SAM/SAL Report and User Manual

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This document describes the SAM/SAL system implemented at the University of Colorado during 1980. SAM is a Static Analysis Machine with a Static Analysis Language, SAL. The main purpose of SAM/SAL is to specify arbitrary programming languages so that when programs in the specified language are run through the SAM/SAL system, an annotated flowgraph representation of the program is generated.

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Abstract

This document describes the SAM/SAL system implemented at the University of Colorado during 1980. SAM is a Static Analysis Machine with a Static Analysis Language, SAL. The main purpose of SAM/SAL is to specify arbitrary programming languages so that when programs in the specified language are run through the SAM/SAL system, an annotated flowgraph representation of the program is generated.

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CHAPTER 1

The SAM/SAL System

1.1. Introduction

1.1.1. Purpose

This document describes the SAM/SAL system implemented at the University of Colorado during 1980. SAM, an acronym for Static Analysis Machine, is the current name given to the whole system. SAL, an acronym for Static Analysis Language, is the specification language provided by SAM through which most of SAM's descriptive capabilities are manifested. Since SAL is such an integral part of the overall system, the system will often be referred to as SAM/SAL.

The main purpose of SAM/SAL is to provide a capability for specifiying arbitrary programming languages. A specification is to be aimed at generating annotated flowgraphs for programs written in the specified language. An annotation is regarded as a defined action occurring to a set of defined objects. As an example, in a specification of the language PASCAL, the user might want the PASCAL statement

X := Y+Z

to generate a single flowgraph node n which is annotated with the action REFERENCE to the set of objects {Y,Z} and DEFINE to the set of objects {X}. In this case, the user must be able to declare X, Y and Z as objects of some class, declare the actions DEFINE and REFERENCE to be valid on subsets of objects from this class, and specify that the assignment statement above results in the creation of a flowgraph node.

Figure 1.1 gives a graphic description of how SAM/SAL works. At the top of the figure, a specification program S is submitted to SAL for compilation. Outputs from SAL are then fed to an automatic parser generator and to a semantic evaluator generator. A parser and semantic evaluator are then produced. A typical program U written in the language specified by S can then be fed to the generated parser; the parser output is in turn fed to the generated semantic evaluator; and the semantic evaluator in turn produces the desired annotated flowgraphs associated with the program U as specified by S.

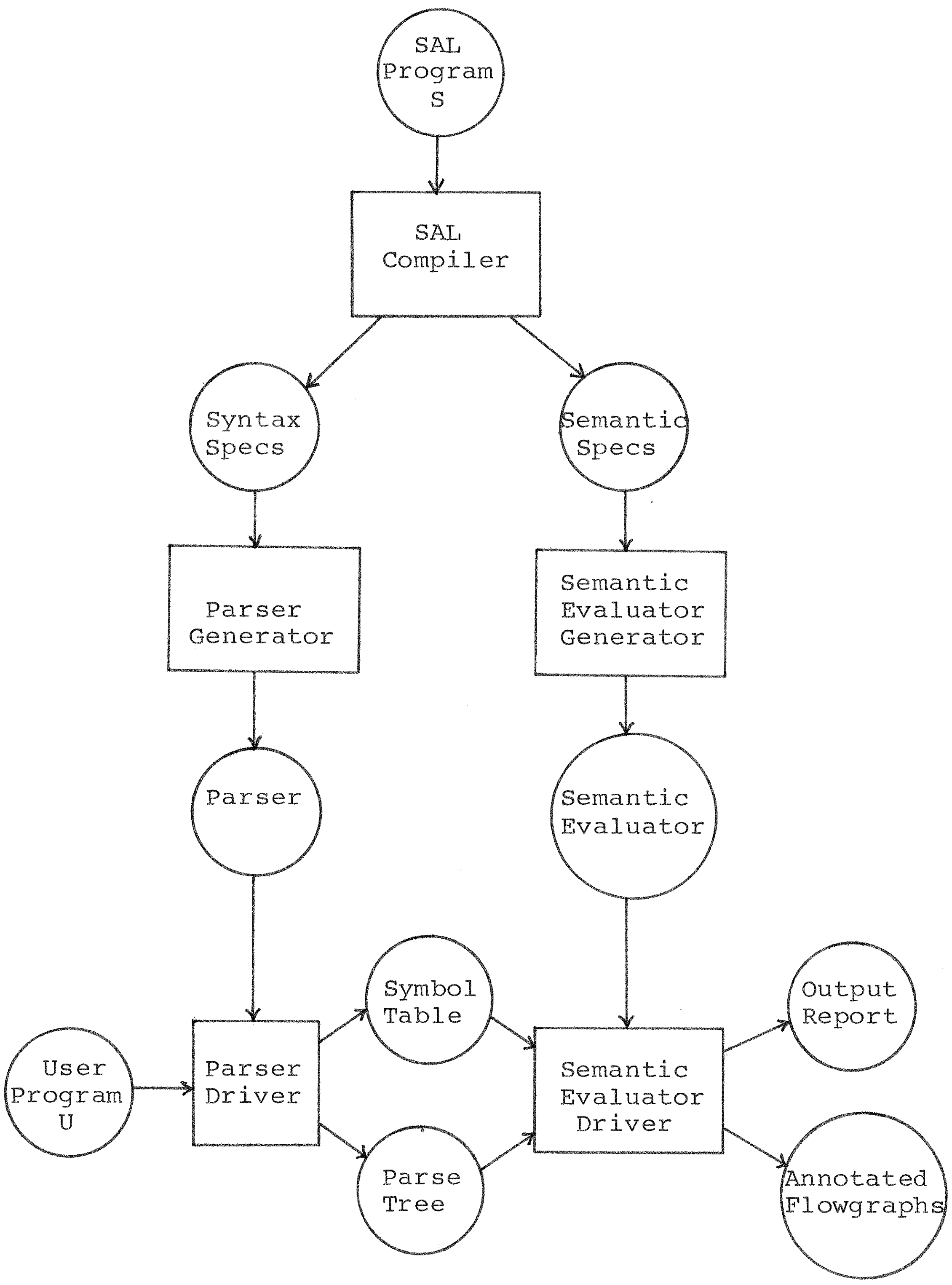

Figure 1.1 SAM/SAL System

Two output files are generated by the semantic evaluator.

(1) Listings File.

The listings file contains (a) any system error messages resulting from the semantic evaluation phase, (b) any special output requested by the user, and (c) a listing of program statistics.

(2) Tables File.

The tables file is automatically generated by the semantic evaluator upon successful semantic analysis of the input. Primarily, this file contains a dump of the symbol table, callgraph and flowgraphs generated by the semantic evaluator for the input.

Details on how this system works on the CU CDC-Cyber system are given in Appendix A.

1.1.2. Motivation

Research directed by Drs. Leon J. Osterweil and Lloyd D. Fosdick has lead to the design and implementation of a software tool, DAVE, which automatically detects certain static-semantic and data-flow errors in ANSI Standard Fortran programs [Fosd 76]. We recently completed a prototype of a revised version of DAVE which facilitates automatic modifications for some dialects of Fortran. Unfortunately, all semantic specifications must be manually redesigned for each such dialect.

The SAM/SAL system was motivated by the desire to have a fully automated system which eliminates the ad hoc manner of specifying programming languages and their dialects.

1.2. Design Requirements

SAL is a specification language in which other (procedural) programming languages are described. SAL was designed to have the power to capture all syntax and semantic descriptions of a large class of programming languages, specifically for the purpose of generating annotated flowgraphs for sample programs written in the specified language.

The device used for semantic specifications is a modified form of attributed grammars [Knuth 68]. It was the intent of this design to take advantage of existing reliable, portable software tools. At a high level, we were able to use an automatic parser generating system, CLEMSW, implemented on the CU CDC Cyber by Geoffrey Clemm [Clemml

79]. The interface to this parse generator is automatically provided by the SAM/SAL system. The SAL compiler itself and the main driver for the semantic evaluator are written in a slightly extended version of PASCAL. This allows modifications and extensions to be made to the SAL compiler very easily, while providing reliable object code by taking advantage of an already existing compiler. (This also lends some portability to the SAM/SAL system -- a property not originally in the design requirements and not completely demonstrated yet). At the time of implementation, no CDC Cyber attribute grammar systems were known to be available. Consequently, the remainder of the SAM/SAL system was completely designed and implemented from scratch.

1.3. Synax Notation

Below is a description of the context-free syntax used to describe SAL. This notation is a variant of the Backus-Naur Form.

(a) Angled brackets enclose grammar variables, for example

```
<PROGRAM>          <LIST OF ATTRIBUTES>
<STATEMENT>        <SUB 12>
```

(b) Double-angled brackets enclose grammar variables whose syntax and semantic rules are given in the PASCAL Report and User's Manual [Jensen 74], for example

```
<<TYPE>>          <<PROCEDURE OR FUNCTION DECLARATION>>

<<IDENTIFIER>>
```

(c) Reserved words and delimiters are enclosed in double quotes, for example

```
":="        ";"        "BEGIN"        "OBJECT"
```

(d) Square brackets enclose optional items, for example

```
<PROGRAM HEADING> [<PREAMBLE PART>] <DECLARATION PART>
```

(e) Braces enclose a repeated item. The item may appear zero or more times, for example

```
<IDENT LIST> ::= <IDENTIFIER> {"," <IDENTIFIER>}
```

1.4. Language Outline

A SAL program is given by

```
<SAL PROGRAM> ::= "PROGRAM" <<IDENTIFIER>> ";"
                      [<PREAMBLE SPECIFICATIONS>]
                      <DECLARATION SPECIFICATIONS>
                      <LANGUAGE SPECIFICATIONS>
                      <PROCEDURE SPECIFICATIONS> "."
```

Each of the four specification parts are described in detail in Chapters 3 through 6 of this report. The program name <<IDENTIFIER>> has no functional purpose other than to name the SAL program.

A SAL program specifies a single programming language. In some cases, the SAL program itself may serve as the definition of the language. However, the intended use of a SAL program is only to capture enough of the semantics of a language (generally defined by other methods) to result in the generation of annotated flowgraphs for programs written in the specified language. As a result, not all language semantics are necessarily specified.

CHAPTER 2

Lexical Elements

This chapter defines the lexical elements of SAL.

2.1. Characters

The basic character set consists of letters, digits, special characters, the space character, and the end-of-line character (denoted by EOL).

(a) Letters

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Implementation restrictions require that only upper case letters be allowed.

(b) Digits

0 1 2 3 4 5 6 7 8 9

(c) Special characters

" # $ ( ) [ ] < > + - / * , . ; : =

(d) The space character.

(e) The end-of-line character.

2.2. Comments

SAL recognizes two forms of comments:

(1) Inline comments

The construct

```
(* <any sequence of characters not containing "*)" > *)
```

is an inline comment. Below are two examples of inline comments.

```
(* THIS IS A COMMENT ON ONE LINE *)

(*
     THIS IS A COMMENT
     OVER FOUR LINES
*)
```

(2) Endline comments

The constructs

```
# <any sequence of characters except EOL> EOL
```

or

```
$ <any sequence of characters except EOL> EOL
```

are endline comments. An example of an endline comment is

```
#
# ENDLINE COMMENTS ARE
# NICE FOR RUNNING TEXT
# ALONG SIDE ACTUAL SAL
# CODE.
#
```

All endline comments begin with a "#" or "$" and are terminated by the next end-of-line. An endline comment beginning with "$" in addition causes a page-eject to occur starting with the next line following the EOL.

2.3. Lexical Units

The lexical units of SAL include names, numbers, delimiters, and literals. Except as explicitly provided, no lexical unit may contain imbedded spaces, comments, or EOL's.

2.3.1. Names

There are essentially three types of names recognized as primitive token units:

(a) Identifiers

The syntax for identifiers is as in the PASCAL Report, and as such its token unit type is denoted by <<IDENTIFIER>> (see Section 1.3(b)).

The _length_ of an identifier is the number of characters comprising its string.

Examples

```
    START     SUB1     A2B3     SAL     X12345
```

(b) Grammar identifiers

The syntax for <GRAMMAR IDENTIFIER> is

```
<GRAMMAR IDENTIFIER> ::=
          "<" <LETTER> {<LETTER>|<DIGIT>|" "} ">"
```

The length of a grammar identifier is the number of characters between its enclosing angled brackets.

Examples

```
    <PROGRAM>                <DECLARATION PART>
    <STATEMENT LIST>         <FORTRAN 4>
```

(c) Qualified grammar identifiers

The syntax for the token unit <QUAL GRAMMAR IDENTIFIER> is

```
    <QUAL GRAMMAR IDENTIFIER> ::=
         "<" <LETTER> {<LETTER>|<DIGIT>|" "}
               "(" <DIGIT> {<DIGIT>} ")" ">"
```

The length of a qualified grammar identifier is the number of characters between its enclosing angled brackets minus its parenthetic qualifier.

Examples

Qualified Grammar Identifier	Length
<PROGRAM(1)>	7
<FORTRAN 4(3)>	9
<STATEMENT LIST(2)>	14
<A1 23 B(1)>	7

2.3.2. Numbers

There are two types of numbers recognized by SAL as token units.

(a) Integers

The syntax for integers is

```
<INTEGER> ::= <<UNSIGNED INTEGER>>
```

Examples

```
12345        22222       5432       0
```

(b) Reals

The syntax for reals is

```
<REAL> ::= <<UNSIGNED REAL>>
```

Examples

```
1.4        25.6E-13        5.0E+12
0.3        1.498E1         3.14159
```

2.3.3. Literals

The token unit <LITERAL> is any sequence of characters not containing EOL and enclosed between two double quotes. To include a double quote in the literal, one writes the quote mark twice.

The length of a literal is the number of characters between the two enclosing double quotes. Two consecutive double quotes appearing within the literal are counted as a single character.

Examples

```
"1"   and  " "              are two literals of length one.
"AB"  and  """"""           are two literals of length two.
"IS THIS A ""LITERAL""?"    is a literal of length 20.
```

A literal must have a length greater than zero.

2.3.4. Delimiters

The characters

```
( ) [ ] + * / - , . ; : < > =
```

serve as one-character delimiters.
The character strings

`<>    <=    >=    :=    ..`

serve as two-character delimiters.
The character string

`::=`

serves as a three-character delimiter.

2.3.5. Lexical-Unit Restrictions

The current SAM/SAL implementation restricts the length of an identifier (2.3.1(a)), grammar identifier (2.3.1(b)), and qualified grammar identifier (2.3.1(c)) to be no more than 30 characters. The length of a literal (2.3.3) may be no more than 15 characters.

2.4. Spaces

All lexical units may be seperated by sequences of spaces, comments, or EOL's. The use of spaces, comments, and EOL's is mainly to provide readability and textual organization to the source program.

2.5. Reserved Words

The following identifiers are reserved words. The SAL programmer may not use reserved words in a context other than that explicit in the definition of SAL.

ACTION	DO	LABEL	PREAMBLE	SPECIFICATIONS
ACTIONS	DOWNTO	LANGUAGE	PROCEDURE	SYNTAX
AND	ELSE	MOD	PROGRAM	THEN
ARRAY	END	NIL	RECORD	TO
ATTRIBUTE	FILE	NODE	REPEAT	TOKEN
ATTRIBUTES	FLOWGRAPH	NOT	RETURN	TYPE
BEGIN	FOR	OBJECT	RULES	TYPES
CASE	FUNCTION	OF	SCANNER	UNTIL
CLASSES	GOTO	OR	SEMANTIC	VAR
CONST	GRAMMAR	OTHER	SEMANTICS	WHILE
DECLARATIONS	IF	PACKED	SET	WITH
DIV	IN			

CHAPTER 3

Preamble

A given implementation of SAM/SAL is expected to provide a standard environment of resources needed to aid the SAL programmer in a language specification. The standard environment should provide:

(a) A default lexical scanner.

(b) Predefined data-structures to represent

(1) Callgraph nodes and edges
(2) Flowgraph nodes and edges
(3) Object Classes
(4) Actions

(c) Appropriate predefined accessing functions and procedures for these structures.

