   ;                APPD2584
    GO TO DONE;                                                          APPD2586
L11: LINE = ' CALL #BOR('||S0||','||S1||','||S2||');'   ;                APPD2588
    GO TO DONE;                                                          APPD2590
L12: LINE = ' CALL BA#D('||S0||','||S1||','||S2||');'   ;                APPD2592
    GO TO DONE;                                                          APPD2594
L13: LINE = ' CALL BX#R('||S0||','||S1||','||S2||');'   ;                APPD2596
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        GO TO DONE;                                                          APPD2598
   L14: LINE = ' CALL BS#L('||SO||',*||S1||',*||S2||');'    ;                APPD2600
        GO TO DONE;                                                          APPD2602
   L15: LINE = ' CALL BS#R('||SO||',*||S1||',*||S2||');'    ;                APPD2604
        GO TO DONE;                                                          APPD2606
   L16: LINE = ' CALL #CNT('||SO||',*||S1||',*||S2||');'    ;                APPD2608
        GO TO DONE;                                                          APPD2610
                                                                             APPD2612
  DONE: CALL OUT(LINE);                                                      APPD2614
        RETURN( '1'B );                                                      APPD2616
END TRANSFER_STMT;                                                           APPD2618
                                                                             APPD2620
  DEST: PROC                              RETURNS( BIT(1) );                 APPD2622
        DCL       R          CHAR(8)      VARYING;                           APPD2624
        DCL       I1         CHAR(8)      VARYING;                           APPD2626
        IF  ¬ID  THEN  RETURN( '0'B );                                       APPD2628
        R = STAR;                                                            APPD2630
        IF  ¬LITERAL( '(' )  THEN  DO;  SO = R;                              APPD2632
                                         GO TO L1;                           APPD2634
                                   END;                                      APPD2636
        IF  ID  THEN  DO;                                                    APPD2638
                IF  LITERAL( ')' )  THEN  DO;                                APPD2640
                     SO = R||'('||STAR||')'    ;                             APPD2642
                     GO TO L1;                 END;                        APPD2644
                                               ELSE  CALL ERROR;             APPD2646
                END;                                                         APPD2648
        IF  ¬INT  THEN  CALL ERROR;                                          APPD2650
        I1 = STAR;                                                           APPD2652
        IF  LITERAL(')')  THEN  DO; SO='$'||R||'('||STAR||')';               APPD2654
                                    GO TO L1;                                APPD2656
                                END;                                         APPD2658
        IF  ¬LITERAL('-')  THEN  CALL ERROR;                                 APPD2660
        IF  ¬INT  THEN  CALL ERROR;                                          APPD2662
        IF  ¬LITERAL(')')  THEN  CALL ERROR;                                 APPD2664
        SO = 'SUBSTR('||R||',*||I1||'+1,'||STAR||'-'||I1||'+1)'    ;         APPD2666
        GO TO L1;                                                            APPD2668
    L1: RETURN( '1'B );                                                      APPD2670
END DEST;                                                                    APPD2672
```

```
                                                                    APPD2674
UNARY_EXP: PROC                          RETURNS( BIT(1) );         APPD2676
        IF  ¬UNARY_OP  THEN  RETURN( '0'B );                        APPD2678
        IF  ¬UNARY_SOURCE  THEN  CALL ERROR;                        APPD2680
        RETURN( '1'B );                                             APPD2682
END UNARY_EXP;                                                      APPD2684
                                                                    APPD2686
UNARY_OP: PROC                           RETURNS( BIT(1) );         APPD2688
        IF  LITERAL('.AND.')  THEN DO;  TYPE = 2;  GO TO L1;  END;  APPD2690
        IF  LITERAL('.OR.')   THEN DO;  TYPE = 3;  GO TO L1;  END;  APPD2692
        IF  LITERAL('.NOT.')  THEN DO;  TYPE = 4;  GO TO L1;  END;  APPD2694
        IF  LITERAL('.SHL.')  THEN DO;  TYPE = 5;  GO TO L1;  END;  APPD2696
        IF  LITERAL('.SHR.')  THEN DO;  TYPE = 6;  GO TO L1;  END;  APPD2698
        IF  LITERAL('.CIRL.') THEN DO;  TYPE = 7;  GO TO L1;  END;  APPD2700
