Report on the Programming Language PLZ/SYS

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PREFACE

This report describes a programming language called PLZ/SYS, which is intended to aid the implementation of system programs for microcomputers. PLZ/SYS is a synthesis of concepts from contemporary programming languages and compilers--the language Pascal has had the most notable influence on the overall design and implementation of PLZ/SYS. In order to reflect this relationship as clearly as possible, this report has been written as a heavily edited version of the revised Pascal Report. In addition to Pascal, several other languages including Euclid, Mesa, C and SIMPL, have features which have contributed to the inclusion of similar constructs in PLZ/SYS.

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1. INTRODUCTION

The PLZ family of languages is designed to satisfy the requirements of a wide range of microcomputer software development areas. This family of syntactically similar and object code compatible language translators serves to separate the machine-dependent aspects of a program from the portions which are machine-independent. Thus, selective portions of a program which are time-critical or need explicit access to low-level machine processes may be written conveniently without reducing the entire programming task to this level. Furthermore, each member of the family shares a kernel grammar defining the data declarations and control structures for the entire PLZ family. These common features facilitate the programmer's transition from one language to another within the PLZ framework. The syntactic and semantic structure of the kernel grammar has been carefully designed to enable efficient code generation and a simple translation process for all the members of the PLZ family of languages.

A PLZ program is a set of modules; a module is the basic unit of translation. A module consists of data declarations and units of execution called procedures. It is intended that modules be used to implement the various data or control abstractions that comprise a program, in the sense that modularization enables the programmer to partition a software system into various tasks and to collect into a single module both the data and the procedures to manipulate that task's data. This serves to localize the scope of attention of the programmer and reinforces "information hiding". Inter-module communication is allowed; each module must explicitly declare which of its procedures and/or data are to be available for use in other modules, as well as which procedures and/or data that are defined in other modules are to be used in this module. Furthermore, a module (procedures and/or data) can serve as a unit of overlay for programs that need not be wholly present in main memory during execution. Isolating high-frequency references within a module reduces the potential for transfers between secondary and primary memory.

PLZ/ASM and PLZ/SYS are examples of a low-level and a high-level system language, respectively, from the PLZ family. A task can be partitioned into PLZ/ASM and PLZ/SYS modules depending on its low-level versus high-level requirements. Once individual modules (written in different languages within the PLZ family) have been translated into relocatable machine code, they can be linked together into a single program. The static and dynamic linkage conventions between modules are facilitated by the syntactic similarity of data declarations throughout the family.

1.1 PLZ/SYS OBJECTIVES

The programming language PLZ/SYS has been designed to facilitate the construction of microcomputer system programs. A system program is one that is part of the basic software of the machine on which it runs; such a program might be an operating system kernel, the core of a data base management system, or a compiler.

An important consequence of this goal is that PLZ/SYS is not intended to be a general-purpose programming language. Furthermore, its design does not specifically address the problems of constructing very large programs; we believe most of the programs written in PLZ/SYS will be modest in size. However, the language has been designed to allow the advantages of separate compilation, including modularization and reduced recompilation of programs.

A system programming language designed especially for microcomputers should have the following characteristics:

1) REINFORCE GOOD PROGRAMMING PRACTICES. Both in form (syntax) and in meaning (semantics), a high-level language can facilitate the programming process by being readable and clearly defined and by providing a natural representation of algorithms. A language whose syntax is complicated by excessive, illogical, or irregular notation is difficult to learn and leads to repeated compilation errors. A language whose semantics are unclear can lead to obscure logical errors. A language whose primitive operations are not suitable for representing the solution to a problem can introduce errors in mapping from the known solution to a computer program.

2) MANAGE COMPUTING RESOURCES. The details of resource management (register and memory allocation in particular), both during the creation and the execution of a program are a critical aspect of the programming process. By managing these details, a programming language can free the programmer to think more about the problem to be solved and less about the state of the machine. On the other hand, if the management of resources is either inappropriate or inefficient for data structures, the language can interfere with the programming process. Ideally, the programmer should be able to control resource management to the degree justified by the circumstances.

3) ALLOW ACCESS TO THE ARCHITECTURE OF THE MACHINE. Most microprocessor applications require precise control of the machine and sometimes require its full operational capability. Forcing these precision requirements through the filter imposed by high-level language constructs can be awkward and prohibitive. All of the primitive elements and operations of the machine which are available through assembly language must be accessible. Otherwise, the barrier created by the language can prevent a viable solution from being achieved.

4) PRODUCE EFFICIENT CODE. Even though the costs associated with computer memory continue to drop dramatically, memory costs remain one of the critical items in determining the economic feasibility of a microprocessor application due to the multiplier effect applied to these costs when the system is replicated. By knowing the efficiency of a particular language translator, and by quantifying the expense of the required memory versus the overall program development costs, it is possible to determine the cross-over point at which it is advantageous to use a high-level language instead of an assembly language. In general, the fewer times a system is to be replicated, the more likely that a high-level language is appropriate. By improving translation efficiency, this cross-over point occurs at a higher replication factor, thus extending the viability of high-level language programming to more and more applications. In addition to satisfying space efficiency requirements, many microprocessor programs must perform their tasks under severe time constraints. The language should enable the generation of execution-time efficient code without employing extensive optimization algorithms. Constructs in the language should reflect the relative efficiency in order to provide the programmer with some estimate of the cost of a particular construct or algorithm.