A SAL preamble is an optional specification which allows the user to extend or somewhat control this standard environment. Through the preamble, some implementation considerations (which are otherwise meant to be invisible to the user) are made visible. The form of a preamble is given by

```
    <PREAMBLE SPECIFICATION> ::=
                   "PREAMBLE"
                       { <IMPLEMENTATION SPECS> }
                   "END" "PREAMBLE"
```

where the form and the content of the implementation specifications may vary from one installation to another. The current implementation specifications allowed on the CU CDC Cyber include (a) a capability to override the default lexical scanner by introducing another scanner more specific to the language being defined; (b) some capability to control data-structure memory allocation; and (c) the capability to control the form of the parser-grammar output. These three capabilities are elaborated below.

3.1. Scanner Specification

This would be given by

```
    <IMPLEMENTATION SPEC> ::= <SCANNER>
```

where the form of the scanner is as described in [Clemm2 79]. The scanner must return four "kept" token types.

(1) "IDNTFR" corresponding to <IDENTIFIER> in the user-specified grammar.

(2) "STRING" corresponding to <STRING> in the user-specified grammar.

(3) "CNSTNT" corresponding to <CONSTANT> in the user-specified grammar.

(4) "FLOAT" corresponding to <FLOAT> in the user-specified grammar.

In addition,

(5) if the user-specified grammar uses any special character as a literal token unit and that character always appears in literals of only length 1, then that character is to be returned as the token type "SINGLE" from the scanner, and

(6) if the user-specified grammar uses any special character as a literal token unit and that character may appear in at least one literal of length greater than one, then that character is to be returned by the scanner as the token type "MANY".

3.2. Data Structure Control

All data structures provided by the standard environment have a default size. Most of these structures may have their default size changed by assigning a new size-value to an appropriate identifier in the preamble. Such assignments are given by the following syntax

```
    <IMPLEMENTATION SPEC> ::=
             <PREAMBLE ID> "=" <INTEGER> ";"
```

where

```
    <PREAMBLE ID> ::= "MAXSETS"      | "MAXSETSIZE" |
                      "MAXDPNODES"   | "MAXEDGES"   |
                      "MAXSYM"       | "MAXCHAR"    |
                      "MAXATTBLCK"   | "MAXPACKET"  |
                      "MAXPARSENODES"
```

3.2.1. MAXSETS (default 100)

This determines the number of SETS to be reserved in the SAM/SAL set-pool. The amount of memory allocated for sets is then given by MAXSETS*MAXSETSIZE words.

3.2.2. MAXSETSIZE (default 10)

This determines the number of words to be used in a set. For the CU CDC Cyber 59 bits of each word are used. Thus if MAXSETSIZE=3 then each set represents 3 x 59 = 177 objects.

3.2.3. MAXDPNODES (default 2000)

.his determines the maximum number of dependency-graph nodes that will be reserved by the semantic evaluator phase. This graph controls the processing during semantic evaluation and is of no direct interest to the user except that its default size may be inadequate for semantic evaluation of large source programs written in the language specified.

3.2.4. MAXEDGES (default 2500)

This determines the maximum number of dependency-graph edges that will be reserved by the semantic evaluator phase. This may need to be explicitly set if the default value is inadequate for semantic evaluation of large source programs written in the specified language.

3.2.5. MAXPARSENODES (default 1000)

This determines the maximum number of parse-tree nodes that will be reserved for the semantic evaluator phase. This may need to be explicitly set if the default value is inadequate for semantic evaluation of large source programs written in the specified language. On the present implementation, each parse-tree node is two central memory words.

3.2.6. MAXSYM (default 250)

This determines the maximum number of symbol entries that will be reserved for the symbol table during the semantic evaluator phase. On the CDC Cyber, the total symbol table size can be given by

MAXSYM * (1 + MAXCHAR/10)

central memory words where MAXCHAR (a multiple of 10) is the maximum number of characters per symbol string.

3.2.7. MAXCHAR (default 10)

This determines the maximum number of characters per symbol string and should be a multiple of the number of characters which can be packed into a central memory word (in the case of the CDC Cyber series, a multiple of 10).

3.2.8. MAXATTBLCK (default 250)

This determines the maximum number of symbol attribute-blocks that will be reserved for the semantic evaluator phase. The attribute table size will then be given by MAXATTBLCK * N words where N is the maximum number of symbol attributes declared for a given object class (see Section 4.1). Since a symbol may possess at most one attribute block, it is always sufficient for MAXATTBLCK to be less than or equal to MAXSYM.

3.2.9. MAXPACKET (default 250)

For the current implementation, a _packet_ is a convenient storage unit which holds action annotations. As such, flowgraph nodes, expression-tree nodes, and use-table nodes are all packets. MAXPACKET determines the total number of packets to be reserved by the semantic evaluator phase. The amount of memory occupied by packet allocation is

```
MAXPACKET * (2 + NUMACT)
```

words where NUMACT represents the total number of actions declared by the user (see Section 4.2).

3.3. Grammar Output Control

Often in practice a group of syntax rules are alternate rules for the same grammar variable. For example, the list of rules

```
<A> ::= <B>
<A> ::= <C>
<A> ::= <D>
```

can be expressed in an "alternatives" form

```
<A> ::= <B> | <C> | <D>
```

By default, since syntax rules in SAL can never explicitly be expressed in "alternatives" form (see Section 5.2.1.1), they are not listed to the grammar output file in this form. However, the parser generator used for the present SAL implementation will require significantly less memory if the grammar file generated by SAL were in "alternatives" form. This can be achieved by the ALTERNATIVES command in the preamble. The syntax for this command is

```
<IMPLEMENTATION SPEC> ::= "ALTERNATIVES" ";"
```

An example of a preamble is

```
PREAMBLE
                   #
  MAXSYM  = 500;   # INCREASES DEFAULT SYMBOL TABLE SIZE.
  MAXSETS = 800;   # INCREASE DEFAULT SET-POOL SIZE.
                   #
  ALTERNATIVES;    # WRITE GRAMMAR OUTPUT FILE
                   # IN ALTERNATIVES FORM.
END PREAMBLE
```

CHAPTER 4

Declarations

Recall that the key idea (see Section 1.1) of a SAL program is to be able to specify actions on objects at flowgraph nodes. The primary purpose of the declarations section is to provide a mechanism for the user to declare classes of objects and actions for these objects in order to reflect the type of node annotations desired on the output flowgraphs. The syntax for the declarations specifications section is

```
    <DECLARATION SPECIFICATION> ::=
                        "DECLARATIONS"
                            <OBJECT CLASS DECLARATIONS>
                            <ACTION DECLARATIONS>
                            [<FLOWGRAPH NODE TYPES>]
                            <OTHER DECLARATIONS>
                        "END" "DECLARATIONS"
```

<OBJECT CLASS DECLARATIONS>, <ACTION DECLARATIONS>, <FLOWGRAPH NODE TYPES>, and <OTHER DECLARATIONS> are elaborated further in Sections 4.1 through 4.4.

4.1. Object Class Declarations

It is convenient to think of objects as belonging to classes, each class having its own set of actions. In PASCAL, for example, the object classes might correspond to variables, labels, procedures, functions, and the main program. Of these five classes, the user may wish to associate one or more actions with only the "variables" class. In the object class declaration section, all object classes are declared, along with a (possibly empty) list of object attributes which objects in that class may possess. The syntax for the object class declarations is

```
    <OBJECT CLASS DECLARATIONS> ::=
                         "OBJECT" "CLASSES" ":"
                             <OBJECT CLASS SPEC>
                             { <OBJECT CLASS SPEC> }


    <OBJECT CLASS SPEC> ::=
                   <OBJECT CLASS> ":"
                      "(" [<OBJECT ATTRIBUTE LIST>] ")" ";"
    <OBJECT CLASS> ::= <<IDENTIFIER>>


    <OBJECT ATTRIBUTE LIST> ::= <OBJECT ATTRIBUTE SPEC>
                                { ";" <OBJECT ATTRIBUTE SPEC> }


    <OBJECT ATTRIBUTE SPEC> ::=
           <OBJECT ATTRIBUTE> { "," <OBJECT ATTRIBUTE> }
              ":" <<TYPE>>


    <OBJECT ATTRIBUTE> ::= <<IDENTIFIER>>
```

For example, in a specification of PASCAL one might have

```
       OBJECT CLASSES :
          VARIABLES : ( );
          LABELS    : (FN:FGNODE);
          PROCEDURES: (PCALL:CALLPTR;PENTRY:FGNODE);
          FUNCTIONS : (FCALL:CALLPTR;FENTRY:FGNODE);
```

This declares four object classes: VARIABLES, LABELS, PROCEDURES, and FUNCTIONS. The class VARIABLES has no object attributes associated with it. The object class LABELS has a single attribute, FN, which is of the predefined flowgraph node descriptor type FGNODE (see Section B.1.5). The object classes PROCEDURES and FUNCTIONS each have two attributes associated with them; the first (PCALL and FCALL, respectively) is of the predefined callgraph node descriptor type CALLPTR (see Section B.1.7) and is to hold the callgraph node for any object in either of these classes; the second (PENTRY and FENTRY, respectively) is to hold the "entry" flowgraph node for any object in these classes.

An object can be inserted into a declared object class via a semantic rule (see Section 5.2.2) or via a SAL procedure or function invoked by a semantic rule (see Section 4.4). Similarly, an attribute for an object can be given a value via a semantic rule or via a procedure or function invoked by a semantic rule.

An Object Attribute is different from a Grammar Attribute (Section 5.1) and it is important that the user does not confuse these two concepts. An Object Attribute annotes the object (or symbol) which possesses it. It may be defined, referenced, and redefined by use of Attribute Table accessing functions (Section B.2.3). A Grammar Attribute, on the other hand, annotates a parse tree node (or equivalently, the grammar variable which names that node), and is subject to the rigorous rules of attributed grammar evaluation [Knuth 68]. As such, a Grammar Attribute may be defined or referenced in a semantic rule (Section 5.2.2), but may never be redefined.

4.2. Actions

Actions are declared for object classes. Each action may affect only one object class, however an object class may own zero or more actions. The syntax for action declarations is

```
<ACTION DECLARATIONS> ::= "ACTIONS" ":"
                             <ACTION DEFINITION>
                             { <ACTION DEFINITION> }


<ACTION DEFINITION> ::=
           <ACTION> { "," <ACTION> } ":"
                "ON" <OBJECT CLASS> ";"


<ACTION> ::= <<IDENTIFIER>>
```

Continuing with our PASCAL specification example, an action declaration might be

```
ACTIONS :
   DEFINE, REFERENCE, UNDEFINE : ON VARIABLES;
   USED : ON LABELS;
```

Such a declaration would allow the user to later associate subsets of the object class VARIABLES with the actions DEFINE, UNDEFINE, and REFERENCE, and associate subsets of the object class LABELS with the action USED.

4.3. Flowgraph Node Types

The user is allowed to declare mnemonic names for the node types of the flowgraphs to aid in program readability. These names may then be used in a SAL statement which sets the type for a particular flowgraph node. These mnemonic names are automatically retained by the semantic evaluator phase for error reporting or user displays. The syntax for the flowgraph node type declaration is

```
<FLOWGRAPH NODE TYPES> ::=
            "FLOWGRAPH" "NODE" "TYPES" ":"
                 <NODE NAME> { "," <NODE NAME> } ";"

<NODE NAME> ::= <<IDENTIFIER>>
```

An example of this declaration form for PASCAL is

```
         FLOWGRAPH NODE TYPES :
            ENTRY, EXIT, ASSIGNMENT, GOTOSTMT, PROCCALL,
            EMPTYSTMT, IFTEST, CASETEST, WHILETEST,
            REPEATTEST, FORINIT, FORTEST, FORINCR, FORUNDF;
```

Each node name must be no more than ten characters in length.

4.4. Other Declarations

The SAL user will often find it necessary to create other procedures and functions based on the primitive capabilities provided by the Standard Environment. The newly created procedures and functions are typically higher level routines which characterize functional properties of the language being specified. The definitions of such procedures and functions are elaborated in the declaration specifications section of the SAL program. Any constants, types, or global variables may also be declared in this section. The syntax for this is given by

```
    <OTHER DECLARATIONS> ::=
            <<CONSTANT DEFINITION PART>>
            <<TYPE DEFINITION PART>>
            <<VARIABLE DECLARATION PART>>
            <<PROCEDURE AND FUNCTION DECLARATION PART>>
```

Note that any of the four parts above may be empty (as per usual PASCAL syntax). The motivation for providing this declaration form in SAL will become more apparent in Chapter 5 (specifically, see Sections 5.1.2.2 and 5.2.2.3(e)).

CHAPTER 5

Language Specifications

The language specifications section contains the primary information to specify a desired programming language. The syntax for this section is

```
    <LANGUAGE SPECIFICATIONS> ::=
                      "LANGUAGE" "SPECIFICATIONS"
                           <GRAMMAR ATTRIBUTE PART>
                           <LANGUAGE RULES>
                      "END" "LANGUAGE" "SPECIFICATIONS"
```

<GRAMMAR ATTRIBUTE PART> and <LANGUAGE RULES> are further elaborated in Sections 5.1 and 5.2, respectively.

5.1. Grammar Attributes

This subsection allows the user to declare all of the grammar variables to be used in the language specification. For each such grammar variable a (possibly empty) list of grammar attributes is also declared. Each such attribute must be given a type.

5.1.1. Grammar Attribute Part : Syntax

The syntax for the grammar attribute part is

```
    <GRAMMAR ATTRIBUTE PART> ::=
            "GRAMMAR" "ATTRIBUTES"
                <GRAMMAR VAR ATTLIST>
                { <GRAMMAR VAR ATTLIST> }
            "END" "GRAMMAR" "ATTRIBUTES"


    <GRAMMAR VAR ATTLIST> ::= <GRAMMAR IDENTIFIER> ":"
                                   {<GRAMMAR ATTLIST>} ";"


    <GRAMMAR ATTLIST> ::= <GRAMMAR ATT DECL>
                               { ";" <GRAMMAR ATT DECL>}


    <GRAMMAR ATT DECL> ::=
          <GRAMMAR ATTRIBUTE> { "," <GRAMMAR ATTRIBUTE> }
              ":" <<TYPE>>
    <GRAMMAR ATTRIBUTE> ::= <<IDENTIFIER>>
```

An example of a grammar var attlist is

```
          <LABELLED STATEMENT> :
               LABELVAL : SYMBOL;
               START, FINISH : FGNODE;
```

5.1.2. Grammar Attribute Part : Semantics

A grammar var attlist serves to declare a grammar variable and its associated grammar attributes. Such a declaration allows the user to later reference or define the attributed variables (see Section 5.2.2.2) constructed from a grammar variable and any one of its grammar attributes. For a more complete discussion of the use and meaning of grammar attributes, see [Knuth 68].

5.1.2.1. Primitive Grammar Variables

Four predefined grammar variables belong to the set of terminal symbols of any user-specified grammar in SAL. These four grammar variables are called _primitive grammar variables_ and include

```
                    <IDENTIFIER>     <CONSTANT>
                    <FLOAT>          <STRING>
```

These are the only four grammar variables allowed in the set of terminals for any user-specified grammar in SAL. As mentioned later in the Syntax Rule / Scanner Interface section (5.2.1.2), these terminal grammar variables name parse tree leaf nodes associated with "kept" tokens ([Clemm2 79]) in the source code of the parsed program being analyzed. A kept token has two pieces of information of use to the SAL programmer: (1) a symbol descriptor identifying the object being kept, and (2) the token number for the occurrence of the object in the source text. As such, for each of the four primitive grammar variables there exists two predefined grammar attributes; namely, VALUE of the standard type SYMBOL (Section B.1.2) and TOKEN of the standard type INTEGER (Section B.1.9). The VALUE and TOKEN attributes of any primitive grammar variable are automatically set by SAM/SAL to contain the symbol descriptor and token number, respectively, of the associated token in the source text.

The SAL user must observe the following rules regarding the declaration of primitive grammar variables.

(a) Only the four primitive grammar variables mentioned above may possess grammar attributes named VALUE and TOKEN.

(b) A primitive grammar variable may possess no grammar attributes other than VALUE and TOKEN.

(c) A user wishing to use any of the four primitive grammar variables must still declare those grammar variables (along with any of the two special grammar attributes VALUE or TOKEN desired) according to the syntax rules of Section 5.1.1.