        IF  LITERAL('.CIRR.') THEN DO;  TYPE = 8;  GO TO L1;  END;  APPD2702
        RETURN( '0'B );                                             APPD2704
    L1: RETURN( '1'B );                                             APPD2706
END UNARY_OP;                                                       APPD2708
                                                                    APPD2710
UNARY_SOURCE: PROC                       RETURNS( BIT(1) );         APPD2712
        DCL       R          CHAR(8)     VARYING;                   APPD2714
        DCL       I1         CHAR(8)     VARYING;                   APPD2716
        IF  ¬ID  THEN  RETURN( '0'B );                              APPD2718
        R = STAR;                                                   APPD2720
        IF  ¬LITERAL( '(' )  THEN  DO;  S2 = R;                     APPD2722
                                         GO TO L1;                  APPD2724
                                   END;                             APPD2726
        IF  ID  THEN  DO;                                           APPD2728
                IF  LITERAL( ')' )  THEN  DO;                       APPD2730
                    S2 = R||'('||STAR||')'   ;                      APPD2732
                    GO TO L1;                END;                   APPD2734
                                         ELSE CALL ERROR;           APPD2736
                END;                                                APPD2738
        IF  ¬INT  THEN  CALL ERROR;                                 APPD2740
        I1 = STAR;                                                  APPD2742
        IF  LITERAL(')')  THEN  DO; S2='$'||R||'('||STAR||')';      APPD2744
                                    GO TO L1;                       APPD2746
                                END;                                APPD2748
```

```
        IF  ¬LITERAL('-')  THEN  CALL ERROR;                                    APPD2750
        IF  ¬INT  THEN  CALL ERROR;                                             APPD2752
        IF  ¬LITERAL(')')  THEN  CALL ERROR;                                    APPD2754
        S2 = 'SUBSTR('||R||','||I1||'+1,'||STAR||'-'||I1||'+1)'   ;             APPD2756
        GO TO L1;                                                               APPD2758
    L1: RETURN( '1'B );                                                         APPD2760
END UNARY_SOURCE;                                                               APPD2762
                                                                                APPD2764
BINARY_EXP: PROC                          RETURNS( BIT(1) );                    APPD2766
        IF  ¬OP1  THEN  RETURN( '0'B );                                         APPD2768
        IF  ¬BINARY_OP  THEN  DO;  TYPE = 0;  GO TO L1;  END;                   APPD2770
        IF  OP2  THEN  GO TO L1;                                                APPD2772
        IF  INT  THEN  DO;  S2 = STAR;  GO TO L1;  END;                         APPD2774
        CALL ERROR;                                                             APPD2776
    L1: RETURN( '1'B );                                                         APPD2778
END BINARY_EXP;                                                                 APPD2780
                                                                                APPD2782
BINARY_OP: PROC                           RETURNS( BIT(1) );                    APPD2784
        IF  LITERAL('.ADD.')  THEN  DO;  TYPE = 59;  GO TO L1;  END;            APPD2786
        IF  LITERAL('.SUB.')  THEN  DO;  TYPE = 60;  GO TO L1;  END;            APPD2788
        IF  LITERAL('.OR.')   THEN  DO;  TYPE = 61;  GO TO L1;  END;            APPD2790
        IF  LITERAL('.AND.')  THEN  DO;  TYPE = 62;  GO TO L1;  END;            APPD2792
        IF  LITERAL('.XOR.')  THEN  DO;  TYPE = 63;  GO TO L1;  END;            APPD2794
        IF  LITERAL('.SHL.')  THEN  DO;  TYPE = 64;  GO TO L1;  END;            APPD2796
        IF  LITERAL('.SHR.')  THEN  DO;  TYPE = 65;  GO TO L1;  END;            APPD2798
        IF  LITERAL('.CNT.')  THEN  DO;  TYPE = 66;  GO TO L1;  END;            APPD2800
        RETURN( '0'B );                                                         APPD2802
    L1: RETURN( '1'B );                                                         APPD2804
END BINARY_OP;                                                                  APPD2806
                                                                                APPD2808
   OP1: PROC                              RETURNS( BIT(1) );                    APPD2810
        DCL        R          CHAR(8)     VARYING;                              APPD2812
        DCL        I1         CHAR(8)     VARYING;                              APPD2814
        IF  ¬ID  THEN  RETURN( '0'B );                                          APPD2816
        R = STAR;                                                               APPD2818