5) BE RELATIVELY EASY TO COMPILE. Certain characteristics of the translation process are critically important in the microprocessor environment. First of all, the compiler should run on the target microprocessor. Otherwise, the user is confronted by the expense and complexity of first running the compiler on a host computer and then transferring the results to the target machine. Second, the speed of the translation process directly and indirectly affects program development. Directly, the time it takes to correct problems in a program is influenced by compilation time. Indirectly, if the translation time is excessive, the programmer is inhibited from using the compiler to its maximum benefit and may resort to debugging strategies which offset the advantages of using a high-level language.

There are a number of other considerations which influenced the design of PLZ/SYS:

It is based on current knowledge of programming languages and compilers; concepts which are not fairly well understood, and features whose implementation is unclear, have been omitted.

Although program portability is not a major goal of the language design, it is necessary to have compilers which generate code for a number of different machines, including hypothetical (interpreter-based) computers.

The ability to enforce strict compile-time type checking must be supported by the data declaration and type definition constructs.

The required run time support must be minimal.

The remainder of this report contains a description of PLZ/SYS, which, for the sake of brevity, is often referred to throughout the report as simply PLZ.

2. SUMMARY OF THE LANGUAGE

This section contains a summary of PLZ. The information here is intended to be consistent with the remainder of the report, but in case of conflict the body of the report (sections 3-12) governs. Because it is a summary, many details are omitted, and some general statements are made without the qualifications which may be found in the body of the report.

2.1 DATA AND STATEMENTS

An algorithm or computer program consists of two essential parts: a description of actions which are to be performed, and a description of the data which are manipulated by these actions. Actions are described by statements, and data are described by declarations and definitions. In general, a definition specifies an identifier as a synonym for a fixed value or type, and a declaration introduces an identifier to denote a variable and associates a type with it. A data type implicitly defines a set of values and the actions which may be performed on elements of that set. The data type may either be directly described in the variable declaration, or it may be referenced by a type identifier, in which case this identifier must have been previously introduced by an explicit type definition.

All data items may take on values. A value occurring in a statement may be represented by a literal constant, an identifier which has been defined to be the same as a literal constant, an identifier which has been declared as a variable, or an expression containing values. Every variable identifier occurring in the program must be introduced by a declaration which associates a data type and, optionally, an initial value with the identifier. Every constant identifier occurring in the program must be introduced by a constant definition, which simply associates a value with the identifier. The value must be determinable at compile-time; thus the expression defining a constant must contain only literal constants, constant identifiers, and built-in operations. The association is valid only within the scope of the definition and cannot be changed therein.

Throughout this report, the word "variable" means a container which can hold different values of a specific type. A "constant" is simply a fixed value, such as the number 123. The fundamental difference is that assignment to a variable is possible.

The basic data types in PLZ are the simple types. A simple type is either a standard simple type, or a user-defined simple type. The standard simple data types are BYTE, WORD, SHORT_INTEGER, INTEGER, and pointer (declared using the symbol '↑'). Types WORD and BYTE correspond to unsigned data values of 16 bits and 8 bits, respectively. Types INTEGER and SHORT_INTEGER correspond to signed values of 16 and 8 bits (two's complement representation), respectively. Type "pointer" is for address values which are machine-dependent quantities. There is a way of writing literal constants for all five types: numbers such as 100 or character constants such as 'A' for INTEGER, SHORT_INTEGER, WORD, or BYTE, and NIL for pointer.

Structured types are defined by describing the types of their components and indicating a structuring method. The various structuring methods differ in the mechanism used to select the components of a variable of the structured type. In PLZ, there are two basic structuring methods available: array and record.

In an array structure, all components are of the same type. A component is selected by one or more array selectors (called array indices). The index is computed as the value of an expression, which may be of base type WORD, INTEGER, BYTE or SHORT_INTEGER. Given a value of the index type, an array yields a variable of the component type.

In a record structure, the components (called fields) are not necessarily of the same type. In order for the type of a selected component to be evident from the program text (without executing the program), a record selector is not a computable value, but instead is an identifier uniquely denoting the component to be selected. These field identifiers are declared in the record type definition.

Variables declared in explicit declarations are called direct, since the declaration associates an identifier with the variable, and the identifier is used to refer to the variable. In contrast, variables may be accessed indirectly through a pointer variable. An explicit declaration of a pointer variable indicates the type of variable to which it can point. The pointer's value may be assigned only to other pointer variables declared to point to the same type. It may also assume the value NIL, which points to no variable. Because pointer variables may also occur as components of structured variables, the use of pointers permits the representation of complex interconnected data structures.

The most fundamental statement in PLZ is the assignment statement. It specifies that a newly computed value be assigned to a variable (or a component of a variable). The value is obtained by evaluating an expression. Expressions consist of variables, constants, operators, and procedures which return exactly one value. PLZ defines a fixed set of operators, each of which can be regarded as describing a mapping from the operand types into the result type. The set of operators is subdivided into groups of:

1. arithmetic operators--addition, subtraction, sign inversion, multiplication, integer division, computing the remainder (MOD), absolute value (ABS), increment (INC), and decrement (DEC).