This discussion on the Grammar Attribute Part in general and the Primitive Grammar Variables in particular is now best illustrated by the following example:

```
GRAMMAR ATTRIBUTES       #
   <PROGRAM> : ;         # NO ATTRIBUTES
                         #
   <IDENTIFIER> :        #
      VALUE : SYMBOL;    # WILL ONLY USE "VALUE" ATTRIBUTE
                         #   OF THIS PRIMITIVE GRAMMAR VAR.
   <STRING> :            #
      VALUE : SYMBOL;    # WILL USE BOTH PREDEFINED ATTRI-
      TOKEN : INTEGER;   #   BUTES FOR THIS PRIM. GRAMMAR VAR.
                         #
   <CONSTANT> :          #
      VALUE : SYMBOL;    # THIS IS OK, SINCE PRIMITIVE.
      NUM   : INTEGER;   # INVALID... "NUM" IS NOT A VALID
                         #   ATTRIBUTE FOR A PRIM. GRAMMAR VAR
   <STATEMENT> :         #
      START : FGNODE;    # OK, SINCE "STATEMENT" IS NOT PRIM.
      VALUE : SYMBOL;    # INVALID... NONPRIMITIVE GRAMMAR
                         "   VAR MAY NOT HAVE ATTRIBUTE NAMED
                         "   "VALUE".
END GRAMMAR ATTRIBUTES   #
```

Note that this example contains two (documented) errors. Also, the attributed variables (see Section 5.2.2.2) <IDENTIFIER>.VALUE, <STRING>.VALUE, and <CONSTANT>.VALUE are predefined to be the symbol descriptors to the identifier, string, and constant, respectively, in the symbol table. The attributed variable <STRING>.TOKEN is predefined to be the token number for the occurrence of the string in the source text associated with this parse-tree terminal. The attributed variable <STATEMENT>.START is not predefined and must be explicitly defined by a semantic rule (see Section 5.2.2).

5.1.2.2. Type Restrictions

For the current implementation of SAL, attribute types must be either an INTEGER or subrange of INTEGER. If a grammar attribute is conceived to be of some structured type T (e.g. a PASCAL RECORD type), then the user should define the type T in the type definition part and declare a variable V in the variable declaration part of the declaration specification section (see Section 4.4), so that V is some array of type T. V then acts as a pool of resources of type T, and an index into V then acts as a descriptor to an object of type T. Since such an index is a subrange of INTEGER, this descriptor is a valid grammar attribute. This is in fact how SETS, FLOWGRAPH NODES, CALLGRAPH NODES, etc. are provided by the current Standard Environment. For any such pool of structured objects declared by the user, the user should also carefully provide accessing functions and procedures to (1) allocate and deallocate an object in the pool, and (2) set or get fields within such an object.

5.2. Language Rules

The syntax for the language rules subsection is

```
<LANGUAGE RULES> ::= "RULES"
                         <RULE>
                         {<RULE>}
                     "END" "RULES"


<RULE> ::= <SYNTAX RULE>
              "SEMANTICS"
                 [ "OBJECT" "SPECIFICATIONS"
                      <SEMANTIC RULE LIST> ]
                 [ "ATTRIBUTE" "SPECIFICATIONS"
                      <SEMANTIC RULE LIST> ]
                 [ "FLOWGRAPH" "SPECIFICATIONS"
                      <SEMANTIC RULE LIST> ]
                 [ "ACTION" "SPECIFICATIONS"
                      <SEMANTIC RULE LIST> ]
                 [ "OTHER" "SPECIFICATIONS"
                      <SEMANTIC RULE LIST> ]
              "END"


<SEMANTIC RULE LIST> ::= <SEMANTIC RULE>
                         { ";" <SEMANTIC RULE> }
```

The syntax rule of any language rule is said to "govern" all semantic rules in any semantic rule list of that same language rule. <SEMANTIC RULE> is further elaborated in Section 5.2.2.2.

5.2.1. Syntax Rules

The collection of syntax rules, when combined, are to form a context-free accepting grammar and tree-building grammar for the specified language. If the language being specified is not context free (e.g. Fortran 66), then the user must carefully define a powerful lexical scanner in the preamble (see Section 3.1) to resolve all context-sensitive features.

5.2.1.1. Syntax Rule Syntax

The syntax of a syntax rule is

```
<SYNTAX RULE> ::=
       <GRAMMAR VARIABLE> "::=" <SYNTAX EXPRESSION>

<GRAMMAR VARIABLE> ::= <GRAMMAR IDENTIFIER> |
                       <QUAL GRAMMAR IDENTIFIER>

<SYNTAX EXPRESSION> ::= <SYNTAX UNIT> {<SYNTAX UNIT>}

<SYNTAX UNIT> ::= <GRAMMAR VARIABLE> | <LITERAL>
```

Examples

```
<PROGRAM> ::= <HEADING> ";" <DECLARATIONS> ";" <BODY> "."

<STMT LST(1)> ::= <STATEMENT> ";" <STMT LST(2)>
```

The presence of a qualifier in a grammar variable has no effect on the syntax rule. Qualifiers are a semantic device only (see Section 5.2.2.3(b)). Thus, the two syntax rules below are grammatically indistinguishable:

```
<IDENT LIST(1)> ::= <IDENT LIST(2)> "," <IDENTIFIER>

<IDENT LIST> ::= <IDENT LIST> "," <IDENTIFIER>
```

The _length_ of a grammar variable is the length of the grammar identifier (Section 2.3.1(b)) or qualified grammar identifier (Section 2.3.1(c)) which it derives.

5.2.1.2. Syntax Rule / Scanner Interface

In Section 3.1 it was mentioned that four special token types must be provided by the lexical scanner. These types correspond to the "kept" tokens ([Clemm2 79]) in a given source stream, and correspond with the four _primitive grammar variables_ mentioned in Section 5.2.1.2. Explicitly, this correspondence is given by

"IDNTRF"	<-->	<IDENTIFIER>
"STRING"	<-->	<STRING>
"CNSTNT"	<-->	<CONSTANT>
"FLOAT"	<-->	<FLOAT>

This correspondence is automatically known to SAM/SAL. All final details of the interface protocol are automatically handled by SAM/SAL.

5.2.1.3. Syntax Rule Restrictions

There are four restrictions to the collection of syntax rules. The first two restrictions have to do with general requirements of a context-free grammar. The last two restrictions are due to implementation requirements peculiar to the automatic parser generator.

(1) There must exist exactly one grammar variable (called the start variable) which is the left side of at least one syntax rule and which appears on the right side of no syntax rule.

(2) The primitive grammar variables (see Section 5.1.2.1) may not appear on the left side of any syntax rule.

(3) The right side of a syntax rule may not be empty. Unfortunately, this may force a large increase in the number of syntax rules than might otherwise be possible if the empty production were permitted.

(4) The right side of a syntax rule may have at most seven syntax units.

5.2.2. Semantic Rules

The semantic rules specified in SAL may be partitioned into five phases: OBJECT SPECIFICATIONS, ATTRIBUTE SPECIFICATIONS, FLOWGRAPH SPECIFICATIONS, ACTION SPECIFICATIONS, and OTHER SPECIFICATIONS. The use of these phases is a simple variation on a pure attributed grammar as defined in [Knuth 68], and is explained as follows. After some practice at using the pure nonprocedural attributed grammar device, it became clear that a specification program using such a device was intellectually more managable if it was at least conceived of as a sequence of successive phases, where the run-time completion of a phase could be characterized as the completion of some conceptual user-level task. In a SAL program, the user's job is to create objects (update a symbol table), possibly decorate these objects (create object attributes in an attribute table), build flowgraphs, annotate flowgraph nodes with actions, and possibly perform other miscellaneous activities on these structures. The five phases mentioned above are intended to correspond to these five conceptual activities. The semantic rules within a phase are directed toward performing these corresponding activities. The concept of partitioning semantic rules into phases thereby allows a user to build or update global structures (symbol table, attribute table, flowgraph node table, edge lists, action packets, etc.) without having to pass copies of these large structures up and down the parse tree.

This might be better realized with the following illustration. In order to create an object attribute in the attribute table the object must first exist as a symbol table entry. A semantic rule relying on either the object being in the symbol table or one of its attributes being in the attribute table must not execute until such table updates have been made. One expensive (but pure) method of signalling the semantic rule that the updates it requires have indeed been made is to propogate a set of grammar attributes up and down the parse tree to signal the completion of the symbol table update phase, and then propogate another set of grammar attributes up and down the parse tree to signal the end of the attribute table creation phase. The propogation of such grammar attributes is costly both in terms of memory (as many as two extra attributes needed per parse tree node per phase) and in terms of time (each attribute would have to be readied, scheduled, and computed).

With the semantic rule partitioning introduced in SAL, all of this effort of defining and propogating extra grammar attributes for end-of-phase signalling can be eliminated or greatly reduced.

5.2.2.1. Evaluation Order of Semantic Rules

The collection of all semantic rules specify a nonprocedural set of instructions. It is generally not clear from the source text ordering of these rules what their actual evaluation order might be.

5.2.2.1.1. Interphase Ordering

The phase-partitioning mentioned above (5.2.2) has the following interpretation: no semantic rule in a given semantic phase can execute until all semantic rules in any preceding phase have executed. This of course implies an ordering to the semantic phases. Explicitly, this ordering is

(1) The OBJECT SPECIFICATIONS phase is first and therefore has no preceding phase. All semantic rules in this phase are therefore constrained by no rules from other phases. The intent of this phase is to contain (among other rules) those semantic rules which update the symbol table by creating objects (symbols).

(2) The ATTRIBUTE SPECIFICATIONS phase is second. All semantic rules in this phase execute only after the semantic rules in the OBJECT SPECIFICATIONS phase have executed. The intent of this phase is to be able to

rely on the existence of a completed symbol table from the previous phase so that any associated symbol attributes may now be added to the attribute table.

(3) The FLOWGRAPH SPECIFICATIONS phase is third. The intent of this phase is to build flowgraph nodes and edges relying on the existence of a completed symbol table and attribute table. A semantic rule in this phase may execute only after all semantic rules in the OBJECT SPECIFICATIONS and ATTRIBUTE SPECIFICATIONS phase have executed.

(4) The ACTION SPECIFICATIONS phase is fourth. The intent of this phase is to annotate the nodes in the flowgraphs created by the previous (FLOWGRAPH SPECIFICATIONS) phase. A semantic rule in this phase may execute only after all semantic rules in the OBJECT SPECIFICATIONS, ATTRIBUTE SPECIFICATIONS, and FLOWGRAPH SPECIFICATIONS phases have executed.

(5) The OTHER SPECIFICATIONS phase is fifth and last. The intent of this phase is to allow the specification of any additional semantic rules which may rely on the existence of all tables and structures completed by the previous four phases. A semantic rule in this phase may execute only after all semantic rules in any of the other four phases have executed.

5.2.2.1.2. Intraphase Ordering

Within a phase semantic rules are executed in an order determined by their dependencies on the other grammar attributes (see [Knuth 68]). In general this will not be a total order in that at any given moment more than one semantic rule may be ready for execution. The determination of grammar attribute dependencies, detection of which semantic rules at a given moment are ready for execution, and scheduling of all "ready" rules for execution is automatically handled by the SAM/SAL semantic evaluator.

An additional intraphase ordering imposed by SAL is that all _assignment rules_ are executed before any _procedure rule_.

5.2.2.1.3. Evaluation Order Restrictions

It is possible to have a collection of semantic rules which cannot all execute. A simple example of this is illustrated by the following language rule.

```
    <A> ::= <B>
       SEMANTICS
          OTHER SPECIFICATIONS
             <A>.ATT1 := F1(<B>.ATT1);
             <B>.ATT1 := F2(<A>.ATT1)
       END
```

From the first semantic rule in the example it is clear that <A>.ATT1 cannot be evaluated until after the evaluation of <B>.ATT1. But from the second rule we see that <B>.ATT1 cannot be evaluated until after the evaluation of <A>.ATT1. From the point of view of the SAM/SAL scheduler, a deadlock exists.

A SAL program in which all semantic rules can be evaluated without interdependency conflicts is called <u>well defined</u>. A valid SAL program must be well-defined, and the user must exercise care to ensure this behavior. The detection of any violations of a well-defined program occurs in the semantic evaluation phase and not during program compilation.

Research performed by other authors ([Bochm 76], [Jazay 75], [Kasten 78], and [Kenned 76]) has been done to investigate methods for improving semantic evaluation by enforcing a fixed evaluation strategy on the attribute grammar. In all cases, these improvements were achieved by restricting the class of attribute grammars accepted from the well-defined class above.

<u>5.2.2.2. Semantic Rule Syntax</u>

The syntax for a semantic rule is

```
<SEMANTIC RULE> ::= <ASSIGNMENT RULE> | <PROCEDURE RULE>


<ASSIGNMENT RULE> ::=
    <ATTRIBUTED VARIABLE> ":=" <SEMANTIC EXPRESSION>


<PROCEDURE RULE> ::=
    <<IDENTIFIER>> {"(" <SEMANTIC EXPRESSION LIST> ")" }


<SEMANTIC EXPRESSION LIST> ::=
    <SEMANTIC EXPRESSION> {"," <SEMANTIC EXPRESSION>}


<ATTRIBUTED VARIABLE> ::=
    <GRAMMAR VARIABLE> "." <GRAMMAR ATTRIBUTE>
```

```
<SEMANTIC EXPRESSION> ::=
    <SEMANTIC SUBEXPRESSION>
           <SET OP> <SEMANTIC SUBEXPRESSION> |
    <SEMANTIC SUBEXPRESSION>


<SET OP> ::= "UNION" | "INTERSECTION" | "MINUS"


<SEMANTIC SUBEXPRESSION> ::=
    <SEMANTIC TERM> <ADD OP> <SEMANTIC TERM> |
    <SEMANTIC TERM>


<ADD OP> ::= "+" | "-"


<SEMANTIC TERM> ::=
    <SEMANTIC FACTOR> <MULT OP> <SEMANTIC FACTOR> |
    <SEMANTIC FACTOR>


<MULT OP> ::= "*" | "/"


<SEMANTIC FACTOR> ::=
    <INTEGER> | <REAL> | <<IDENTIFIER>> |
    <FUNCTION REFERENCE> | <ATTRIBUTED VARIABLE> |
    <<SIGN>> <SEMANTIC FACTOR> |
    "(" <SEMANTIC EXPRESSION> ")"


<FUNCTION REFERENCE> ::=
    <<IDENTIFIER>>  {"(" <SEMANTIC EXPRESSION LIST> ")"}
```

5.2.2.3. Semantic Rule Semantics

(a) For an attributed variable appearing in any semantic rule, the following must hold.

(1) The grammar attribute composing the attributed variable must appear in the grammar attribute list for the declaration of the associated (unqualified) grammar identifier (see Section 5.1.2).

(2) The grammar variable part of the attributed variable must appear in the syntax rule governing (see Section 5.2) the semantic rule containing the attributed variable.

(b) A qualified grammar identifier is syntactically interpreted no differently than the same grammar identifier without the qualifier. However, in semantic rules such qualifiers are often needed to destinguish between two or more occurrences of the same grammar variable. This is best illustrated by an example of a language rule:

```
<ID LIST(1)> ::= <ID> "," <ID LIST(2)>
   SEMANTICS
      OBJECT SPECIFICATIONS
         <ID>.ENVIRON := <ID LIST(1)>.ENVIRON
   END
```

The syntax rule describes a subtree of the parse tree rooted at <ID LIST(1)> and having two sons <ID> and <ID LIST(2)>. The semantic rule explicitly assigns to the ENVIRON attribute of <ID> the ENVIRON attribute of the root of this subtree. Without qualifiers on <ID LIST> such a semantic rule would be ambiguous since <ID LIST>.ENVIRON could refer to the ENVIRON attribute of either the subtree root or the second son.