        IF  ¬LITERAL( '(' )  THEN  DO;  S1 = R;                                 APPD2820
                                        GO TO L1;                               APPD2822
                                   END;                                         APPD2824
```

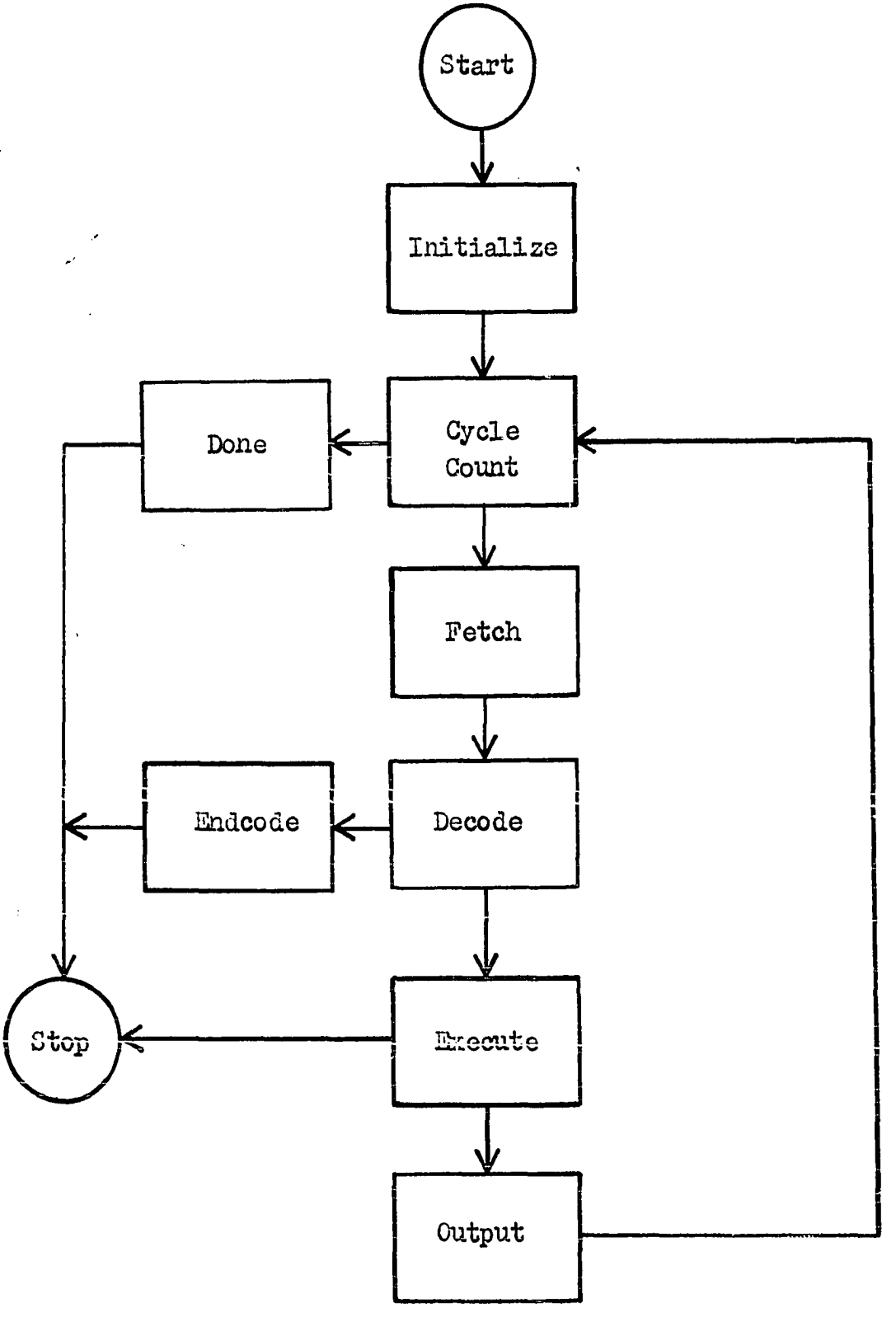
```
      IF  ID  THEN  DO;                                                    APPD2826
            IF  LITERAL( ')' )  THEN  DO;                                  APPD2828
                 S1 = R||'('||STAR||')'    ;                             APPD2830
                 GO TO L1;                 END;                          APPD2832
                                ELSE  CALL ERROR;                          APPD2834
            END;                                                           APPD2836
      IF  ¬INT  THEN  CALL ERROR;                                          APPD2838
      I1 = STAR;                                                           APPD2840
      IF  LITERAL(':')  THEN  DO; S1='$'||R||'('||STAR||')';               APPD2842
                                  GO TO L1;                                APPD2844
                              END;                                         APPD2846
      IF  ¬LITERAL('-')  THEN  CALL ERROR;                                 APPD2848
      IF  ¬INT  THEN  CALL ERROR;                                          APPD2850
      IF  ¬LITERAL(')')  THEN  CALL ERROR;                                 APPD2852
      S1 = 'SUBSTR('||R||',1'||I1||'+1,'||STAR||'-'||I1||'+1)'    ;        APPD2854
      GO TO L1;                                                            APPD2856
 L1:  RETURN( '1'B );                                                      APPD2858
END OP1;                                                                   APPD2860
                                                                           APPD2862
 OP2: PROC                          RETURNS( BIT(1) );                     APPD2864
      DCL       R          CHAR(8)   VARYING;                             APPD2866
      DCL       I1         CHAR(8)   VARYING;                             APPD2868
      IF  ¬ID  THEN  RETURN( '0'B );                                       APPD2870
      R = STAR;                                                            APPD2872
      IF  ¬LITERAL( '(' )  THEN  DO;  S2 = R;                              APPD2874
                                       GO TO L1;                           APPD2876
                                 END;                                      APPD2878
      IF  ID  THEN  DO;                                                    APPD2880
            IF  LITERAL( ')' )  THEN  DO;                                  APPD2882
                 S2 = R||'('||STAR||')'    ;                             APPD2884
                 GO TO L1;                 END;                          APPD2886
                                ELSE  CALL ERROR;                          APPD2888
            END;                                                           APPD2890
      IF  ¬INT  THEN  CALL ERROR;                                          APPD2892
      I1 = STAR;                                                           APPD2894
      IF  LITERAL(':')  THEN  DO; S2='$'||R||'('||STAR||')';               APPD2896
                                  GO TO L1;                                APPD2898
                              END;                                         APPD2900
```

```
        IF  ¬LITERAL('-')  THEN  CALL ERROR;                              APPD2902
        IF  ¬INT  THEN  CALL ERROR;                                       APPD2904
        IF  ¬LITERAL(')')  THEN  CALL ERROR;                              APPD2906
        S2 = 'SUBSTR('||R||',"||I1||'+1,'||STAR||'-'||I1||'+1)' ;         APPD2908
        GO TO L1;                                                         APPD2910
    L1: RETURN( '1'B );                                                   APPD2912
END OP2;                                                                  APPD2914
                                                                          APPD2916
TERMINAL_STMT:  PROC                    RETURNS( BIT(1) );                APPD2918
        DCL       BACKUP    FIXED BINARY(31);                             APPD2920
        S0 = ' ';             S1 = ' ';                                   APPD2922
        BACKUP = I;           /*  SAVE PTR TO TEXT POSITION  */           APPD2924
        IF  ¬TERMINAL  THEN  RETURN( '0'B );                              APPD2926
        IF  ¬LITERAL( ':=' )  THEN  DO;                                   APPD2928
                I = BACKUP;           /*  BACKUP  TEXT  PTR  */           APPD2930
                RETURN( '0'B );   END;                                    APPD2932
        TEMP = ' '||S0||' = '    ;                                        APPD2934
        IF  ¬LABEL  THEN  CALL ERROR;                                     APPD2936