2. logical operators--negation (NOT), conjunction (AND), disjunction (OR), and exclusive or (XOR).

3. relational operators--equality, inequality, and ordering, which may appear only in if statements.

4. conditional operators--ANDIF and ORIF, which can be used where partial evaluation of conditional expressions is desired, and may appear only in if statements.

In order to allow a controlled breach of the type compatibility checking system, explicit type converters may be used as unary operators causing the value of the associated operand type to be converted to a value of the converter type. Type converters may be either standard or user-defined type identifiers.

The procedure statement causes the execution of the designated procedure and the assignment of any returned values (see below).

The return statement is used to terminate execution of the procedure in which it appears, and to continue execution following the procedure invocation in the calling procedure.

There are two kinds of loop control statements: the exit statement is used to terminate a loop, and the repeat statement is used to continue execution at the top of the loop. Both of these statements may be qualified by a loop identifier which allows multiple-level control of execution with respect to nested loop statements.

Assignment, procedure, return and loop control statements are referred to as simple statements. Structured statements specify conditional, selective, or repeated execution of their components; a component of a structured statement is a sequence of simple and/or structured statements. Sequential execution of simple or structured statements is implied by their sequence in the program text.

Conditional or selective execution is controlled by the if statement and the select statement. The if statement serves to make the execution of a component dependent on the value of an expression; the select statement allows for the selection among many components according to the value of a selector. Thus, the select statement is a natural extension of the if statement. Repeated execution is controlled by the loop statement.

2.2 THE CONSTRUCTION OF A PROGRAM

A program consists of one or more separately compiled modules which serve to define the scope of data and action statements and permit the combination of portions of a program written in different members of the PLZ family of languages.

A group of statements (including both action and data statements) defining an executable portion of a module may be named by an identifier and is then called a procedure, and its declaration is called a procedure declaration. A variable which is not declared LOCAL in a given procedure body and is not a parameter to that procedure is accessible in that body only if it is accessible in the scope of the module containing the procedure body. A variable is accessible throughout a module only if:

1) it is explicitly declared in a GLOBAL or INTERNAL declaration, or

2) it is explicitly imported into the given module by an EXTERNAL declaration.

A procedure has a fixed number of parameters, each of which is denoted within the procedure heading by an identifier called the formal parameter, which is considered local to the procedure body. Upon an invocation of the procedure statement, an actual quantity must be indicated for each parameter which can be referenced from within the procedure through the formal parameter. This quantity is called the actual parameter. Parameters are passed to procedures by value only. An actual parameter is an expression which is evaluated once. The formal parameter represents a local variable whose value is the result of this evaluation. Thus, a call by reference can be achieved only by passing a pointer to a variable.

A procedure may return one or more values; the values to be returned are the values (at the time of return from the procedure) of the variables declared in the RETURNS portion of the procedure heading. These variables are also considered local to the procedure body, but unlike the formal parameters, their values are undefined upon procedure entry. Thus, some explicit assignment of values to these variables must appear within the procedure body for the returned values to be meaningful.

Variables and procedures must be associated with exactly one of the following declaration classes: GLOBAL, EXTERNAL, INTERNAL, or LOCAL. GLOBAL specifies that the variable is defined in the current module, and may be used in other modules as well. EXTERNAL specifies that the variable is used in the current module, but defined in another module. INTERNAL specifies that the variable is defined in the current module and cannot be used in other modules. LOCAL specifies that the variable can be accessed only inside the procedure in which it is declared. Of these four classes, EXTERNAL, GLOBAL and INTERNAL can be used only to declare variables at the module level; LOCAL can be used only to declare variables at the procedure level. Procedure declarations must be either GLOBAL, INTERNAL or EXTERNAL, with access by other modules in a manner analogous to variables.

Constant identifiers are defined using the CONSTANT class, and can be defined only at the module level. Thus, the scope of a constant identifier is the module scope, and it cannot be used outside the module unless it is redefined.

Type identifiers are defined using the TYPE class; they can be defined only at the module level and are valid type definitions only within the scope of the module.

PLZ has been designed to permit one-pass translation. To this end, identifiers must be declared before they are used.

The PLZ/SYS language has intentionally been designed to not include any specific Input/Output statements; instead, a program may invoke other PLZ procedures which actually perform the desired I/O. These procedures might be provided by the system in which the PLZ program is executed, or they might be provided by the user.

Example:

```
bubble_sort MODULE

CONSTANT
   false := 0
   true := 1

EXTERNAL
   printarray PROCEDURE (first ↑WORD count BYTE)

INTERNAL
   a ARRAY [10 WORD]
     := [33  10  2000  400   410
          3   3    33  500  1999]

   sort PROCEDURE (n BYTE)
      LOCAL
         i  j  limit BYTE
         temp WORD
         switched BYTE

      ENTRY
      DO
         switched := false
         i := 0
         limit := n-2
         DO
            IF i > limit THEN EXIT FI
            j := i + 1
            IF a[i] > a[j] THEN
                  switched := true
                  temp := a[i]
                  a[i] := a[j]
                  a[j] := temp
            FI
            i += 1
         OD
         IF switched = false THEN RETURN FI
      OD
      END sort

GLOBAL
   main PROCEDURE
      ENTRY
         sort (10)
         printarray(#a[0] 10)
      END main

END bubble_sort
```