(c) The qualifier numbering within a language rule is up to the user. The only restriction is that a specific _qualified_ grammar variable may appear at most once in a given syntax rule. Thus the following is invalid

```
<A(1)> ::= <A(1)> "ELSE" <B>
```

since the qualified grammar variable <A(1)> appears twice in the same syntax rule. The following two examples are valid

```
<A> ::= <A> "ELSE" <B>

<B(1)> ::= <B(2)> <A(1)> <A(2)>
```

In the first example, since <A> is not qualified it may appear more than once in the syntax rule. However it may not appear as part of an attributed variable in a semantic rule since such an attributed variable would result in an ambiguous reference. In the second example, each qualified grammar variable is correctly used at most once in the syntax rule.

(d) The _length_ of a _grammar attribute_ is the number of characters in the attribute name. The _length_ of an _attributed variable_ is the length of its grammar variable part (Section 5.2.1.1) plus the length of its grammar attribute part plus one. For example, the grammar attribute ENVIRON has length 7, and the attributed variable <ID LIST(12)>.ENVIRON has length 15. The current SAM/SAL implementation restricts the length of any grammar attribute and attributed variable to be no more than 30.

(e) A Procedure Rule or Function Reference may apply to any procedure or function declared either in the Standard Environment (see Appendix B) or in the Other Declarations section (see Section 4.4).

CHAPTER 6

Procedural Specifications

This final specification section of a SAL program allows the user to perform any post semantic computations to augment the output listing file of the semantic evaluator phase of SAM/SAL. Any computations in this section will automatically occur after all semantic rules have been computed, and after the symbol table, callgraph tables, and flowgraph tables have been dumped to the output tables file. Thus any computations occuring in this section cannot alter the output tables file. The computations may (and indeed are intended to) add to the output listing file. All global variables provided by the Standard Environment or declared by the user in the Other Declarations part (4.4) are available for use here. This specification section was added to the SAL language to provide the user with some post semantic control. It is expected that in most SAL programs there will no code in this specification section. The syntax for the procedural specifications section is

```
<PROCEDURAL PART> ::=
     "PROCEDURE" "SPECIFICATIONS"
          <OTHER DECLARATIONS>
          "BEGIN"
              <<STATEMENT>>
              { ";" <<STATEMENT>> }
          "END"
     "END" "PROCEDURE" "SPECIFICATIONS"
```

where <<STATEMENT>> has the usual PASCAL syntax and semantics, and in particular may be empty. Examples of a procedural specification are

```
(1)   PROCEDURE SPECIFICATIONS      # EXAMPLE OF AN EMPTY
         BEGIN                      # PROCEDURE SPECIFICATION
         END                        #
      END PROCEDURE SPECIFICATIONS #
```

and

```
(2)   PROCEDURE SPECIFICATIONS
       (*
         WRITE THE COMPLETED SYMBOL TABLE TO
         THE STANDARD FILE "OUTPUT".
       *)
         VAR
            SYM : SYMBOL;
         BEGIN
            WRITELN("  DUMP OF SYMBOL TABLE");
            FOR SYM:=1 TO NUMSYM DO
               BEGIN
                  WRITE(" ":5,SYM:5," ":5);
                  WRITESYM(OUTPUT,SYM);
                  WRITELN
               END
         END
      END PROCEDURE SPECIFICATIONS
```

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APPENDIX A

Using SAM/SAL on the CU CDC Cyber

Each of the phases listed below uses special files built for the SAM/SAL system. The names of these files, and the CU projects and CCID's under which they are accessed may change. The file names, projects, and CCID's given below are valid as of January, 1981.

A.1 Compiling a SAL Program, S

Nine output files are generated by the SAL compiler. Of these, six have SAM/SAL system names which are not to be altered by the user, and thus do not explicitly appear in the compile command. To compile a SAL source program, S:

```
    GET,SAL=SALTRAN/PAPM,J973.
    SAL,S,SALIST,SCANNER,GRCLEM.
```

The single input file is:

S	User specified source file to be compiled.

The nine output files are:

SALIST	Listing file. This includes a paginated copy of the original source text with line numbers, error diagnostics, cross-reference information, and program statistics.
SCANNER	Scanner file. This file contains the default or user-defined scanner specifications to be used by FSCAN.
GRCLEM	Grammar file. This file contains all sytax rules in the form expected by the tree-builder phase of parse generation.
DECLF	Declarations file. This file contains all declarations as specified in 4.4.
EVALF	Command Evaluation file. This file contains all semantic rules translated into PASCAL statements.
DGRAPHF	Dependency-Graph file. This file contains the sequence of PASCAL commands generated by SAL to build the dependency graph for any program in the

	specified language for analysis by the semantic evaluator.
CNSTMOD	Constants file. This file contains all constants which govern the size of the Standard Environment data structures.
PTCLF	Productions Table file. This file contains PASCAL code for creation of the productions table in the semantic evaluator.
SALBODY	Body file. This file contains PASCAL code as specified in Chapter 6.

A.2 Generating the Evaluators

A.2.1 Parser Generation

To automatically generate a parser for the language specified by S, the two output files SCANNER and GRCLEM from SAL are needed. Parse generation proceeds over several phases.

Phase 1. Process Scanner Specifications.

```
GET,FSCAN/PAPM,J973.
FSCAN,SCANNER,SCNLST,TBL1,ERRSCN.
```

The single input file is:

SCANNER	Output from SAL compiler.

The three output files are:

SCNLST	Scanner listing file.
TBL1	Fortran tables produced by FSCAN.
ERRSCN	Error file.

If ERRSCN is empty, then you can proceed to the second phase of parse generation.

Phase 2. Process Scanner/Grammar Interface.

```
GET,SALTGB/PAPM,J973.
SALTGB,GRCLEM,TBL1,GRLIST,TBL2,TBL3,ERRTGB.
```

The two input files are:

GRCLEM	Output from SAL compiler.
TBL1	Output from FSCAN.

The four output files are:

GRLIST	Tree-grammar listing file.
TBL2	Fortran tables produced by SALTGB.
TBL3	Grammar table produced by SALTGB.
ERRTGB	Error file.

If ERRTGB is empty, you can proceed to the third phase of parse generation.

Phase 3. Create Fortran Grammar Tables.

```
    GET,CLEMSW=CLMSWB/PAPM,J973.
    CLEMSW,TBL3,CLMLIST,TBL4.
```

The single input file is:

TBL3	Output from SALTGB.

The two output files are:

CLMLIST	CLEMSW listing file.
TBL4	Fortran table produced by CLEMSW.

If no errors were detected by CLEMSW, you can proceed to the final phase of parse generation.

Phase 4. Producing the Actual Parser.

To produce the actual parser for the language specified by S, the Fortran tables produced in the previous phases need to be compiled and edited into a parse-driver template. The KCL for this phase is:

```
    REWIND,TBL1,TBL2,TBL4.
    FTN,I=TBL1,L=0,B=BIN.
    FTN,I=TBL2,L=0,B=BIN.
    FTN,I=TBL4,L=0,B=BIN.
    REWIND,BIN.
    GET,PRSDRVB/PAPM,J973.
    LIBEDIT,P=PRSDRVB,L=0,B=BIN,I=0,N=PARSE.
```

The three input files are:

TBL1	Output from FSCAN.
TBL2	Output from SALTGB.
TBL4	Output from CLEMSW.

The single output file is:

PARSE	Object file for the parser for the language specified by S.

A.2.2 Semantic Evaluator Generation

To build a semantic evaluator for S:

```
GET,GENEVAL/PAPM,J973.
PASCAL,GENEVAL,GENLIST,SMEVAL.
```

The six (implicit) input files are:

EVALF, DGRAPHF, PTCLF, SALBODY, DECLF, and CNSTMOD
Output files from the SAL compiler.

The two output files are:

GENLIST	PASCAL listing of the semantic evaluator.
SMEVAL	Object file for the semantic evaluator for the language specified by S.

A.3 Using the Evaluators

This section describes how to use the parser and semantic evaluator created in Section A.2.

A.3.1 Using the Parser

To parse a program U in the language specified by S:

```
PARSE,U,ULIST,UTBL,UERR.
```

The two input files are:

PARSE	The parser generated in A.2.1.
U	A sample program in the language specified by S.

The three output files are:

ULIST	A listing of file U with token numbers.
UTBL	File containing symbol table and parse-tree for U.
UERR	Listing of syntax errors in U.

A.3.2 Using the Semantic Evaluator

To perform the semantic evaluation of program U as specified by S:

```
GET,FTNSETB/PAPM,J973.
LOAD,FTNSETB.
SMEVAL,UTBL,SAMLIST,SAMTBL.
```

The two input files are:

SMEVAL	The semantic evaluator generated in A.2.2.
UTBL	The table-file generated by the parser for program U.

The two output files are:

SAMLIST	Listing file containing (a) any system errors detected by the semantic evaluator, (b) any output requests issued by the user in S, and (c) program statistics for U.
SAMTBL	This file contains the symbol table, call graph, and flowgraphs for program U.

A.4 Fancy Display

The current SAM/SAL system has a post phase which allows the user to get a readable listing of the tables file from the semantic evaluator. To invoke this display tool:

```
GET,SALPOST/PAPM,J973.
SALPOST,SAMTBL,PLIST.
```

The single input file is:

SAMTBL	Output from semantic evaluator.

The single output file is:

PLIST	User-readable listing of input.

APPENDIX B

The Standard Environment

This appendix lists the Standard Environment TYPEs, PROCEDUREs and FUNCTIONs for the SAM/SAL system.

B.1 Standard Types

B.1.1 Set types

SETS	SET descriptor type
UNPSET	Unpacked representation of a set

B.1.2 Symbol Types

SYMBOL	Symbol descriptor type
OBJECT	Synonym for SYMBOL
SYMREP	Type for the character string of a symbol
SYMLNG	Subrange type for the length value of a symbol
UNPSTR	Unpacked type for SYMREP

B.1.3 Symbol Attribute Types

ATTRIBUTE	Attribute-name selector type
ATTBLOCK	Attribute-block descriptor

B.1.4 Object Class Types

OBJCTCLASS	Object-Class name type

B.1.5 Packet Types

PACKET	Flowgraph node, expression-tree node, use-table node descriptor type
ACTION	Scalar type of user-defined actions
FGNODE	Synonym for PACKET
EXPNODE	Synonym for PACKET

B.1.6 Parameter Building Types

FPRMPTR	Formal parameter node descriptor

B.1.7 Callgraph Types

CALLPTR	Callgraph node descriptor type

B.1.8 Parse-Tree Types

PARSENODE	Parse-tree node descriptor type

B.1.9 Other Types

These include all other primitive types provided by the PASCAL Report ([Jensen 74]). Specifically

INTEGER

REAL

CHAR

BOOLEAN

B.2 Standard Procedures/Functions

B.2.1 Set Routines

```
FUNCTION NEWSET:SETS;
   (*
         RETURNS A NEW (EMPTY) SET FROM THE SET-POOL.
   *)
```

```
FUNCTION NULLSET:SETS;
   (*
         SAME AS NEWSET

   *)


PROCEDURE RETURNSET(VAR S:SETS);
   (*
         RETURNS A SET TO THE SET-POOL.
   *)


FUNCTION ISEMPTY(S:SETS):BOOLEAN;
   (*
         RETURNS  TRUE  <=> SET  S  IS EMPTY.
   *)


PROCEDURE UNIONP(S1,S2:SETS; VAR RESULT:SETS);
   (*
         RETURNS A NEW SET  RESULT  WHOSE VALUE IS THE
         UNION OF SETS  S1 AND S2.
   *)


FUNCTION UNION(S1,S2:SETS):SETS;
   (*
         SAME AS UNIONP EXCEPT THIS IS A FUNCTION, AND
         HENCE HAS NO CONTROL OF GARBAGE COLLECTING ON
         USED SETS.
   *)


PROCEDURE INTERSECTP(S1,S2:SETS; VAR RESULT:SETS);
   (*
         RETURNS A NEW SET  RESULT  WHOSE VALUE IS THE
         INTERSECTION OF SETS  S1  AND  S2.
   *)


FUNCTION INTERSECT(S1,S2:SETS):SETS;
   (*
         SAME AS INTERSECTP EXCEPT THIS IS A FUNCTION,
         AND HENCE HAS NO CONTROL OF GARBAGE COLLECTING
         ON UNUSED SETS.
   *)
```

```
PROCEDURE MINUSP(S1,S2:SETS; VAR RESULT:SETS);
   (*
         RETURNS A NEW SET  RESULT  WHOSE VALUE IS THE
         SET-DIFFERENCE OF SETS  S1  AND  S2.
   *)


FUNCTION MINUS(S1,S2:SETS):SETS;
   (*
          AME AS MINUSP EXCEPT THIS IS A FUNCTION, AND
         HENCE HAS NO CONTROL OF GARBAGE COLLECTING ON
         UNUSED SETS.
   *)


PROCEDURE ASSIGNSET(S:SETS; VAR RESULT:SETS);
   (*
         RETURNS A NEW SET  RESULT  WHOSE VALUE IS SET
         S.  (CREATES A COPY OF  S).
   *)


PROCEDURE SETINSERT(ELEMENT:INTEGER; S:SETS);
   (*
         INSERTS  ELEMENT  INTO SET  S.
   *)


FUNCTION ISMEMBER(ELEMENT:INTEGER; S:SETS):BOOLEAN;
   (*
         RETURNS  TRUE  <=>  ELEMENT  IS IN SET  S.
   *)


FUNCTION ISSUBSET(S1,S2:SETS):BOOLEAN;
   (*
         RETURNS  TRUE  <=>  S1  IS A SUBSET OF  S2.
   *)


FUNCTION ISEQUAL(S1,S2:SETS):BOOLEAN;
   (*
         RETURNS  TRUE  <=> SET  S1  AND SET  S2  CON-
         TAIN THE SAME ELEMENTS.
   *)
```

```
PROCEDURE UNPACKSET(S:SETS; VAR UNP:UNPSET);
   (*
         UNPACK SET  S  INTO ARRAY  UNP.  THE ZEROETH
         ELEMENT OF  UNP  IS THE NUMBER, N, OF ELEMENTS
         IN  S.  THE NEXT N ELEMENTS IN  UNP  ARE THE
         ELEMENT VALUES OF  S.
   *)


PROCEDURE WRITESET(VAR F:TEXT;S:SETS; IND:INTEGER;
                                      VAR NUM:INTEGER);
   (*
         WRITE SET  S  TO FILE  F, USING NO MORE THAN
         130 CHARACTERS PER LINE.  START EACH NEW LINE
         WITH AN INDENTATION OF  IND (IF IND>0) ELSE
         WITH AN INDENTATION OF 5.  ALSO, IF IND=0
         THEN PRECEED FIRST LINE WITH NUMBER OF OBJECTS
         IN THE SET.  RETURN THE NUMBER OF OBJECTS IN
         THE SET IN THE OUTPUT PARAMETER  NUM.
   *)
```

B.2.2 Symbol Routines

```
PROCEDURE SETSYMMAX(SYM:SYMBOL; MAXATTR:INTEGER);
   (*
         SET MAXIMUM ATTRIBUTES ALLOWED BY  SYM  TO
         MAXATTR.
   *)


FUNCTION GETSYMMAX(SYM:SYMBOL):INTEGER;
   (*
         RETURNS MAXIMUM NUMBER OF ATTRIBUTES FOR SYMBOL
         SYM.
   *)


PROCEDURE SETSYMOBJ(SYM:SYMBOL; OBJC:OBJCTCLASS);
   (*
         SET OBJECT-CLASS FOR SYMBOL  SYM  TO BE  OBJC.
   *)


FUNCTION GETSYMOBJ(SYM:SYMBOL):INTEGER;
   (*
         RETURN OBJECT-CLASS FOR SYMBOL  SYM.
         (NOTE - RESULT IS INTEGER SINCE OBJCTCLASS
         CANNOT HAVE A VALUE OF ZERO.)
   *)
```

```
PROCEDURE SETSYMAUX(SYM:SYMBOL;AUX:INTEGER;VAL:INTEGER);
   (*
         SET AUXILLARY ATTRIBUTE  AUX  OF SYMBOL  SYM
         TO  VAL.
   *)


FUNCTION GETSYMAUX(SYM:SYMBOL;AUX:INTEGER):INTEGER;
   (*
         GET AUXILLARY ATTRIBUTE  AUX  OF SYMBOL  SYM.
   *)


FUNCTION HASH(VAR STR:SYMREP; LEN:SYMLNG;
                         VAR WASTHERE:BOOLEAN):SYMBOL;
   (*
         HASH STRING  STR  OF LENGTH  LEN.  RETURN SYMBOL
         POINTER FOR STRING.  IF STRING ALREADY IN SYMBOL
         TABLE RETURN ITS PREDEFINED HASHED VALUE AND
         SET  WASTHERE  TO TRUE, OTHERWISE CREATE AND
         RETURN A NEW SYMBOL POINTER AND SET  WASTHERE
         TO FALSE.
   *)


PROCEDURE GETSTRING(SYM:SYMBOL; VAR STR:SYMREP;
                                           VAR LEN:SYMLNG);
   (*
         GET STRING VALUE <STR,LEN> ASSOCIATED WITH
         SYMBOL  SYM.
   *)


PROCEDURE WRITESYM(VAR F:TEXT; SYM:SYMBOL);
   (*
         WRITE SYMBOL  SYM  TO FILE  F.
   *)


PROCEDURE LISTSYMSET(VAR F:TEXT; S:SETS; INDENT:INTEGER);
   (*
         WRITE THE SET OF SYMBOLS IN SET  S  TO FILE  F
         USING NO MORE THAN 130 CHARACTERS PER LINE.
         START EACH NEW LINE WITH AN INDENTATION OF
         INDENT  SPACES.
   *)
```