        LINE = TEMP||';'    ;                                             APPD2938
        CALL OUT(LINE);                                                   APPD2940
        RETURN( '1'B );                                                   APPD2942
END TERMINAL_STMT;                                                        APPD2944
                                                                          APPD2946
TERMINAL:  PROC                         RETURNS( BIT(1) );                APPD2948
        DCL       R           CHAR(8)   VARYING;                          APPD2950
        IF  ¬ID  THEN  RETURN( '0'B );                                    APPD2952
        R = STAR;                                                         APPD2954
        IF  ¬LITERAL( '(' )  THEN  DO;  S0 = R;  GO TO L1;  END;          APPD2956
        IF  ¬INT  THEN  CALL ERROR;                                       APPD2958
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                            APPD2960
        S0 = '$'||R||'('||STAR||')'    ;                                  APPD2962
    L1: RETURN( '1'B );                                                   APPD2964
END TERMINAL;                                                             APPD2966
                                                                          APPD2968
LABEL:  PROC                            RETURNS( BIT(1) );                APPD2970
        IF  ¬TERM  THEN  RETURN( '0'B );                                  APPD2972
     L: IF  ¬BOP  THEN  GO TO L1;                                         APPD2974
        IF  ¬TERM  THEN  CALL ERROR;                                      APPD2976
```

```
        GO TO L;                                                        APPD2978
    L1: RETURN( '1'B );                                                 APPD2980
END LABEL;                                                              APPD2982
                                                                        APPD2984
TERM:  PROC                                 RETURNS( BIT(1) );          APPD2986
        IF  DEF1  THEN  GO TO L1;                                       APPD2988
        IF  DEF2  THEN  GO TO L1;                                       APPD2990
        RETURN( '0'B );                                                 APPD2992
    L1: RETURN( '1'B );                                                 APPD2994
END TERM;                                                               APPD2996
                                                                        APPD2998
DEF1:  PROC                                 RETURNS( BIT(1) );          APPD3000
        DCL       R          CHAR(8)   VARYING;                        APPD3002
        IF  ¬ID  THEN  RETURN( '0'B );                                  APPD3004
        R = STAR;                                                       APPD3006
        IF  ¬LITERAL( '(' )  THEN  DO;  S1 = R;  GO TO L1;  END;        APPD3008
        IF  ¬INT  THEN  CALL ERROR;                                     APPD3010
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPD3012
        S1 = '$'||R||'('||STAR||')'   ;                                 APPD3014
    L1: TEMP = TEMP||S1;                                                APPD3016
        RETURN( '1'B );                                                 APPD3018
END DEF1;                                                               APPD3020
                                                                        APPD3022
DEF2:  PROC                                 RETURNS( BIT(1) );          APPD3024
        IF  ¬LITERAL( '(' )  THEN  RETURN( '0'B );                      APPD3026
        IF  ¬ LITERAL( '¬' )  THEN  CALL ERROR;                         APPD3028
        TEMP = TEMP||' ¬ '   ;                                          APPD3030
        IF  ¬DEF1  THEN  CALL ERROR;                                    APPD3032
        IF  ¬LITERAL( ')' )  THEN  CALL ERROR;                          APPD3034
        RETURN( '1'B );                                                 APPD3036
END DEF2;                                                               APPD3038
                                                                        APPD3040
BOP:  PROC                                  RETURNS( BIT(1) );          APPD3042
        IF  LITERAL('*')  THEN  DO; TEMP=TEMP||' & '; GO TO L1; END;    APPD3044
        IF  LITERAL('+')  THEN  DO; TEMP=TEMP||' | '; GO TO L1; END;    APPD3046
        RETURN( '0'B );                                                 APPD3048
    L1: RETURN( '1'B );                                                 APPD3050
END BOP;                                                                APPD3052
```

```
                                                                        APPD3054
                                                                        APPD3056
                                                                        APPD3058