3. NOTATION, TERMINOLOGY, AND VOCABULARY

The syntax is described in a modification of Backus-Naur form, in which syntactic constructs are denoted by lower-case English words or phrases not enclosed in any special marks. These words also suggest the nature or meaning of the construct, and are used in the accompanying description of semantics. Basic symbols of the language are either written in upper case (for keywords) or enclosed in quote marks (for symbols); e.g., PROCEDURE and '+'. Possible repetition of a construct is indicated by appending the construct with either a + to signify 1 or more repetitions or a * to signify 0 or more repetitions. Parentheses are metasymbols used to enclose a group of constructs to be followed by a repetition symbol. Possible omission of a construct is indicated by enclosing the construct within metasymbols [and]. The metasymbol | is used to signify that one of several constructs may be selected, e.g., A|B means that either A or B may be specified.

A descriptive grammar defining the syntax of PLZ is distributed throughout this report; occasionally, simplifications are made in the interests of clarity of presentation. For convenient reference, the complete grammar has been collected in the Appendix.

3.1 VOCABULARY

The primitive vocabulary of PLZ consists of basic symbols classified into letters, digits, and special symbols. This vocabulary is not the character set; the character set is implementation dependent, and each implementation must define, in its character set, distinct representations for all the basic symbols. Notice that a particular implementation need define only one character set (in general, at least 64-character ASCII).

The basic symbols are:

```
letter          => 'A' | 'B' | ... | 'Z'
                => 'a' | 'b' | ... | 'z'

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

hex_digit       => digit
                => 'A' | 'B' | 'C' | 'D' | 'E' | 'F'
                => 'a' | 'b' | 'c' | 'd' | 'e' | 'f'

special_symbol  => '+' | '-' | '*' | '/' | '='
                => '<' | '>' | '<=' | '>=' | '<>'
                => '.' | '%' | '↑' | ':=' | '#'
                => '[' | ']' | '(' | ')' | '+='
                => '-=' | '?' | '...'
```

```
word_symbol      => ABS | AND | ANDIF | ARRAY
                 => BYTE | CASE | CONSTANT | DEC
                 => DO | ELSE | END | ENTRY | EXIT
                 => EXTERNAL | FI | FROM | GLOBAL
                 => IF | INC | INTEGER | INTERNAL
                 => LOCAL | MOD | MODULE | NIL
                 => NOT | OD | OR | ORIF | PROCEDURE
                 => RECORD | REPEAT | RETURN | RETURNS
                 => SHORT_INTEGER | SIZEOF | THEN
                 => TYPE | WORD | XOR

delimiter        => ',' | ';' | ':' |  space
                 => tab  |  formfeed  |  linefeed
                 => carriage_return
```

The construct

```
'!' any_sequence_of_symbols_not_containing_! '!'
```

may be inserted anywhere that a delimiter may appear (see 3.2). It is called a comment and is treated as a single delimiter.

3.2 LEXICAL STRUCTURE

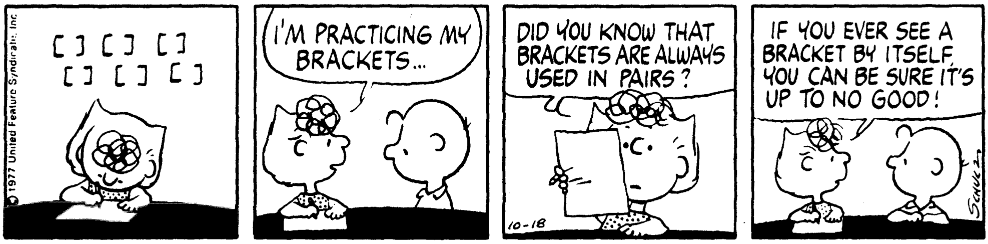
The primitive lexical unit of PLZ is called a token. A token is either a special_symbol or word_symbol of the vocabulary, an identifier, or a literal constant (see section 4). The text of a program is built up out of declarations and statements, which are in turn built up of tokens according to the syntax specified below. In general, tokens are delimited by separators. The syntax is constructed in such a way that a token may always be legally followed by one or more separators.

Delimiters and special_symbols are collectively referred to as separators. The distinction between delimiters and special_symbols is that the special_symbols have semantic significance (for example, the symbols '(', ')' and '[', ']' serve to enclose parameter lists and array indices, respectively), whereas delimiters have no meaning other than as separators of tokens. The class of delimiters includes spaces, tabs, carriage returns, commas, colons, semicolons, and comments. Aside from the requirement that at least one separator must appear between two word_symbols or identifiers, PLZ requires no punctuation between declarations and/or statements. This may be interpreted to mean that the user may utilize punctuation such as semicolons, colons or commas however he wishes to improve readability.

```
PLZ_text              => separator* [id_constant_text]
                            (separator+ id_constant_text)*

id_constant_text      => identifier
                      => word_symbol
                      => literal_constant

separator             => delimiter_text
                      => special_symbol
```

There are several kinds of brackets which are used to group statements for various purposes. The following list gives the unique closing bracket for each opening bracket.