B.2.3 Symbol Attribute Routines

```
PROCEDURE SETSYMATT(SYM:SYMBOL; ATT:ATTBLOCK);
   (*
         SET ATTRIBUTE-FIELD OF SYMBOL  SYM  TO  ATT.
   *)


FUNCTION GETSYMATT(SYM:SYMBOL):ATTBLOCK;
   (*
         GET ATTRIBUTE-FIELD OF SYMBOL  SYM.
   *)


FUNCTION NEWATTBLCK: ATTBLOCK;
   (*
         RETURNS A NEW ATTRIBUTE-BLOCK POINTER AND UP-
         DATES TOTAL NUMBER OF ALLOCATED POINTERS.
   *)


PROCEDURE SETATT(ATT:ATTRIBUTE; SYM:SYMBOL; VAL:INTEGER);
   (*
         IF SYMBOL  SYM  HAS ACCES TO ATTRIBUTE  ATT
         THEN SET ATTRIBUTE  ATT  OF  SYM  TO  VAL, ELSE
         REPORT ERROR.
   *)


FUNCTION  GETATT(ATT:ATTRIBUTE; SYM:SYMBOL):INTEGER;
   (*
         GET ATTRIBUTE  ATT  OF SYMBOL  SYM  PROVIDED
         SYM HAS ACCESS TO THIS ATTRIBUTE, ELSE REPORT
         ERROR.
   *)
```

B.2.4 Object-Class Routines

```
FUNCTION GETOBJSET(OBJCL:OBJCTCLASS):SETS;
   (*
         GET THE SET OF OBJECTS ASSOCIATED WITH OBJECT
         CLASS OBJCL.
   *)


PROCEDURE OBJCLDEBUG(VAR F:TEXT);
   (*
         DUMP ALL VALID OBJECT-CLASSES (INCLUDING THEIR
         OBJECTS) TO FILE F.
   *)
```

```
    PROCEDURE SETMAXATT(OBJCL:OBJCTCLASS; VAL:INTEGER);
       (*
             SET MAXIMUM NUMBER OF ATTRIBUTES FOR OBJECT-
             CLASS  OBJCL  TO  VAL.
       *)


    FUNCTION GETMAXATT(OBJCL:OBJCTCLASS):INTEGER;
       (*
             RETURN MAXIMUM NUMBER OF ATTRIBUTES FOR
             OBJECT-CLASS  OBJCL.
       *)


    PROCEDURE INCLUDE(OBJ:OBJECT; OBJCL:OBJCTCLASS);
       (*
             INCLUDE OBJECT  OBJ  INTO OBJECT-CLASS  OBJCL.
       *)


    FUNCTION INCLASS(OBJ:OBJECT; OBJCL:OBJCTCLASS): BOOLEAN;
       (*
             RETURNS  TRUE  <=> OBJECT  OBJ  IS IN OBJECT-
             CLASS  OBJCL.
       *)
```

B.2.5 Packet Routines

```
  PROCEDURE SETACTION(ACTN:ACTION; P:PACKET; S:SETS);
     (*
           SET SPECIFIED ACTION OF PACKET  P  TO BE SET  S.
     *)


  FUNCTION GETACTION(ACTN:ACTION; P:PACKET):SETS;
     (*
           GET ACTION  ACTN  FROM PACKET  P.
     *)
```

B.2.5.1 Use-Table Routines

```
  PROCEDURE SETPCKPLST(P:PACKET; VAL:INTEGER);
     (*
           SET PARAM-LIST OF PACKET  P  TO  VAL.
     *)


  FUNCTION GETPCKPLST(P:PACKET):INTEGER;
     (*
           GET PARAM-LIST OF PACKET P.
     *)
```

```
PROCEDURE SETPCKNAME(P:PACKET; VAL:SYMBOL);
   (*
         SET REFERENCED SUBPROG OF PACKET  P  TO  VAL.
   *)


FUNCTION GETPCKNAME(P:PACKET):SYMBOL;
   (*
         GET REFERENCED SUBPROG OF PACKET P.
   *)


PROCEDURE SETPCKEDGE(P:PACKET; VAL:PACKET);
   (*
         SET USE-EDGE OF PACKET  P  TO  VAL.
   *)


FUNCTION GETPCKEDGE(P:PACKET):PACKET;
   (*
         GET USE-EDGE OF PACKET P.
   *)


PROCEDURE SETPCKNPRM(P:PACKET; VAL:INTEGER);
   (*
         SET NUMBER OF ACTUAL PARAMS OF PACKET  P  TO
         VAL.
   *)


FUNCTION GETPCKNPRM(P:PACKET):INTEGER;
   (*
         GET NUMBER OF ACTUAL PARAMS OF PACKET P.
   *)


PROCEDURE SETPCKREF(P:PACKET; VAL:INTEGER);
   (*
         SET CODE-REFERENCE OF PACKET  P  TO  VAL.
   *)


FUNCTION GETPCKREF(P:PACKET):INTEGER;
   (*
         GET CODE-REFERENCE OF PACKET P.
   *)


FUNCTION NEWPACKET:PACKET;
   (*
         RETURN A NEW PACKET FROM THE PACKET-POOL.
   *)
```

B.2.5.2 Flowgraph Routines

```
FUNCTION NEWFGNNODE:FGNODE;
   (*
         RETURN A NEW FLOWGRAPH NODE FROM PACKET POOL.
   *)


PROCEDURE SETFGNTYP(F:FGNODE; VAL:INTEGER);
   (*
         SET TYPE OF FLOWGRAPH NODE  F  TO VAL.
   *)


FUNCTION GETFGNTYP(F:FGNODE):INTEGER;
   (*
         GET TYPE OF FLOWGRAPH NODE  F.
   *)


PROCEDURE SETFGNEXP(F:FGNODE; E:PACKET);
   (*
         SET EXPRESSION TREE ATTRIBUTE OF FLOWGRAPH NODE
         F  TO  E.
   *)


FUNCTION GETFGNEXP(F:FGNODE):PACKET;
   (*
         GET EXPRESSION TREE FOR FLOWGRAPH NODE  F.
   *)


PROCEDURE SETFGNNSON(F:FGNODE; VAL:INTEGER);
   (*
         SET NUMBER OF SON-EDGES OF FLOWGRAPH NODE  F
         TO  VAL.
   *)


FUNCTION GETFGNNSON(F:FGNODE):INTEGER;
   (*
         GET NUMBER OF SON-EDGES FOR FLOWGRAPH NODE  F.
   *)


PROCEDURE SETFGNNPAR(F:FGNODE; VAL:INTEGER);
   (*
         SET NUMBER OF PARENT-EDGES OF FLOWGRAPH NODE  F
         TO  VAL.
   *)
```

```
FUNCTION GETFGNNPAR(F:FGNODE):INTEGER;
   (*
         GET NUMBER OF PARENT-EDGES FOR FLOWGRAPH NODE  F.
   *)


PROCEDURE SETFGNSON(F:FGNODE; VAL:SETS);
   (*
         SET SON-EDGES OF FLOWGRAPH NODE  F  TO  VAL.
   *)


FUNCTION GETFGNSON(F:FGNODE):SETS;
   (*
         GET SON-EDGES FOR FLOWGRAPH NODE  F.
   *)


PROCEDURE SETFGNPAR(F:FGNODE; VAL:SETS);
   (*
         SET PARENT-EDGES OF FLOWGRAPH NODE  F  TO  VAL.
   *)


FUNCTION GETFGNPAR(F:FGNODE):SETS;
   (*
         GET PARENT-EDGES FOR FLOWGRAPH NODE  F.
   *)


PROCEDURE NNEDGE(FROMNODE,TONODE:FGNODE);
   (*
         CREATE A FLOWGRAPH EDGE FROM NODE  FROMNODE
         TO NODE  TONODE.
   *)


PROCEDURE NSEDGE(FROMNODE:FGNODE; TOSET:SETS);
   (*
         CREATE A FLOWGRAPH EDGE FROM NODE  FROMNODE
         TO EVERY NODE IN SET  TOSET.
   *)


PROCEDURE SNEDGE(FROMSET:SETS; TONODE:FGNODE);
   (*
         CREATE A FLOWGRAPH EDGE FROM EVERY NODE IN SET
         FROMSET  TO NODE  TONODE.
   *)
```

```
  PROCEDURE SSEDGE(FROMSET,TOSET:SETS);
     (*
            CREATE A FLOWGRAPH EDGE FROM EVERY NODE IN SET
            FROMSET  TO EVERY NODE IN SET  TOSET.
     *)
```

B.2.5.3 Expression-Tree Routines

```
  FUNCTION NEWEXPNODE:EXPNODE;
     (*
            RETURN A NEW EXPRESSION-TREE NODE FROM THE
            PACKET POOL.
     *)


  PROCEDURE SETEXPTYP(E:EXPNODE; TYP:INTEGER);
     (*
            SET TYPE OF EXPRESSION-TREE NODE  E  TO TYP.
     *)


  FUNCTION GETEXPTYP(E:EXPNODE):INTEGER;
     (*
            GET TYPE OF EXPRESSION-TREE NODE  E.
     *)


  PROCEDURE SETEXPSON(I:INTEGER; E:EXPNODE; VAL:INTEGER);
     (*
            SET THE ITH SON OF EXPRESSION-TREE NODE  E  TO
            VAL.
     *)


  FUNCTION GETEXPSON(I:INTEGER; E:EXPNODE):INTEGER;
     (*
            GET THE ITH SON OF EXPRESSION-TREE NODE  E.
     *)


  PROCEDURE SETEXPUSE(E:EXPNODE; VAL:INTEGER);
     (*
            SET USE-LINK FIELD OF EXPRESSION-TREE NODE  E
            TO  VAL.
     *)


  FUNCTION GETEXPUSE(E:EXPNODE):INTEGER;
     (*
            GET USE-LINK OF EXPRESSION-TREE NODE  E.
     *)
```

```
PROCEDURE SETEXPOBJ(E:EXPNODE; VAL:INTEGER);
   (*
         SET OBJECT FIELD OF EXPRESSION-TREE NODE  E  TO
         VAL.
   *)


FUNCTION GETEXPOBJ(E:EXPNODE):INTEGER;
   (*
         GET OBJECT OF EXPRESSION-TREE NODE  E.
   *)
```

B.2.6 Parameter Building Routines

```
FUNCTION NEWFPNODE: FPRMPTR;
   (*
         RETURN NEW FORMAL-PARAMETER NODE.
   *)


PROCEDURE SETFPUSE(FP:FPRMPTR; L:INTEGER);
   (*
         SET USE-LINK OF PARAMETER NODE  FP  TO  L.
   *)


FUNCTION GETFPUSE(FP:FPRMPTR):INTEGER;
   (*
         GET USE-LINK OF PARAMETER NODE  FP.
   *)


PROCEDURE SETFPLINK(FP:FPRMPTR; L:INTEGER);
   (*
         SET FP-LINK OF PARAMETER NODE  FP  TO  L.
   *)


FUNCTION GETFPLINK(FP:FPRMPTR):INTEGER;
   (*
         GET FP-LINK OF PARAMETER NODE  FP.
   *)


PROCEDURE SETFPSET(FP:FPRMPTR; L:SETS);
   (*
         SET GLOBAL SET OF PARAMETER NODE  FP  TO  L.
   *)
```

```
FUNCTION GETFPSET(FP:FPRMPTR):SETS;
   (*
         GET GLOBAL SET OF PARAMETER NODE  FP.
   *)
```

B.2.7 Callgraph Routines

```
FUNCTION NEWCGRNODE:CALLPTR;
   (*
         RETURN A NEW CALLGRAPH POINTER
   *)


PROCEDURE SETCGRNAME(C:CALLPTR; VAL:SYMBOL);
   (*
         SET NAME-FIELD OF CALLGRAPH NODE  C  TO  VAL.
   *)


FUNCTION GETCGRNAME(C:CALLPTR):SYMBOL;
   (*
         GET NAME-FIELD OF CALLGRAPH NODE  C.
   *)


PROCEDURE SETCGRNMFP(C:CALLPTR; VAL:INTEGER);
   (*
         SET NUM-PARAM-FIELD OF CALLGRAPH NODE  C  TO
         VAL.
   *)


FUNCTION GETCGRNMFP(C:CALLPTR):INTEGER;
   (*
         GET NUM-PARAM-FIELD OF CALLGRAPH NODE  C.
   *)


PROCEDURE SETCGRFPL(C:CALLPTR; VAL:INTEGER);
   (*
         SET FP-FIELD OF CALLGRAPH NODE  C  TO  VAL.
   *)


FUNCTION GETCGRFPL(C:CALLPTR):INTEGER;
   (*
         GET FP-FIELD OF CALLGRAPH NODE  C.
   *)
```

```
PROCEDURE SETCGREDGE(C:CALLPTR; VAL:PACKET);
   (*
         SET EDGE-FIELD OF CALLGRAPH NODE  C  TO  VAL.
   *)


FUNCTION GETCGREDGE(C:CALLPTR):PACKET;
   (*
         GET EDGE-FIELD OF CALLGRAPH NODE  C.
   *)


PROCEDURE SETCGRNTRY(C:CALLPTR; VAL:PACKET);
   (*
         SET ENTRY-FIELD OF CALLGRAPH NODE  C  TO  VAL.
   *)


FUNCTION GETCGRNTRY(C:CALLPTR):PACKET;
   (*
         GET ENTRY-FIELD OF CALLGRAPH NODE  C.
   *)


PROCEDURE SETCGREXIT(C:CALLPTR; VAL:PACKET);
   (*
         SET EXIT-FIELD OF CALLGRAPH NODE  C  TO  VAL.
   *)


FUNCTION GETCGREXIT(C:CALLPTR):PACKET;
   (*
         GET EXIT-FIELD OF CALLGRAPH NODE  C.
   *)


PROCEDURE SETMAINCALL(VAL:CALLPTR);
   (*
         SET MAIN PROGRAM INDICATOR TO BE CALLGRAPH
         NODE  C.
   *)


FUNCTION CALLEDGE(C:CALLPTR; OBJ:SYMBOL;
                              NUMPARAM:INTEGER):PACKET;
   (*
         SEARCH USE-EDGES OF CALLGRAPH ENTRY  C  FOR A
         PACKET WITH NAME-FIELD  OBJ, AND RETURN PACKET.
         IF PACKET DOESNT EXIST, THEN CREATE A PACKET
         WITH NAME  OBJ.
   *)
```

B.2.8 Parse-Tree Routines

```
FUNCTION GETPRSATT(PND:PARSENODE;SEL:PRSSELECT):INTEGER;
   (*
         GET SELECTED FIELD FROM PARSE-TREE NODE #PND#.
   *)


PROCEDURE SETPRSATT(PND:PARSENODE; SEL:PRSSELECT;
                                        VAL:INTEGER);
   (*
         SETS THE SELECTED FIELD OF PARSE-TREE NODE
         "PND" TO VAL.
   *)


PROCEDURE TREEDUMP(VAR F:TEXT);
   (*
         DUMP OF PARSE TREE IN TREE REPRESENTATION.
   *)
```

B.2.9 Other Routines

These include all the standard routines provided by the PASCAL Report ([Jensen 74, Appendix A]).