        /*  THIS IS THE END OF THE INTERNAL PROCEDURES  */              APPD3060
                                                                        APPD3062
                                                                        APPD3064
                                                                        APPD3066
                                                                        APPD3068
FINIS: PUT EDIT('END OF FILE SENSED ON SYSIN')(SKIP(2),COL(10),A);      APPD3070
  DONE:                                                                 APPD3072
        END COMPILE;                                                    APPD3074
```

Appendix 5. Simulator Flow Chart


Start
Initialize
Cycle Count
Done
Fetch
Decode
Endcode
Execute
Stop
Output

Appendix 6. DCLS

```
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPF1010
        /*                                                               */APPF1020
        /*                              DCLS                             */APPF1030
        /*                                                               */APPF1040
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPF1050
                                                                          APPF1060
                                                                          APPF1070
/*  %INCLUDE  DCLS;  */                                                  APPF1080
        /*  STANDARD  DECLARES  */                                       APPF1090
        DECLARE                                                           APPF1100
        OVERFLOW  BIT(1),                                                 APPF1110
        #SET      ENTRY( BIT(*),FIXED BINARY(31) ),                       APPF1120
        UA#D      ENTRY( BIT(*), BIT(*) ),                                APPF1130
        #UOR      ENTRY( BIT(*), BIT(*) ),                                APPF1140
        US#L      ENTRY( BIT(*), BIT(*) ),                                APPF1150
        US#R      ENTRY( BIT(*), BIT(*) ),                                APPF1160
        CI#L      ENTRY( BIT(*), BIT(*) ),                                APPF1170
        CI#R      ENTRY( BIT(*), BIT(*) ),                                APPF1180
        #ADD      ENTRY( BIT(*), BIT(*), BIT(*) ),                        APPF1190
        #SUB      ENTRY( BIT(*), BIT(*), BIT(*) ),                        APPF1200
        #BOR      ENTRY( BIT(*), BIT(*), BIT(*) ),                        APPF1210
        BA#D      ENTRY( BIT(*), BIT(*), BIT(*) ),                        APPF1220
        BX#R      ENTRY( BIT(*), BIT(*), BIT(*) ),                        APPF1230
        BS#L      ENTRY( BIT(*), BIT(*), FIXED BINARY(31) ),              APPF1240
        BS#R      ENTRY( BIT(*), BIT(*), FIXED BINARY(31) ),              APPF1250
        #CNT      ENTRY( BIT(*), BIT(*), FIXED BINARY(31) ),              APPF1260
        #TEMP     BIT(32)   VARYING,                                      APPF1270
        C#CLE     FIXED BINARY(31)    INITIAL(0),                         APPF1280
        CH#CK     FIXED BINARY(31);                                       APPF1290
        GO TO INITI#L;                                                    APPF1300
                                                                          APPF1310
  #NCR: C#CLE = C#CLE + 1;                                                APPF1320
        IF  C#CLE>CH#CK  THEN  GO TO D#NE;                                APPF1330
        GO TO F#TCH;                                                      APPF1340
                                                                          APPF1350
  HE#D: PUT FILE(SYSPRINT) EDIT                                           APPF1360
        ('THIS IS A RUN OF THE ''BAPSIM'' SIMULATOR')                     APPF1370
        (PAGE,LINE(2),COL(40),A);                                         APPF1380
```

```
GO TO #NCR;                                                    APPF1390
/*  END  OF  STANDARD  DECLARES  */                            APPF1400
```

Appendix 7. ENDCODE

```
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPG1010
        /*                                                                 */APPG1020
        /*                              ENDCODE                            */APPG1030
        /*                                                                 */APPG1040
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPG1050
                                                                             APPG1060
                                                                             APPG1070
/*  %INCLUDE ENDCODE;  */                                                   APPG1080
        /*  ENDCODE  STATEMENTS  FOLLOW  */                                 APPG1090
        PUT FILE(SYSPRINT) EDIT                                             APPG1100
        ('***  ILLEGAL OP CODE  -  SIMULATION ABORTED  ***')                APPG1110