IF	FI
DO	OD
PROCEDURE	END
MODULE	END



4. IDENTIFIERS AND LITERAL CONSTANTS

Identifiers serve to denote constants, variables, loop names, and procedures. Their association must be unique within their scope of validity; i.e., within the scope in which they are declared (see 6, 7.4).

Each time an identifier is used, it must be written in exactly the same way (i.e., with the same capitalization) as it was written when it was declared.

```
      identifier      => letter (letter | digit | '_')*
```

The usual decimal notation is used for numbers, which are the literal constants of the data types BYTE, WORD, SHORT_INTEGER and INTEGER. Numbers may also be written in hexadecimal notation. Note that numbers are always written without a sign; a negative constant can be written as an expression, e.g., -14.

```
      number          => integer
                      => hex_number

      integer         => digit+

      hex_number      => '%' hex_digit+
```

A sequence of one or more characters enclosed by single quote marks is called a character_sequence. Each character represents an 8-bit quantity that may be manipulated as a BYTE or SHORT_INTEGER data type whose value is dependent on the underlying character set. A character, whether or not it is in the printing character set, can also be represented in a character_sequence as follows:

```
      %hh
```

where each h stands for a hexadecimal digit and represents the character code with the hexadecimal representation hh.

For convenience, %L, %T, %R, %P, %%, and %Q represent linefeed, tab, carriage return, page (formfeed), %, and single quote, respectively, within a character_sequence.

```
      character_sequence
                      => ''' character_text+ '''

      character_text  => character
                      => special_character_text
```

```
character          => any_character_except_%_or_'

special_character_text
                   => '%' special_character
                   => '%' hex_digit hex_digit

special_character
                   => 'L' | 'T' | 'R' | 'P' | 'Q' | '%'
                   => 'l' | 't' | 'r' | 'p' | 'q'
```

Examples:

```
'A'
'Here is an ESC character:  %1B'
'First line%RSecond line%R'
'Quote%Qinside a quote%Q'
```

5. CONSTANTS

A constant is either a literal constant (such as a number or a character_sequence), an identifier declared as a constant, or an expression involving only constants. The value of a constant expression must be computable at compile time.

A constant represents a fixed value whose type is compatible with one of the two disjoint classes of simple types: arithmetic or pointer types. Numbers and character constants (see 5.2) are only compatible with arithmetic types, which include any type whose base type is INTEGER, WORD, SHORT_INTEGER, or BYTE. The literal NIL is a value which is only compatible with pointer types (see 6.3).

The rules for constructing constant expressions are similar to those for general arithmetic expressions (see section 8 for a description of the various operators).

```
constant_expression  => constant_term
                           (add_op constant_term)*

constant_term        => constant_factor
                           (mult_op constant_factor)*

constant_factor      => unary_op constant_factor
                     => constant
                     => '(' constant_expression ')'

constant             => number
                     => character_constant
                     => constant_identifier
                     => SIZEOF static_variable
                     => SIZEOF type_identifier
                     => SIZEOF constant_identifier
```

Examples:

```
16
'A' OR %80
'This is a character_sequence'
(BUF_LENGTH+1)/2
```

5.1 CONSTANT DEFINITIONS

A constant definition introduces an identifier as a synonym to a constant value. The value to be assigned to the constant identifier is the value of a constant expression; all constant identifiers appearing in the expression must have been previously defined.

Constants are defined at the module level and thus have the module as their scope. Constant definitions which are to be used within the scope of more than one module must have their complete definition in each module.

The general form of a constant definition is

```
identifier ':=' constant_expression
```

Examples:

```
CONSTANT

  REC_LENGTH          := 64
  BUF_LENGTH          := 4*REC_LENGTH
  SEMICOLON           := ';'
  BIGNUM              := 65000
  SMALLNUM            := -1
```

5.2 CHARACTER AND TEXT CONSTANTS

A character constant is a character_sequence of one or two characters whose value can be represented either by a constant identifier or by a variable of arithmetic type only. For example, 'A' can be assigned to either a BYTE or a WORD variable, while 'AB' can be assigned to a WORD. The order of bytes in character constants longer than 8 bits is implementation dependent, and thus the use of multiple-byte character constants should be avoided.

A text constant is a character_sequence of one or more characters that can be represented by a one-dimensional array of 8-bit values (see 5.3 and 7.2.1).

```
character_constant
                  => ''' character_text [character_text] '''

text_constant     => character_sequence
```

5.3 ADDRESS CONSTANTS

An address constant is a pointer value which the compiler can calculate based on its knowledge of the allocation of variables, and is either used either to initialize a pointer variable when it is declared, or can be assigned to an appropriate pointer variable during program execution. An address constant evaluates to the address of a variable of any type including structured types.

One form of an address constant is

```
'#' static_variable
```

where static_variable is either a variable of any simple type, an array or record identifier (in which case the first memory location of the structure is used), or a particular array element or record field. The only restriction is that the static_variable has an address which can be calculated at compile-time, thus prohibiting variable indices in an array, pointer operators, procedure invocations, etc.

The other form of an address constant is

```
'#' text_constant
```

where the value is a pointer to the first element of an unnamed, one-dimensional array of 8-bit values initialized to the character values in the text_constant. This is similar to the explicit declaration of an array of unspecified length (see 7.2.1) except the array has no associated identifier, and the type of the array element is compatible with any variable whose base type is BYTE or SHORT_INTEGER (see 8.1.2).