APPENDIX C

Output Tables Format

C.1 Data Structure Representations

```
-----------------------------------------------------

 ------------
| CNAME      |   SYMBOL pointer to name of program-unit.
|------------|
| CEDGE      |   PACKET pointer to first use-table node
|------------|      in edge-list.
| CENTRY     |   PACKET pointer to ENTRY flowgraph node
|------------|      for this program-unit.
| CNUMFP     |   Number of formal parameters for
|------------|      program-unit.
| CFIRSTFP   |   SET pointer to first formal parameter
 ------------       node.
```

Figure C.1 Callgraph Node Structure

```
-----------------------------------------------------

 --------------
|NOBJ  | FOBJ |  NOBJ  is the number of objects in
|------|------|     action-class , and FOBJ  is a SET
|NOBJ  | FOBJ |     pointer for the first object.
|------|------|
|NOBJ  | FOBJ |
 --------------
```

Figure C.2 Action Packet Structure

```
-----------------------------------------------------

 ------------
| MODE       |   Parameter-mode indicator (1 => "IN",
|------------|      2 => "OUT",  3 => "IN/OUT").
| LINK       |   FP-pointer link to next parameter.
 ------------
```

Figure C.3 Fp-Node Structure

```
-----------------------------------------------------
```

PACKETS

```
-------------------------------------------------------

 -------------
 | FNODETYPE |    Flowgraph node-type indicator.
 |-----------|
 | FEXPTR    |    PACKET pointer to expression-tree root
 |-----------|       for this node.
 | FNSON     |    Number of sons for this node.
 |-----------|
 | FFSON     |    PACKET pointer to first son.
 |-----------|
 | FNPAR     |    Number of parents for this node.
 |-----------|
 | FFPAR     |    PACKET pointer to first parent.
 |-----------|  \
 |           |  |
 |-----------|  |
 |           |  >    ACTIONS
 |-----------|  |
 |           |  |
 -------------  /
```

_igure C.4 Flowgraph Node Structure

```
-------------------------------------------------------

 -------------
 | ENODETYPE |    Expression-tree node-type indicator.
 |-----------|
 | ESON1     |    PACKET pointer to first son.
 |-----------|
 | ESON2     |    PACKET pointer to second son.
 |-----------|
 | EUSE      |    PACKET pointer to link use-table
 |-----------|       information.
 | EOBJ      |    Symbol pointer to object whose action
 |-----------|       is currently unknown.
 | (unused)  |
 |-----------|  \
 |           |  |
 |-----------|  |
 |           |  >   ACTIONS
 |-----------|  |
 |           |  |
 -------------  /
```

Figure C.5 Expression-Tree Node Structure

```
-------------
| UNPARAM    |   Number of parameters in an invocation
|------------|      of this program-unit.
| UPLIST     |   FP pointer to first actual-parameter
|------------|      node.
| UNAME      |   SYMBOL pointer to name of program-unit.
|------------|
| UCODEREF   |   PACKET pointer to first expression-tree
|------------|      node for call to this program-unit.
| ULINK      |   PACKET pointer to next entry in use-
|------------|      table.
| (unused)   |
|------------| \
|            |  |
|------------|  |
|            |   >  ACTIONS
|------------|  |
|            |  |
-------------  /
```

Figure C.6 Use-Table Node Structure

C.2 File Format

Pages 61 and 62 represent the format for the output Tables File. This file is a text file composed of lines (records). Each line holds no more than 130 characters. Below is a line-by-line description of the information on those pages.

Notice that lines 12, 17, 18, 19, 20, 22, 23, 24 and the ends of lines 13 and 14 describe sets or lists of objects. Such descriptions are represented by (1) the number, n, of objects in the list, and (2) a list of the n objects. The list may extend over a line boundary. After the last object in a given list is printed (within the file), the line holding that object is terminated.

line 1	n_a is the number of user-defined actions.
lines 2,3	Action names. Each string is exactly 10 characters long and each begins in column 2 of a new line.
line 4	n_t is the number of expression-tree plus flowgraph node types.
lines 5,6	Node-type names. Each string is exactly 10 characters long and each begins in column 2 of a new line.
line 7	n_s is the number of Symbol Table entries (symbols).
lines 8,9	Symbols. length_i is the number of characters in string_i. att_i is the Attribute Table descriptor owned by symbol_i. There is exactly one blank between att_i and string_i.
line 10	Number of callgraph nodes, and callgraph node descriptor (index) for the main program.
lines 11-32	Describe all information for callgraph node 1.
line 11	Information for callgraph node 1. See Figure C.1.
line 12	Information for callgraph node 1. See Figures C.1 and C.3.
lines 13-15	Describe all use-table information for callgraph node 1.
line 13	Information for use-table node indexed by $\text{UNODE}_{1,1}$ of callgraph node 1. See Figure C.6.
line 14	Information for use-table node indexed by $\text{UNODE}_{1,n}$ of callgraph node 1. See Figure C.6. NOTE: The value for ULINK_i is UNODE_{i+1}.
line 15	Zero. Indicates end-of-use-table information for callgraph node 1.
lines 16-25	Describe all flowgraph information for flowgraph owned by callgraph node 1.

line 16	Information for flowgraph node indexed by $FNODE_{1,1}$ of callgraph node 1. See Figure C.4.
line 17	Set of sons for flowgraph node $FNODE_{1,1}$ of callgraph node 1.
line 18	Set of parents for flowgraph node $FNODE_{1,1}$ of callgraph node 1.
line 19	Set of objects in $Action\text{-}Class_1$ for flowgraph node $FNODE_{1,1}$ of callgraph node 1.
line 20	Set of objects in $Action\text{-}Class_{n_a}$ (n_a given in line 1) for flowgraph node $FNODE_{1,1}$ of callgraph node 1.
lines 21-24	Same as lines 16-20 except for flowgraph node indexed by $FNODE_{1,m}$. The total number of flowgraph nodes, m, is indeterminate.
line 25	Zero. Indicates end-of-flowgraph information for callgraph node 1.
lines 26-32	Describe all expression-tree information for callgraph node 1.
line 26	Information for expression-tree node indexed by $ENODE_{1,1}$ of callgraph node 1. See Figure C.5.
lines 27,28	Action sets (format as in lines 19, 20) for expression-tree node $ENODE_{1,1}$ of callgraph node 1.
lines 29-31	Same as lines 26-28 except for expression-tree node $ENODE_{1,k}$ of callgraph node 1. The total number of expression-tree nodes, k, is indeterminate.
line 32	Zero. Indicates end-of-expression-tree information for callgraph node 1.
lines 33-34	Represent same information as lines 11-32 except for callgraph node 2.
lines 35-36	Represent same information as lines 11-32 except for callgraph node numcall, where numcall is given in line 10.

1. $\underline{n}_a$
2. $\underline{\text{string}}_1$

   $\vdots$

3. $\underline{\text{string}}_{n_a}$
4. $\underline{n}_t$
5. $\underline{\text{string}}_1$

   $\vdots$

6. $\underline{\text{string}}_{n_t}$
7. $\underline{n}_s$
8. $\underline{\text{length}}_1 \quad \underline{\text{att}}_1 \quad \underline{\text{string}}_1$

   $\vdots \qquad \vdots \qquad \vdots$

9. $\underline{\text{length}}_{n_s} \quad \underline{\text{att}}_{n_s} \quad \underline{\text{string}}_{n_s}$
10. $\underline{\text{numcall}} \quad \underline{\text{maincall}}$
11. $\underline{\text{CNAME}}_1 \ \underline{\text{CEDGE}}_1 \ \underline{\text{CENTRY}}_1 \ \underline{\text{CEXIT}}_1$
12. $\underline{\text{CNUMFP}}_1 \ \underline{\text{MODE}}_{1,1} \ \underline{\text{MODE}}_{1,2} \cdots \underline{\text{MODE}}_{1,\text{CNUMFP}_1}$
13. $\underline{\text{UNODE}}_{1,1} \ \underline{\text{UNAME}}_{1,1} \ \underline{\text{UCODEREF}}_{1,1} \ \underline{\text{UNPARAM}}_{1,1} \ \underline{P}_{1,1,1} \cdots \underline{P}_{1,1,\text{UNPARAM}_{1,1}}$

    $\vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots$

14. $\underline{\text{UNODE}}_{1,n} \ \underline{\text{UNAME}}_{1,n} \ \underline{\text{UCODEREF}}_{1,n} \ \underline{\text{UNPARAM}}_{1,n} \ \underline{P}_{1,n,1} \quad \underline{P}_{1,n,\text{UNPARAM}_{1,n}}$
15. 0
16. $\underline{\text{FNODE}}_{1,1} \ \underline{\text{FNODETYPE}}_{1,1} \ \underline{\text{FEXPTR}}_{1,1}$
17. $\underline{\text{FNSON}}_{1,1} \quad \underline{\text{SON}}_{1,1,1} \cdots \underline{\text{SON}}_{1,1,\text{FNSON}_{1,1}}$
18. $\underline{\text{FNPAR}}_{1,1} \quad \underline{\text{PAR}}_{1,1,1} \cdots \underline{\text{PAR}}_{1,1,\text{FNPAR}_{1,1}}$
19. $\underline{\text{NOBJ}}_{1,1,1} \quad \underline{\text{OBJ}}_{1,1,1,1} \ \cdots \ \underline{\text{OBJ}}_{1,1,1,\text{NOBJ}_{1,1,1}}$

    $\vdots \qquad \vdots \qquad \vdots$

20. $\underline{\text{NOBJ}}_{1,1,n_a} \quad \underline{\text{OBJ}}_{1,1,n_a,1} \ \cdots \ \underline{\text{OBJ}}_{1,1,n_a,\text{NOBJ}_{1,1,n_a}}$

    $\vdots \qquad \vdots \qquad \vdots$

21. $\underline{\text{FNODE}}_{1,m} \ \underline{\text{FNODETYPE}}_{1,m} \ \underline{\text{FEXPTR}}_{1,m}$
22. $\underline{\text{FNSON}}_{1,m} \quad \underline{\text{SON}}_{1,m,1} \cdots \underline{\text{SON}}_{1,m,\text{FNSON}_{1,m}}$

    $\vdots \qquad \vdots \qquad \vdots$

23. $\underline{\text{NOBJ}}_{1,m,1} \quad \underline{\text{OBJ}}_{1,m,1,1} \ \cdots \ \underline{\text{OBJ}}_{1,m,1,\text{NOBJ}_{1,m,1}}$

    $\vdots \qquad \vdots \qquad \vdots$

24. $\underline{\text{NOBJ}}_{1,m,n_a} \quad \underline{\text{OBJ}}_{1,m,n_a,1} \ \cdots \ \underline{\text{OBJ}}_{1,m,n_a,\text{NOBJ}_{1,m,n_a}}$
25. 0

26. $\underline{\text{ENODE}}_{1,1}$ $\underline{\text{ENODETYPE}}_{1,1}$ $\underline{\text{ESON1}}_{1,1}$ $\underline{\text{ESON2}}_{1,1}$ $\underline{\text{EUSE}}_{1,1}$ $\underline{\text{EOBJ}}_{1,1}$

27. $\underline{\text{NOBJ}}_{1,1,1}$ $\underline{\text{OBJ}}_{1,1,1,1}$ $\cdots$ $\underline{\text{OBJ}}_{1,1,1,\text{NOBJ}_{1,1,1}}$

$\vdots \quad \vdots \quad \vdots$

28. $\underline{\text{NOBJ}}_{1,1,n_a}$ $\underline{\text{OBJ}}_{1,1,n_a,1}$ $\cdots$ $\underline{\text{OBJ}}_{1,1,n_a,\text{NOBJ}_{1,1,n_a}}$

$\vdots \quad \vdots \quad \vdots$

29. $\underline{\text{ENODE}}_{1,k}$ $\underline{\text{ENODETYPE}}_{1,k}$ $\underline{\text{ESON1}}_{1,k}$ $\underline{\text{ESON2}}_{1,k}$ $\underline{\text{EUSE}}_{1,k}$ $\underline{\text{EOBJ}}_{1,k}$

30. $\underline{\text{NOBJ}}_{1,k,1}$ $\underline{\text{OBJ}}_{1,k,1,1}$ $\cdots$ $\underline{\text{OBJ}}_{1,k,1,\text{NOBJ}_{1,k,1}}$

$\vdots \quad \vdots \quad \vdots$

31. $\underline{\text{NOBJ}}_{1,k,n_a}$ $\underline{\text{OBJ}}_{1,k,n_a,1}$ $\cdots$ $\underline{\text{OBJ}}_{1,k,n_a,\text{NOBJ}_{1,k,n_a}}$

32. 0

33. $\underline{\text{CNAME}}_2$ $\underline{\text{CEDGE}}_2$ $\underline{\text{CENTRY}}_2$ $\underline{\text{CEXIT}}_2$

$\vdots \quad \vdots \quad \vdots \quad \vdots$

34. 0

$\vdots \quad \vdots \quad \vdots \quad \vdots$

35. $\underline{\text{CNAME}}_{\text{numcall}}$ $\underline{\text{CEDGE}}_{\text{numcall}}$ $\underline{\text{CENTRY}}_{\text{numcall}}$ $\underline{\text{CEXIT}}_{\text{numcall}}$

$\vdots \quad \vdots \quad \vdots \quad \vdots$

36. 0

APPENDIX D

SAM/SAL System Sample Program

This appendix presents an example of the various inputs to and outputs from the SAM/SAL system. The language specified by this example is TURINGOL, a simple language described in [Knuth 68].

Section D.1 lists a SAL program specifying TURINGOL. This listing corresponds to "SAL Program S" in Figure 1.1.

Section D.2 lists a sample TURINGOL program. This program corresponds to the "User Program U" in Figure 1.1.

Section D.3 lists the "Output Report" in Figure 1.1 for the sample program of Section D.2.

Section D.4 lists the "Annotated Flowgraphs" file in Figure 1.1 for the sample program of Section D.2. This file is the Tables File whose general format is given in Section C.2.

Section D.5 presents a user-readable listing of the Tables File of Section D.4.

Section D.6 gives a graphic illustration of the output for the sample program of Section D.2.

Note that TURINGOL allows no procedures or functions. As a result, (1) the output Tables File will always consist of a callgraph having only a single node; (2) the use-table list (dependent sons of a callgraph node) will be empty; and (3) no expression trees are necessary. These properties are apparent from the listing in Section D.5.