        (SKIP(5),COL(10),A);                                                APPG1120
        CLOSE FILE(SYSPRINT);                                               APPG1130
        STOP;                                                               APPG1140
        /*  END  OF  ENDCODE  */                                            APPG1150
```

Appendix 8. PRIMPROC

```
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPH1010
        /*                                                                 */APPH1020
        /*                          PRIMPROC                               */APPH1030
        /*                                                                 */APPH1040
        /* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * */APPH1050
                                                                            APPH1060
                                                                            APPH1070
/*  %INCLUDE PRIMPROCS;  */                                                APPH1080
        /*  THE  PRIMITIVE  OPERATIONS  FOLLOW  */                         APPH1090
                                                                            APPH1100
                                                                            APPH1110
  #SET: PROC(REG,INT);                                                      APPH1120
        DCL         REG         BIT(*),                                     APPH1130
                    INT         FIXED BINARY(31);                           APPH1140
        REG = SUBSTR( UNSPEC(INT), 33-LENGTH(REG) );                        APPH1150
        END #SET;                                                           APPH1160
                                                                            APPH1170
                                                                            APPH1180
  UA#D: PROC(DEST,SOURCE);                                                  APPH1190
        DCL         (DEST,SOURCE)         BIT(*);                         APPH1200
        IF  LENGTH(DEST)¬=1  THEN                                           APPH1210
            PUT  FILE(SYSPRINT)  EDIT                                       APPH1220
            ('***  LENGTH ERROR -- UA#D PROCEDURE  ***')                    APPH1230
            (SKIP(5),COL(10),A);                                            APPH1240
        DO  I = 1  TO  LENGTH(SOURCE)  BY  1;                               APPH1250
            IF  SUBSTR(SOURCE,I,1) = '0'B  THEN  GO TO L1;                  APPH1260
            END;                                                            APPH1270
        DEST = '1'B;                                                        APPH1280
        RETURN;                                                             APPH1290
    L1: DEST = '0'B;                                                        APPH1300
        END UA#D;                                                           APPH1310
                                                                            APPH1320
                                                                            APPH1330
  #UOR: PROC(DEST,SOURCE);                                                  APPH1340
        DCL         (DEST,SOURCE)         BIT(*);                         APPH1350
        IF  LENGTH(DEST)¬=1  THEN                                           APPH1360
            PUT  FILE(SYSPRINT)  EDIT                                       APPH1370
            ('***  LENGTH ERROR -- #UOR PROCEDURE  ***')                    APPH1380
```

```
          (SKIP(5),COL(10),A);                                          APPH1390
      DO  I = 1  TO  LENGTH(SOURCE)  BY  1;                             APPH1400
          IF  SUBSTR(SOURCE,I,1) = '1'B  THEN  GO TO L1;                APPH1410
          END;                                                          APPH1420
      DEST = '0'B;                                                      APPH1430
      RETURN;                                                           APPH1440
L1:   DEST = '1'B;                                                      APPH1450
      END #UOR;                                                         APPH1460
                                                                        APPH1470
                                                                        APPH1480
US#L: PROC(DEST,SOURCE);                                                APPH1490
      DCL         (DEST,SOURCE)         BIT(*);                       APPH1500
      IF  LENGTH(DEST) ¬= LENGTH(SOURCE)  THEN                          APPH1510
          PUT  FILE(SYSPRINT)  EDIT                                     APPH1520
          ('***  LENGTH ERROR -- US#L PROCEDURE  ***')                  APPH1530
          (SKIP(5),COL(10),A);                                          APPH1540
 SUBSTR(DEST,1,LENGTH(DEST)-1) = SUBSTR(SOURCE,2,LENGTH(SOURCE)-1);     APPH1550