Examples:

```
#ROOT
#A[10]
#PATIENT.NAME
#'PROGRAM ABORT%R'
```

6. DATA TYPES

A data type determines the set of values which variables of that type may assume and the set of basic operations that may be performed on them.

A type definition associates an identifier with a type. A type must be either one of the five predefined simple types (BYTE, WORD, INTEGER, SHORT_INTEGER, and pointer), one of the two structured types (ARRAY and RECORD), or the name of a previously defined type. Thus, type identifiers must be declared before they are used; recursive or mutually recursive types (i.e., types which contain themselves as components, or types which reference each other) are not permitted. This restriction is relaxed in the case of pointers, so that the type to which a pointer is bound may remain undeclared until the pointer is used in some denotation (see 7.2.3). This allows, for instance, records which contain pointers to records of the same type.

Sometimes it is neither necessary nor desirable to associate an identifier with a type. For such cases, PLZ allows the user to define the type directly in the variable declaration (see section 7). Notice that structures declared in this way cannot contain pointers to structures of the same type, since there is no name for the type.

Internally, a base type is associated with every type. The base type is implicit in every type definition; it is the standard type which the defined type ultimately represents. For example, in the sequence of definitions:

```
      TYPE
              CHAR BYTE
              STR_CHAR CHAR
```

the base type of both CHAR and STR_CHAR is BYTE. Thus, the base type provides the information necessary to determine the set of basic operations that can be performed on a defined type. The fundamental difference between the defined type and the base type is that the defined type, not the base type, is used to determine type compatibility in expressions, assignments, and actual/formal parameter correspondence for procedures.

Types are defined at the module level and thus have the module as their scope. Type definitions that are to be used within the scope of more than one module must have their complete definition in each module.

The identifiers which appear as field names of a record type are considered local to that record type (and not to the scope in which the record type is defined), in the sense that the same identifier name may appear (possibly in different positions) in other record type definitions, and even in the enclosing scope of the record type definition.

6.1 SIMPLE TYPES

The following simple types are standard in PLZ and may be used in all programs.

WORD	a 16-bit quantity whose values are the non-negative integers in the range 0 to 65535.
BYTE	an 8-bit quantity whose values are the non-negative integers in the range 0 to 255. This value may also be the representation of a single character from the character set.
INTEGER	a 16-bit quantity whose values represent the positive and negative integers in the range -32768 to 32767.
SHORT_INTEGER	an 8-bit quantity whose values represent the positive and negative integers in the range -128 to 127. This value may also be the representation of a single character from the character set.
pointer (↑)	a machine-dependent quantity whose value represents a memory address (see 6.3).

6.2 STRUCTURED TYPES

A structured type is characterized by the type(s) of its components and by the structuring method.

6.2.1 ARRAY TYPES

An array type is a structure consisting of a fixed number of components which are all of the same type, called the component type. The elements of the array are designated by indices whose values belong to one of the simple base types WORD, INTEGER, BYTE or SHORT_INTEGER. The array type definition specifies the component type and the number and maximum value of each of the indices, and associates an identifier with the type. Each index ranges from the value 0 to one less than the maximum indicated in the declaration. For example, an array with 10 elements may be indexed from 0 to 9. Each index value in the definition must be specified as a constant expression; thus, variable upper bounds are not permitted. The array type definition does not specify (either implicitly or explicitly) the type of the index and thus the same array may be indexed by values of either WORD, INTEGER, BYTE, or SHORT_INTEGER base type.

```
   array_type_definition  => identifier array_type

   array_type  => ARRAY '[' constant_expression+ type ']'
               => array_type_identifier
```

Examples:

```
      TYPE
              BUFFER ARRAY [128 BYTE]
              TABLE ARRAY [256 WORD]
              MATRIX ARRAY [100 100 BYTE]
              TABLE_COPY TABLE
```

6.2.2 RECORD TYPES

A record type is a structure consisting of a fixed number of components called fields. Unlike the array, components are not constrained to be of identical type and are accessed, not by an index, but by a field identifier. The record type definition specifies a type and an identifier for each component, and associates an identifier with the record structure itself. The scope of these field identifiers is the record definition itself. As for all types, there are two ways to declare a record type: in a record type definition (in which an identifier is associated with the record structure), or in a record variable declaration (in which an identifier is associated with an instance or collection of instances; e.g., arrays of records) of the record structure. In the latter case, the declaration cannot include an identifier for the structure itself, so that records declared in this way cannot have fields which are pointers to themselves.

```
record_type_definition  => identifier record_type

record_type             => RECORD '[' field_declaration+ ']'
                        => record_type_identifier

field_declaration       => identifier+ type
```

Examples:

```
    TYPE
            PATIENT RECORD [AGE, HEIGHT, WEIGHT BYTE
                            BIRTH RECORD [DAY, MO, YR BYTE]
                            SEX BYTE
                            ROOM WORD
                           ]
            MSG RECORD [LENGTH BYTE
                        CHAR ARRAY [50 BYTE]
                       ]
            TITLE MSG
```

6.3 POINTER TYPES

Any variable may be referred to directly by its identifier; any use of the variable through its associated identifer is thus called a direct reference. In contrast, variables may also be accessed indirectly via a pointer value which is contained in a variable declared to be a pointer to a particular type. The values of a pointer variable can thus only be addresses of other variables of the type specified in the declaration. A pointer variable may be used to point to any type of variable, including all the simple types as well as arrays, records and other pointers.