D.1 TURINGOL: A SAL Program

```
SALTRAN  (VERSION: 02/17/81)    DATE: 81/03/05.    TIME: 11.07.31.                    PAGE 1

   0    PROGRAM TURINGOL;
   0       #
   0       #  TURINGOL IS A SAMPLE LANGUAGE SPECIFIED IN:
   0       #
   0       #     KNUTH, D. E.,"SEMANTICS OF CONTEXT-FREE LANGUAGES", MATHEMATICAL
   0       #     SYSTEMS THEORY, VOL. 2, NO. 2, (JUNE 1968), PP. 127-145.
   0       #
   0       #  INSTEAD OF TURING-MACHINE DELTA FUNCTIONS, THIS SPECIFICATION
   0       #  PRODUCES AN ANNOTATED FLOWGRAPH.
   0       #
   0       #  SINCE THIS IMPLEMENTATION CANNOT HANDLE THE EMPTY PRODUCTION,
   0       #  THE EMPTY STATEMENT WILL BE DENOTED BY "NULL".
   0       #
   0
   0       PREAMBLE
   0
   0          SCANNER SCANTOK:
   0             SCANTOK -> (SPACES / TOKEN)* SPACES;
   0             SPACES  -> (' ' / 'EOL')* ;
   0             SCANNER TOKEN:
   0                TOKEN -> IDNT / '#"' STRNG '#"' / LITERAL / MISC1 / MISC2 ;
   0             END TOKEN;
   0             IDNT    -> CHAR+ => "IDNTFR" ;
   0             STRNG   -> CHAR+ => "STRING" ;
   0             LITERAL -> "." / "," / ";" / ":" / "[" / "]" => "SINGLE" ;
   0             CHAR    -> "A" / "B" / "C" / "D" / "E" / "F" /
   0                        "G" / "H" / "I" / "J" / "K" / "L" /
   0                        "M" / "N" / "O" / "P" / "Q" / "R" /
   0                        "S" / "T" / "U" / "V" / "W" / "X" /
   0                        "Y" / "Z" ;
   0             MISC1   -> "#?" => "CNSTNT";
   0             MISC2   -> "#$" => "FLOAT";
   0          END SCANTOK.
   0
   0       END PREAMBLE
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.31.                     PAGE 2

   0
   0      DECLARATIONS
   0
   0         OBJECT CLASSES :
   0            ALPHABET : ( );
   0            LABELS   : (FN : FGNODE);
   0
   0         ACTIONS :
   0            DECLARE, REF : ON ALPHABET;
   0            USE, DEF     : ON LABELS;
   0
   0         FLOWGRAPH NODE TYPES :
   0            ENTRYSTMT, EXITSTMT, IFSTMT, EMPTYSTMT,
   0            GOTOSTMT, MOVESTMT, PRINTSTMT;
   0
   0         $ PROCEDURES AND FUNCTIONS
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.31.                PAGE 3
0
0        FUNCTION SETLABEL(L:OBJECT; S:FGNODE):INTEGER;
0           (*
0              SET FLOWGRAPH NODE FOR LABEL  L  TO BE  S.
0           *)
0           BEGIN (* SETLABEL *)
1              SETATT(FN, L, S);
1              SETLABEL:=1
1           END (* SETLABEL *);
0
0        FUNCTION GETLABEL(L:OBJECT; CONTROL:INTEGER):FGNODE;
0           (*
0              GET FLOWGRAPH NODE ASSOCIATED WITH LABEL  L.
0           *)
0           BEGIN (* GETLABEL *)
1              GETLABEL:=GETATT(FN, L)
1           END (* GETLABEL *);
0
0        PROCEDURE CHECKVAR(OBJ:OBJECT; TOKEN:INTEGER);
0           (*
0              REPORT SEMANTIC ERROR IF  OBJ  HAS NOT BEEN DECLARED
0              TO BE IN THE TAPE ALPHABET.
0           *)
0           BEGIN (* CHECKVAR *)
1              IF NOT INCLASS(OBJ,ALPHABET) THEN
1                 BEGIN (* THEN *)
2                    WRITELN;
2                    WRITELN(" ":10,"SEMANTIC ERROR:");
2                    WRITE(" ":20,"SYMBOL  ");
2                    WRITESYM(OUTPUT,OBJ);
2                    WRITELN("  AT TOKEN ",TOKEN:1," NOT DECLARED.")
2                 END (* THEN *)
1           END (* CHECKVAR *);
0
0        PROCEDURE CHECKLABEL(OBJ:OBJECT; TOKEN:INTEGER);
0           (*
0              REPORT SEMANTIC ERROR IF  OBJ  HAS NOT BEEN DEFINED
0              AS A LABEL.
0           *)
0           BEGIN (* CHECKLABEL *)
1              IF NOT INCLASS(OBJ,LABELS) THEN
1                 BEGIN (* THEN *)
2                    INCLUDE(OBJ,LABELS);
2                    WRITELN;
2                    WRITELN(" ":10,"SEMANTIC ERROR:");
2                    WRITE(" ":20,"LABEL  ");
2                    WRITESYM(OUTPUT,OBJ);
2                    WRITELN("  AT TOKEN ",TOKEN:1," NOT DEFINED.")
2                 END (* THEN *)
1           END (* CHECKLABEL *);
0
0        FUNCTION MAKEMAIN:SYMBOL;
0           (*
0              CREATE THE SYMBOL "TURINGOL" AND RETURN ITS DESCRIPTOR.
0           *)
0           VAR
0              WASTHERE : BOOLEAN;
0              REP      : SYMREP;
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.32.          PAGE 4

  0              STR       : UNPSTR;
  0              I         : INTEGER;
  0           BEGIN (* MAKEMAIN *);
  1              STR[1]:="T";
  1              STR[2]:="U";
  1              STR[3]:="R";
  1              STR[4]:="I";
  1              STR[5]:="N";
  1              STR[6]:="G";
  1              STR[7]:="O";
  1              STR[8]:="L";
  1              FOR I:=9 TO MAXCHAR DO
  1                 STR[I]:=" ";
  1              PACK(STR,1,REP);
  1              MAKEMAIN:=HASH(REP,8,WASTHERE)
  1           END (* MAKEMAIN *);
  0
  0     END DECLARATIONS
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.32.                      PAGE 5

0
0      LANGUAGE SPECIFICATIONS
0
0         GRAMMAR ATTRIBUTES
0
0            <PROGRAM> :
0               ENTRY, EXIT : FGNODE;
0               CALLNODE : CALLPTR;
0
0            <STMT LIST> :
0               START : FGNODE;
0               FINISH : SET OF FGNODE;
0               LABELREF, LABELDEF : INTEGER;
0
0            <STATEMENT> :
0               START : FGNODE;
0               FINISH : SET OF FGNODE;
0               LABELREF, LABELDEF : INTEGER;
0
0            <DIRECTION> : ;
0
0            <IF PART> : ;
0
0            <DECLARATION> : ;
0
0            <IDENTIFIER> :
0               VALUE : SYMBOL;
0               TOKEN : INTEGER;
0
0            <STRING> :
0               VALUE : SYMBOL;
0               TOKEN : INTEGER;
0
0            <EMPTY> : ;
0
0         END GRAMMAR ATTRIBUTES
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.32.                PAGE 6

        RULES

            <PROGRAM> ::= <DECLARATION> ";" <STMT LIST> "."
               SEMANTICS

                  FLOWGRAPH SPECIFICATIONS

                      <PROGRAM>.ENTRY := NEWFGNNODE;
                      <PROGRAM>.EXIT := NEWFGNNODE;
                      <PROGRAM>.CALLNODE := NEWCGRNODE;
                      <STMT LIST>.LABELREF := <STMT LIST>.LABELDEF;
                      SETFGNTYP(<PROGRAM>.ENTRY, ENTRYSTMT);
                      SETFGNTYP(<PROGRAM>.EXIT, EXITSTMT);
                      NNEDGE(<PROGRAM>.ENTRY, <STMT LIST>.START);
                      SNEDGE(<STMT LIST>.FINISH, <PROGRAM>.EXIT);
                      SETMAINCALL(<PROGRAM>.CALLNODE);
                      SETCGRNAME(<PROGRAM>.CALLNODE, MAKEMAIN);
                      SETCGREDGE(<PROGRAM>.CALLNODE, 0);
                      SETCGRNTRY(<PROGRAM>.CALLNODE, <PROGRAM>.ENTRY);
                      SETCGREXIT(<PROGRAM>.CALLNODE, <PROGRAM>.EXIT);
                      SETCGRNMFP(<PROGRAM>.CALLNODE, 0);
                      SETCGRFPL(<PROGRAM>.CALLNODE, 0)

                  ACTION SPECIFICATIONS

                      SETACTION(DECLARE, <PROGRAM>.ENTRY, GETOBJSET(ALPHABET))
               END

            <STMT LIST> ::= <STATEMENT>
               SEMANTICS

                  FLOWGRAPH SPECIFICATIONS

                      <STMT LIST>.LABELDEF := <STATEMENT>.LABELDEF;
                      <STATEMENT>.LABELREF := <STMT LIST>.LABELREF;
                      <STMT LIST>.START := <STATEMENT>.START;
                      <STMT LIST>.FINISH := <STATEMENT>.FINISH
               END

            <STMT LIST(1)> ::= <STMT LIST(2)> ";" <STATEMENT>
               SEMANTICS

                  FLOWGRAPH SPECIFICATIONS

                      <STMT LIST(1)>.LABELDEF := <STMT LIST(2)>.LABELDEF +
                                                  <STATEMENT>.LABELDEF;
                      <STMT LIST(2)>.LABELREF := <STMT LIST(1)>.LABELREF;
                      <STATEMENT>.LABELREF := <STMT LIST(1)>.LABELREF;
                      <STMT LIST(1)>.START := <STMT LIST(2)>.START;
                      <STMT LIST(1)>.FINISH := <STATEMENT>.FINISH;
                      SNEDGE(<STMT LIST(2)>.FINISH, <STATEMENT>.START)
               END

            <STATEMENT(1)> ::= <IDENTIFIER> ":" <STATEMENT(2)>
               SEMANTICS

                  OBJECT SPECIFICATIONS
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.34.                        PAGE 7
4
4                     INCLUDE(<IDENTIFIER>.VALUE, LABELS)
4
4                  FLOWGRAPH SPECIFICATIONS
4
4                     <STATEMENT(1)>.LABELDEF := SETLABEL(<IDENTIFIER>.VALUE,
4                                                  <STATEMENT(2)>.START);
4                     <STATEMENT(2)>.LABELREF := <STATEMENT(1)>.LABELREF;
4                     <STATEMENT(1)>.START := <STATEMENT(2)>.START;
4                     <STATEMENT(1)>.FINISH := <STATEMENT(2)>.FINISH
4
4                  ACTION SPECIFICATIONS
4
4                     SETACTION(DEF, <STATEMENT(1)>.START, [ <IDENTIFIER>.VALUE ])
4               END
5
5            <STATEMENT> ::= "[" <STMT LIST> "]"
5               SEMANTICS
5
5                  FLOWGRAPH SPECIFICATIONS
5
5                     <STATEMENT>.LABELDEF := <STMT LIST>.LABELDEF;
5                     <STMT LIST>.LABELREF := <STATEMENT>.LABELREF;
5                     <STATEMENT>.START := <STMT LIST>.START;
5                     <STATEMENT>.FINISH := <STMT LIST>.FINISH
5               END
6
6            <STATEMENT(1)> ::= <IF PART> <STRING> "THEN" <STATEMENT(2)>
6               SEMANTICS
6
6                  ATTRIBUTE SPECIFICATIONS
6
6                     CHECKVAR(<STRING>.VALUE, <STRING>.TOKEN)
6
6                  FLOWGRAPH SPECIFICATIONS
6
6                     <STATEMENT(1)>.LABELDEF := <STATEMENT(2)>.LABELDEF;
6                     <STATEMENT(2)>.LABELREF := <STATEMENT(1)>.LABELREF;
6                     <STATEMENT(1)>.START := NEWFGNNODE;
6                     <STATEMENT(1)>.FINISH := [ <STATEMENT(1)>.START ] UNION
6                                                  <STATEMENT(2)>.FINISH;
6                     SETFGNTYP(<STATEMENT(1)>.START, IFSTMT);
6                     NNEDGE(<STATEMENT(1)>.START, <STATEMENT(2)>.START)
6
6                  ACTION SPECIFICATIONS
6
6                     SETACTION(REF, <STATEMENT(1)>.START, [ <STRING>.VALUE ])
6               END
7
7            <STATEMENT> ::= <EMPTY>
7               SEMANTICS
7
7                  FLOWGRAPH SPECIFICATIONS
7
7                     <STATEMENT>.LABELDEF := 0;
7                     <STATEMENT>.START := NEWFGNNODE;
7                     <STATEMENT>.FINISH := [ <STATEMENT>.START ];
7                     SETFGNTYP(<STATEMENT>.START, EMPTYSTMT)
```

```
SALTRAN   (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.35.                    PAGE 8

 7                 END
 8
 8              <STATEMENT> ::= "GO" "TO" <IDENTIFIER>
 8                 SEMANTICS
 8
 8                    ATTRIBUTE SPECIFICATIONS
 8
 8                       CHECKLABEL(<IDENTIFIER>.VALUE, <IDENTIFIER>.TOKEN)
 8
 8                    FLOWGRAPH SPECIFICATIONS
 8
 8                       <STATEMENT>.LABELDEF := 0;
 8                       <STATEMENT>.START := NEWFGNNODE;
 8                       <STATEMENT>.FINISH := [ ];
 8                       SETFGNTYP(<STATEMENT>.START, GOTOSTMT);
 8                       NNEDGE(<STATEMENT>.START,
 8                           GETLABEL(<IDENTIFIER>.VALUE, <STATEMENT>.LABELREF)
 8
 8                    ACTION SPECIFICATIONS
 8
 8                       SETACTION(USE, <STATEMENT>.START, [ <IDENTIFIER>.VALUE ])
 8                 END
 9
 9              <STATEMENT> ::= "MOVE" <DIRECTION> "ONE" "SQUARE"
 9                 SEMANTICS
 9
 9                    FLOWGRAPH SPECIFICATIONS
 9
 9                       <STATEMENT>.LABELDEF := 0;
 9                       <STATEMENT>.START := NEWFGNNODE;
 9                       <STATEMENT>.FINISH := [ <STATEMENT>.START ];
 9                       SETFGNTYP(<STATEMENT>.START, MOVESTMT)
 9                 END
10
10              <STATEMENT> ::= "PRINT" <STRING>
10                 SEMANTICS
10
10                    ATTRIBUTE SPECIFICATIONS
10
10                       CHECKVAR(<STRING>.VALUE, <STRING>.TOKEN)
10
10                    FLOWGRAPH SPECIFICATIONS
10
10                       <STATEMENT>.LABELDEF := 0;
10                       <STATEMENT>.START := NEWFGNNODE;
10                       <STATEMENT>.FINISH := [ <STATEMENT>.START ];
10                       SETFGNTYP(<STATEMENT>.START, PRINTSTMT)
10
10                    ACTION SPECIFICATIONS
10
10                       SETACTION(REF, <STATEMENT>.START, [ <STRING>.VALUE ])
10                 END
11
11              <DIRECTION> ::= "LEFT"
11                 SEMANTICS
11                 END
12
12              <DIRECTION> ::= "RIGHT"
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.35.                    PAGE 9

12                SEMANTICS
12                END
13
13             <IF PART> ::= "IF" "THE" "TAPE" "SYMBOL" "IS"
13                SEMANTICS
13                END
14
14             <DECLARATION> ::= "TAPE" "ALPHABET" "IS" <IDENTIFIER>
14                SEMANTICS
14
14                   OBJECT SPECIFICATIONS
14
14                      INCLUDE(<IDENTIFIER>.VALUE, ALPHABET)
14                END
15
15             <DECLARATION(1)> ::= <DECLARATION(2)> "," <IDENTIFIER>
15                SEMANTICS
15
15                   OBJECT SPECIFICATIONS
15
15                      INCLUDE(<IDENTIFIER>.VALUE, ALPHABET)
15                END
16
16             <EMPTY> ::= "NULL"
16                SEMANTICS
16                END
17
17
17       END RULES
 0    END LANGUAGE SPECIFICATIONS
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.37.                    PAGE 10

0
0      PROCEDURE SPECIFICATIONS
0
0         BEGIN
1         END
0
0      END PROCEDURE SPECIFICATIONS.
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.37.                          PAGE 11

      *************************       CROSS REFERENCE MAP      *************************


 GRAMMAR SYMBOLS               RHS                 LINES

 * <PROGRAM>                     4                133  167
   <STMT LIST>                   3                137  167  193  204  204  238
   <STATEMENT>                   4                142  193  204  218  218  238  249  249  271  2
                                                  303  314
   <DIRECTION>                   1                147  303  333  337
   <IF PART>                     5                149  249  341
   <DECLARATION>                 4                151  167  345  353  353
   <IDENTIFIER>                  0                153  218  282  345  353
   <STRING>                      0                157  249  314
   <EMPTY>                       1                161  271  361
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.37.                PAGE 12


 GRAMMAR ATTRIBUTES                                          LINES

   <PROGRAM>.ENTRY                  SYNTHESIZED     134  172  176  178  183  190
   <PROGRAM>.EXIT                   SYNTHESIZED     134  173  177  179  184
   <PROGRAM>.CALLNODE               SYNTHESIZED     135  174  180  181  182  183  184  185  186

   <STMT LIST>.START                SYNTHESIZED     138  178  200  213  213  245
   <STMT LIST>.FINISH               SYNTHESIZED     139  179  201  214  215  246
   <STMT LIST>.LABELREF             INHERITED       140  175  199  211  211  212  244
   <STMT LIST>.LABELDEF             SYNTHESIZED     140  175  198  209  209  243

   <STATEMENT>.START                SYNTHESIZED     143  200  215  228  230  230  235  245  260  2
                                                    263  264  264  268  277  278  279  292  294  2
                                                    300  309  310  311  324  325  326  330
   <STATEMENT>.FINISH               SYNTHESIZED     144  201  214  231  231  246  261  262  278  2
                                                    310  325
   <STATEMENT>.LABELREF             INHERITED       145  199  212  229  229  244  259  259  296
   <STATEMENT>.LABELDEF             SYNTHESIZED     145  198  210  227  243  258  258  276  291  3
                                                    323

   <IDENTIFIER>.VALUE               SYNTHESIZED     154  223  227  235  287  296  300  350  358
   <IDENTIFIER>.TOKEN               SYNTHESIZED     155  287

   <STRING>.VALUE                   SYNTHESIZED     158  254  268  319  330
   <STRING>.TOKEN                   SYNTHESIZED     159  254  319


 RESERVED TOKENS

   ;            .            :            [            ]            THEN
   GO           TO           MOVE         ONE          SQUARE       PRINT
   LEFT         RIGHT        IF           THE          TAPE         SYMBOL
   IS           ALPHABET     ,            NULL
```

```
SALTRAN  (VERSION: 02/17/81)   DATE: 81/03/05.   TIME: 11.07.37.                     PAGE 13
        ************************     PROGRAM STATISTICS     ************************


        SYMBOLS                                         109 (TOTAL SYMBOLS)
             SPECIAL SALTRAN SYMBOLS                     63
             GRAMMAR/ATTRIBUTE SYMBOLS                   24
             OTHER SYMBOLS                               22

        HASHING
             NUMBER OF CALLS                            603
             NUMBER OF PROBES                           736
             MAXIMUM PROBE                                4
             AVERAGE PROBE                             1.22

        PRODUCTION-TABLE / PRODUCTION-LIST               50 (TOTAL ENTRIES)
             PRODUCTION-TABLE                            16
             PRODUCTION-LIST                             34

        SYNTAX RULES                                     16 (TOTAL)

        SEMANTIC RULES                                   67 (TOTAL)
             OBJECT-CLASS RULES                           3
             ATTRIBUTE RULES                              3
             FLOWGRAPH RULES                             56
             ACTION RULES                                 5
             OTHER RULES                                  0

        TABLES (PERCENT FULL)
             SYMBOL TABLE                              13.6
             CROSS-REFERENCE TABLE                      3.3

        TOTAL PRODUCTION SYMBOLS    =                     9
        TOTAL GRAMMAR ATTRIBUTES    =                    15
        TOTAL RESERVED TOKENS       =                    22
        TOTAL PROGRAM LINES         =                   374

        MAXIMUM RIGHT-HAND-SIDE HAS 5 TERMINALS AND NONTERMINALS


TRANSLATION TIME =   4.06 SECONDS  =>  92.07 LINES/SECOND.
```