      SUBSTR(DEST,LENGTH(DEST),1) = '0'B;      /*  ZERO  FILL  */      APPH1560
      END US#L;                                                         APPH1570
                                                                        APPH1580
                                                                        APPH1590
US#R: PROC(DEST,SOURCE);                                                APPH1600
      DCL         (DEST,SOURCE)         BIT(*);                       APPH1610
      IF  LENGTH(DEST) ¬= LENGTH(SOURCE)  THEN                          APPH1620
          PUT  FILE(SYSPRINT)  EDIT                                     APPH1630
          ('***  LENGTH ERROR -- US#R PROCEDURE  ***')                  APPH1640
          (SKIP(5),COL(10),A);                                          APPH1650
      SUBSTR(DEST,2) = SUBSTR(SOURCE,1,LENGTH(SOURCE)-1);               APPH1660
      SUBSTR(DEST,1,1) = '0'B;       /*  ZERO  FILL  */               APPH1670
      END US#R;                                                         APPH1680
                                                                        APPH1690
                                                                        APPH1700
CI#L: PROC(DEST,SOURCE);                                                APPH1710
      DCL         (DEST,SOURCE)         BIT(*),                       APPH1720
                  TEMP       BIT(1);                                    APPH1730
      IF  LENGTH(DEST) ¬= LENGTH(SOURCE)  THEN                          APPH1740
          PUT  FILE(SYSPRINT)  EDIT                                     APPH1750
          ('***  LENGTH ERROR -- CI#L PROCEDURE  ***')                  APPH1760
```

```
          (SKIP(5),COL(10),A);                                                    APPH1770
      TEMP = SUBSTR(SOURCE,1,1);                                                  APPH1780
 SUBSTR(DEST,1,LENGTH(DEST)-1) = SUBSTR(SOURCE,2,LENGTH(SOURCE)-1);               APPH1790
      SUBSTR(DEST,LENGTH(DEST),1) = TEMP;      /*  END   AROUND  */              APPH1800
      END CI#L;                                                                   APPH1810
                                                                                  APPH1820
                                                                                  APPH1830
CI#R: PROC(DEST,SOURCE);                                                          APPH1840
      DCL         (DEST,SOURCE)        BIT(*),                                    APPH1850
                  TEMP       BIT(1);                                             APPH1860
      IF  LENGTH(DEST) ¬= LENGTH(SOURCE)  THEN                                    APPH1870
           PUT  FILE(SYSPRINT)  EDIT                                              APPH1880
           ('***  LENGTH ERROR -- CI#R PROCEDURE  ***')                          APPH1890
           (SKIP(5),COL(10),A);                                                   APPH1900
      TEMP = SUBSTR(SOURCE,LENGTH(SOURCE),1);                                     APPH1910
 SUBSTR(DEST,2,LENGTH(DEST)-1) = SUBSTR(SOURCE,1,LENGTH(SOURCE)-1);               APPH1920
      SUBSTR(DEST,1,1) = TEMP;                 /*  END  AROUND  */               APPH1930
      END CI#R;                                                                   APPH1940
                                                                                  APPH1950
                                                                                  APPH1960
#ADD: PROC(DEST,S1,S2);                                                           APPH1970
      DCL         (DEST,S1,S2)         BIT(*);                                    APPH1980
      #TEMP = S1 + S2;     /*  CONVERSION  HERE  */                              APPH1990
      DEST = SUBSTR( #TEMP, 32 - LENGTH(DEST) );                                  APPH2000
      OVERFLOW = SUBSTR( #TEMP, 31 - LENGTH(DEST), 1 );                           APPH2010
      END #ADD;                                                                   APPH2020
                                                                                  APPH2030
                                                                                  APPH2040
#SUB: PROC(DEST,OP1,OP2);                                                         APPH2050
      DCL         (DEST,OP1,OP2)       BIT(*);                                    APPH2060
      IF  OP2 > OP1  THEN                                                         APPH2070
           PUT  FILE(SYSPRINT)  EDIT                                              APPH2080
           ('***  MAGNITUDE ERROR -- #SUB PROCEDURE  ***')                       APPH2090
           (SKIP(5),COL(10),A);                                                   APPH2100
      #TEMP = OP1 - OP2;                /*  CONVERSION  HERE  */                APPH2110
      DEST = SUBSTR(#TEMP, 32-LENGTH(DEST));                                      APPH2120