The pointer value NIL belongs to every pointer type, and points to no variable at all.

```
      pointer_type_definition => identifier pointer_type

      pointer_type            => '↑' type
                              => pointer_type_identifier
```

A pointer to a BYTE, WORD, INTEGER, SHORT_INTEGER, or pointer (or to a user-defined type whose base type is one of these types) is used to refer to any variable of the declared type, including variables which are part of a structure. For example,

```
      TYPE
              PTRB ↑BYTE
              CHAR  BYTE
              PTRC ↑CHAR
              PTRB2 ↑↑BYTE
              A ARRAY [10 BYTE]
              B ARRAY [10 BYTE]
```

In this example, any variable of type PTRB can be used to point to a variable of type BYTE, for instance, an element of any array of type A or type B. Any variable of type PTRC can be used to point to a variable of type CHAR (the defined type), but it cannot be used to point to any variable of type BYTE (the base type). A variable of type PTRB2 can be used to point to any variable that has itself been declared as a pointer to type BYTE. For example, with the following variable declaration,

```
      INTERNAL
          BYTEPTR ↑BYTE
```

A variable of type PTRB2 can point to BYTEPTR, but not to a variable of type PTRB, which is a different type from '↑BYTE'.

A pointer to a structure is declared by using the type identifier of the structure. It is used as a pointer to the base address (first memory location) of an instance of that structure. It cannot be used to point to an element of the structure. Continuing the above example,

```
      TYPE
              PTRA ↑A
              R RECORD [F1, F2 BYTE
                        F3 WORD
                        F4 CHAR]
              S RECORD [F1, F2 BYTE
                        F3 WORD
                        F4 CHAR]
              PTRR ↑R
```

A variable of type PTRA can point only to arrays that are declared to be of type A, and thus cannot point to any other type of array, including arrays of type B whose declaration looks identical to A. Similarly, a variable of type PTRR can point only to records that are declared to be of type R, and thus cannot point to any other type of record, including records of type S whose declaration looks identical to R. (See section 7.3 for a discussion on how to use these pointers to access elements of the structure to which they point.)

6.4 TYPE COMPATIBILITY

The general rule throughout PLZ concerning data values is that only variables with compatible types may appear together in expressions, assignments, and actual/formal parameter bindings in procedure invocations. Mixing variables of different defined types causes an error. (See 8.1.3 for a mechanism to convert data types).

Two variables of simple types (not including pointers) are said to have compatible types only if their defined types are identical. That is, the types appearing in the declaration of each variable must be the same identifiers, regardless of whether the type is one of the standard types BYTE, SHORT_INTEGER, WORD, INTEGER, or a user-defined type whose base type is one of the standard simple types.

Example:

```
      TYPE
              CHAR    BYTE
      INTERNAL
              A,B     BYTE
              C       CHAR
              D       BYTE
              E       WORD
```

Here A, B and D are all compatible, while C and E are incompatible with any of the others.

Two variables of structured types (array or record) are said to have compatible types only if either they appear in the same declaration list, or their declarations use the same user-defined type identifier. That is, each time a structured type is explicitly described within a module, a unique type is defined.

Example:

```
      TYPE
              BUFFER ARRAY [128 BYTE]
              DATE RECORD [DAY MONTH YEAR BYTE]
      INTERNAL
              A,B     BUFFER
              C,D     ARRAY [128 BYTE]
              E       BUFFER
              F       ARRAY [128 BYTE]
              G       DATE
              H       DATE
              I,J     RECORD [DAY MONTH YEAR BYTE]
              K       RECORD [DAY MONTH YEAR BYTE]
```

Here A, B and E are compatible; C and D are compatible; G and H are compatible; I and J are compatible; F and K are incompatible with any of the others.

Two pointer variables are compatible only if the declaration of the objects pointed to are compatible, that is, after replacing each '↑' operator with the textual declaration for the objects pointed to, the resulting types are compatible. This allows pointers to be bound only to objects of a specific type, thus inhibiting modifications to data values at arbitrary memory addresses.

Example:

```
TYPE
    BUFFER ARRAY [128 BYTE]
    STRING ↑BYTE
INTERNAL
    BUF    BUFFER
    A,B    STRING
    C,D    ↑BYTE
    E      STRING
    F      ↑BYTE
    G      ↑BUFFER
    H      ↑BUFFER
    I      ↑ARRAY [128 BYTE]
    J      ↑ARRAY [128 BYTE]
    K      ↑STRING
```

Here A, B and E are compatible; C, D and F are compatible; G and H are compatible; I and J are not only incompatible, but because each occurrence of a structured type is considered a unique type, they are useless since there is no way to create a type-compatible structure to which they can point; K is incompatible with any of the others but is nonetheless useful as illustrated below. The following assignments are allowed (see 7.3, 8.1.2, and 9.1.1):

```
A     := #BUF[3]
C     := #BUF[3]
A↑    := C↑
G     := #BUF
A↑    := G↑[3]
K     := #A
E     := K↑
C↑    := K↑↑
```

7. DECLARATION AND DENOTATION OF VARIABLES

A variable declaration associates an identifier with a variable of that type. It consists of a list of identifiers denoting the variables, followed by their type and optional initialization. An initialization value must be type-compatible with the associated variable. The initialization is similar to an assignment statement executed immediately after the PLZ program is loaded into memory, except no program code is generated. This implies that, after execution, a program must either reinitialize its variables or be reloaded before being executed again. EXTERNAL and LOCAL variables cannot be initialized.