D.2 Sample TURINGOL Program

```
TREE BUILDING ANALYZER  VERSION=05/13/80
TIME= 11.28.04. DATE= 81/03/05.
      1
      1    TAPE ALPHABET IS BLANK, EIN, ZERO, POINT;
     12    PRINT "POINT";
     15    GO TO CARRY;
     19    TEST: IF THE TAPE SYMBOL IS "EIN" THEN
     28              [PRINT "ZERO"; CARRY: MOVE LEFT ONE SQUARE; GO TO TEST];
     44    PRINT "EIN";
     47    REALIGN: MOVE RIGHT ONE SQUARE;
     54       IF THE TAPE SYMBOL IS "ZERO" THEN GO TO REALIGN.
END OF ANALYSIS   COMPILE TIME=    .7 SECONDS
```

D.3 Output Report for Sample Program

```
------------------------------   STATISTICS   ------------------------------

ALLOCATED MEMORY:
                             BASIC UNIT   NO. UNITS   WORDS/UNIT   TOTAL WORDS
                             ----------------------------------------------

    SYMBOL TABLE               SYMBOL          32         2 (1)          64

    ATTRIBUTE TABLE             ENTRY           3         1 (2)           3

    PARSE TREE                   NODE          47         2              94

    DEPENDENCY GRAPH             NODE         155         2             310

    DEPENDENCY GRAPH             EDGE          80         1              80

    FLOW GRAPH                   NODE          12         4 (3)          48

    EXPRESSION TREE              NODE           0         4 (3)           0

    CALL GRAPH                   NODE           1         2                2

    PRODUCTION TABLE           NUMBER          20         1              20

    SET POOL                      SET          47        10             470

                                                     TOTAL WORDS =  1091

     (1) INCLUDES 1 WORD(S)/STRING
     (2) INCLUDES 1 ATTRIBUTE(S)/ENTRY
     (3) INCLUDES 4 ACTION(S)/NODE


PROGRAM SIZE:

     NUMBER OF PARSE TREE NODES      47
     NUMBER OF PROGRAM LINES          9   =>    5.22 NODES/LINE
     NUMBER OF PROGRAM TOKENS        65   =>    0.72 NODES/TOKEN


TIMING (SECONDS):
     PARSING PHASE                 0.64   =>   13.95 LINES/SEC
     ATTRIBUTE ANALYSIS PHASE      1.12   =>    8.04 LINES/SEC
               (    0.18 FOR READING TABLES AND INITIALIZING MODULES)
               (    0.09 FOR DEP. GRAPH BUILDING                    )
               (    0.31 FOR DEP. GRAPH EVALUATION                  )
               (    0.54 FOR DUMPING TABLES AND STATS               )

     TOTAL SAM ANALYSIS TIME       1.76   =>    5.10 LINES/SEC
                                          =>   36.85 TOKENS/SEC
```

D.4 Tables File for Sample Program

```
   4   WRITE OUT ACTION NAMES
DECLARE
REF
USE
DEF
  10  WRITE OUT FLOWGRAPH NODE-TYPES
BASE
CONCAT
STRUCT
ENTRYSTMT
EXITSTMT
IFSTMT
EMPTYSTMT
GOTOSTMT
MOVESTMT
PRINTSTMT
  32  BEGINNING OF SYMBOL TABLE
   4     0 .EOF
   1     0 ;
   1     0 .
   1     0 :
   1     0 [
   1     0 ]
   4     0 THEN
   2     0 GO
   2     0 TO
   4     0 MOVE
   3     0 ONE
   6     0 SQUARE
   5     0 PRINT
   4     0 LEFT
   5     0 RIGHT
   2     0 IF
   3     0 THE
   4     0 TAPE
   6     0 SYMBOL
   2     0 IS
   8     0 ALPHABET
   1     0 ,
   4     0 NULL
   5     0 BLANK
   3     0 EIN
   4     0 ZERO
   5     0 POINT
   5     3 CARRY
   4     2 TEST
   7     1 REALIGN
   0     0
   8     0 TURINGOL
   1     1
  32     0     2     1          CALLGRAPH OVERHEAD FOR CALL-NODE 1
   0
   0                            END OF USE TABLE FOR CALL-NODE 1
   2     4     0
   1    12
   0
   4    24    25    26    27
   0
   0
   0
  12    10     0
   1    11
```

```
 1    2
 0
 1   27
 0
 0
11    8    0
 1    9
 1   12
 0
 0
 1   28
 0
 9    9    0
 1    8
 2   10   11
 0
 0
 0
 1   28
 8    8    0
 1    7
 1    9
 0
 0
 1   29
 0
 7    6    0
 2    6   10
 1    8
 0
 1   25
 0
 1   29
10   10    0
 1    9
 1    7
 0
 1   26
 0
 0
 6   10    0
 1    5
 1    7
 0
 1   25
 0
 0
 5    9    0
 1    3
 2    4    6
 0
 0
 0
 1   30
 3    6    0
 2    1    4
 1    5
 0
 1   26
 0
 0
 4    8    0
```

```
1     5
1     3
0
0
1    30
0
1     5     0
0
1     3
0
0
0
0
0                              END OF FLOWGRAPH FOR CALL-NODE 1
0                              END OF EXPRESSION-TREE FOR CALL-NODE 1
```

D.5 User-Readable Report of Tables File

```
LISTING OF CALLGRAPH INFORMATION:  MAINCALL= TURINGOL

    NODE                      EDGES

    TURINGOL                :

    NODE                      NUM PARAM   PARAM MODES

    TURINGOL                :       0
```

```
 DUMP OF PARTIAL FLOWGRAPH FOR SUBPROGRAM TURINGOL :

   ENTRY NODE = 2, EXIT NODE = 1

-------------------- USE-TABLE  --------------------

-------------------- FLOW-GRAPH --------------------

   2  DESCRPT=ENTRYSTMT   EXP-TREE= 0
      SONS    =    12
      PARENTS=
         DECLARE    =               BLANK                 EIN
                                     ZERO               POINT
         REF        = <EMPTY>
         USE        = <EMPTY>
         DEF        = <EMPTY>
  12  DESCRPT=PRINTSTMT   EXP-TREE= 0
      SONS    =    11
      PARENTS=     2
         DECLARE    = <EMPTY>
         REF        =               POINT
         USE        = <EMPTY>
         DEF        = <EMPTY>
  11  DESCRPT=GOTOSTMT    EXP-TREE= 0
      SONS    =     9
      PARENTS=    12
         DECLARE    = <EMPTY>
         REF        = <EMPTY>
         USE        =               CARRY
         DEF        = <EMPTY>
   9  DESCRPT=MOVESTMT    EXP-TREE= 0
      SONS    =     8
      PARENTS=    10    11
         DECLARE    = <EMPTY>
         REF        = <EMPTY>
         USE        = <EMPTY>
         DEF        =               CARRY
   8  DESCRPT=GOTOSTMT    EXP-TREE= 0
      SONS    =     7
      PARENTS=     9
         DECLARE    = <EMPTY>
         REF        = <EMPTY>
         USE        =                TEST
         DEF        = <EMPTY>
   7  DESCRPT=IFSTMT      EXP-TREE= 0
      SONS    =     6    10
      PARENTS=     8
         DECLARE    = <EMPTY>
         REF        =                 EIN
         USE        = <EMPTY>
         DEF        =                TEST
  10  DESCRPT=PRINTSTMT   EXP-TREE= 0
      SONS    =     9
      PARENTS=     7
         DECLARE    = <EMPTY>
         REF        =                ZERO
         USE        = <EMPTY>
         DEF        = <EMPTY>
   6  DESCRPT=PRINTSTMT   EXP-TREE= 0
      SONS    =     5
      PARENTS=     7
```

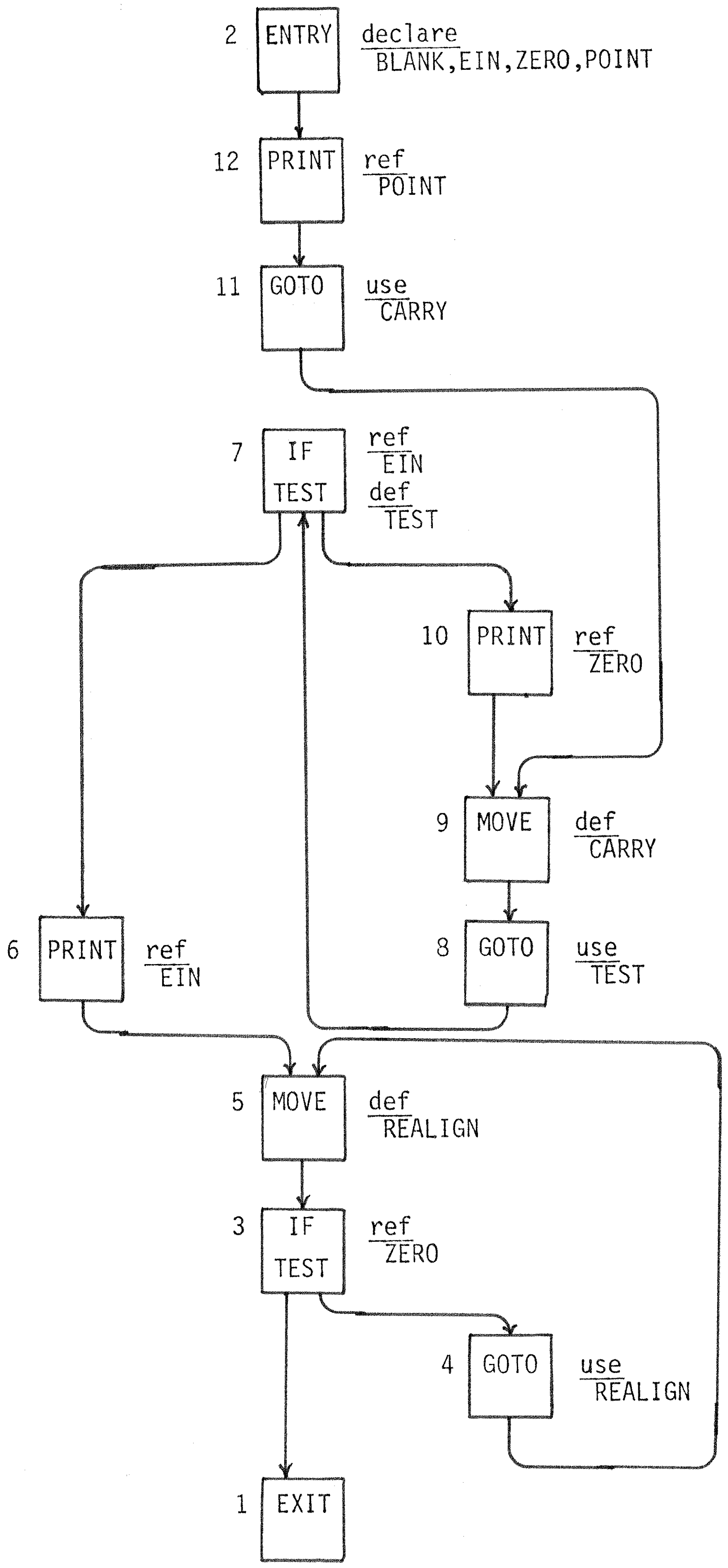
```
            DECLARE    = <EMPTY>
            REF        =                    EIN
            USE        = <EMPTY>
            DEF        = <EMPTY>
     5  DESCRPT=MOVESTMT     EXP-TREE= 0
        SONS    =     3
        PARENTS=     4     6
            DECLARE    = <EMPTY>
            REF        = <EMPTY>
            USE        = <EMPTY>
            DEF        =                REALIGN
     3  DESCRPT=IFSTMT       EXP-TREE= 0
        SONS    =     1     4
        PARENTS=     5
            DECLARE    = <EMPTY>
            REF        =                   ZERO
            USE        = <EMPTY>
            DEF        = <EMPTY>
     4  DESCRPT=GOTOSTMT     EXP-TREE= 0
        SONS    =     5
        PARENTS=     3
            DECLARE    = <EMPTY>
            REF        = <EMPTY>
            USE        =                REALIGN
            DEF        = <EMPTY>
     1  DESCRPT=EXITSTMT     EXP-TREE= 0
        SONS    =
        PARENTS=     3
            DECLARE    = <EMPTY>
            REF        = <EMPTY>
            USE        = <EMPTY>
            DEF        = <EMPTY>

-------------------- EXPRESSION-TREE INFORMATION --------------------



                        SET-POOL IS 2 PERCENT FULL
                           0.28 SECONDS
```

D.6 Graphic Display of Tables File


2
ENTRY
declare
BLANK,EIN,ZERO,POINT
12
PRINT
ref
POINT
11
GOTO
use
CARRY
7
IF
TEST
ref
EIN
def
TEST
10
PRINT
ref
ZERO
9
MOVE
def
CARRY
6
PRINT
ref
EIN
8
GOTO
use
TEST
5
MOVE
def
REALIGN
3
IF
TEST
ref
ZERO
4
GOTO
use
REALIGN
1
EXIT