      END #SUB;                                                                   APPH2130
                                                                                  APPH2140
```

```
#BOR:  PROC(DEST,OP1,OP2);                                          APPH2150
       DCL        (DEST,OP1,OP2)       BIT(*);                     APPH2160
       IF  LENGTH(OP1) ¬= LENGTH(OP2)  THEN                        APPH2170
            PUT  FILE(SYSPRINT)  EDIT                              APPH2180
            ('***  LENGTH ERROR -- #BOR PROCEDURE  ***')           APPH2190
            (SKIP(5),COL(10),A);                                   APPH2200
       DEST = OP1 | OP2;                                           APPH2210
       END #BOR;                                                   APPH2220
                                                                   APPH2230
                                                                   APPH2240
BA#D:  PROC(DEST,OP1,OP2);                                         APPH2250
       DCL        (DEST,OP1,OP2)       BIT(*);                     APPH2260
       IF  LENGTH(OP1) ¬= LENGTH(OP2)  THEN                        APPH2270
            PUT  FILE(SYSPRINT)  EDIT                              APPH2280
            ('***  LENGTH ERROR -- BA#D PROCEDURE  ***')           APPH2290
            (SKIP(5),COL(10),A);                                   APPH2300
       DEST = OP1 & OP2;                                           APPH2310
       END BA#D;                                                   APPH2320
                                                                   APPH2330
                                                                   APPH2340
                                                                   APPH2350
BX#R:  PROC(DEST,OP1,OP2);                                         APPH2360
       DCL        (DEST,OP1,OP2)       BIT(*);                     APPH2370
       IF  LENGTH(OP1) ¬= LENGTH(OP2)  THEN                        APPH2380
            PUT  FILE(SYSPRINT)  EDIT                              APPH2390
            ('***  LENGTH ERROR -- BX#R PROCEDURE  ***')           APPH2400
            (SKIP(5),COL(10),A);                                   APPH2410
       DO  I = 1  TO  LENGTH(OP1)  BY  1;                          APPH2420
         IF  SUBSTR(OP1,I,1)='1'B & SUBSTR(OP2,I,1)='1'B           APPH2430
         THEN  SUBSTR(DEST,I,1) = '1'B;                            APPH2440
         ELSE  SUBSTR(DEST,I,1) = '0'B;                            APPH2450
         END;                                                      APPH2460
       END BX#R;                                                   APPH2470
                                                                   APPH2480
                                                                   APPH2490
BS#L:  PROC(DEST,SOURCE,INT);                                      APPH2500
       DCL        (DEST,SOURCE)        BIT(*),                     APPH2510
                  INT          FIXED BINARY(31);                   APPH2520
```

```
     IF  LENGTH(DEST) ¬= LENGTH(SOURCE)  THEN                          APPH2530
          PUT  FILE(SYSPRINT)  EDIT                                    APPH2540
          ('***  LENGTH ERROR -- BS#L PROCEDURE  ***')                 APPH2550
          (SKIP(5),COL(10),A);                                         APPH2560
     IF  INT>=LENGTH(SOURCE)  THEN  DO; DEST='0'B;  GO TO L1; END;     APPH2570
     DEST = SUBSTR(SOURCE,INT+1);                                      APPH2580
L1:  END BS#L;                                                         APPH2590
                                                                       APPH2600
                                                                       APPH2610
BS#R: PROC(DEST,SOURCE,INT);                                           APPH2620
     DCL       (DEST,SOURCE)       BIT(*),                           APPH2630
               INT        FIXED BINARY(31);                           APPH2640
     IF  LENGTH(DEST) ¬= LENGTH(SOURCE)  THEN                          APPH2650
          PUT  FILE(SYSPRINT)  EDIT                                    APPH2660
          ('***  LENGTH ERROR -- BS#R PROCEDURE  ***')                 APPH2670
          (SKIP(5),COL(10),A);                                         APPH2680
     IF  INT>=LENGTH(SOURCE)  THEN  DO; DEST='0'B;  GO TO L1; END;     APPH2690
     #TEMP = SOURCE/(2**INT);       /*  CONVERSION  HERE  */          APPH2700
     DEST = SUBSTR( #TEMP, 32 - LENGTH(DEST) );                        APPH2710
L1:  END BS#R;                                                         APPH2720
                                                                       APPH2730
                                                                       APPH2740
     /*  THIS IS THE END OF THE PRIMITIVE OPERATIONS  */               APPH2750
```