There are several rules and special symbols used for initializations in general. When a single declaration contains more than one variable identifier, the corresponding initialization values are listed within square brackets. A simple variable is initialized using a value which must be determinable at compile time. A structured variable is initialized using a "constructor", which is simply a list of values enclosed by square brackets, with each level of nesting within the structure denoted by a matching set of brackets. A special symbol, '...', indicates that the immediately preceding value or constructor is to be repeated for the rest of the variables at the current level of nesting. The special symbol '?' can be used as a placeholder in a list of initial values for simple variables or components of simple type within a structure, and indicates that the corresponding simple variable remains unassigned. An empty constructor, '[]', indicates that the corresponding structured variable remains unassigned.

Variable identifiers must be declared before they are used. Denotations of variables either designate a simple variable, a component of a structured variable, or a variable referenced by a pointer.

7.1 SIMPLE VARIABLES

Simple variables are variables whose base type is one of the simple types. The declaration of a GLOBAL or INTERNAL simple variable may optionally initialize the variable. There are two ways to initialize simple variables: with a single constant value if there is only one variable identifier, or with a list of constants enclosed in square brackets if there is more than one variable identifier in a single declaration. In the second case, the variables are initialized in left to right order from the initial list. (Having fewer constants than variables is permitted, but having more is flagged as an error.)

```
simple_variable_declaration
                        => identifier simple_type
                             [ ':=' initial_value ]
                        => identifier identifier+ simple_type
                             [ ':=' '[' initial_value*
                                               ['...'] ']' ]

initial_value           => type_converter initial_value
                        => (INC|DEC) initial_value
                        => constant_expression
                        => '#' static_variable
                        => '#' text_constant
                        => NIL
                        => '?'
```

A simple variable is denoted by the identifier appearing in its declaration.

Examples:

```
TYPE
        COLOR BYTE
INTERNAL
        HUE COLOR
        LIMIT WORD := %FFFF
        SUBTOTAL, TOTAL INTEGER := [0...]
        A,B,C BYTE := ['A', 'B', 'C']
```

7.2 STRUCTURED VARIABLES

A structured variable is a variable whose base type is one of the structured types. The variable type may be represented either by a type identifier which has already been associated with a structure via a type definition, or by specifying the structure in the structured variable declaration itself.

A component of a structured variable is denoted by the variable identifier followed by a selector specifying the component. The form of the selector depends on the structuring type of the variable.

7.2.1 INDEXED VARIABLES

An indexed variable is a variable whose base type is ARRAY. Several array identifiers may appear in a single declaration, and may optionally be initialized if declared GLOBAL or INTERNAL. Each array component is initialized in left to right order from the values given in the initial list, and in row major form (i.e., the right-most subscript varies fastest). There are two ways to initialize an array: with a single constructor if there is only one array identifier, or with a list of constructors enclosed in square brackets if there is more than one array identifier in a single declaration. In the first case, for a constructor containing N elements, the first N components of the array taken in row-major order are initialized. (Having more constants than the number of array elements is flagged as an error.) In the second case, the elements of each array are initialized to the specified values within the corresponding constructor in a manner similar to the first case.

For one-dimensional array initializations where the component is a simple type, PLZ allows the length of the array to be unspecified (by writing '*' for the index value in the declaration), so that the length of the array is determined by the number of elements in the initialization list. When '*' is used, there are two ways to initialize the array: with a list of constants enclosed in square brackets or with a list of text_constants. In the second case, the array component type must have an 8-bit base type (BYTE or SHORT_INTEGER), and each byte of the array is initialized to a single character value; the characters are taken in left to right order from the sequence of text_constants and put into the array in ascending memory locations. For instance:

```
ALPHA ARRAY [* BYTE] := 'ABCDEFGHIJKLMNOPQRSTUVWXYZ'
```

could be written:

```
ALPHA ARRAY [* BYTE] := 'ABCDEFGHIJKLM'
                        'NOPQRSTUVWXYZ'
```

A unary operator, called SIZEOF, can be given the name of an array variable or array type identifier as its argument and produces a constant value which is the number of bytes in the array (see 8.1.2).

```
   array_variable_declaration
           => identifier array_type
                [ ':=' constructor ]
           => identifier identifier+ array_type
                [ ':=' '[' constructor* ['...'] ']' ]
           => identifier ARRAY '[' '*' simple_type ']'
                ':=' '[' initial_value+ ']'
           => identifier ARRAY '[' '*' simple_type ']'
                ':=' text_constant+

  constructor => '[' initial_component* ['...'] ']'

  initial_component
           => initial_value
           => constructor
```

In the following examples, the array type is specified in the variable declaration, instead of defining the arrays as types:

```
      INTERNAL
              ONEDIM1, ONEDIM2 ARRAY [2 BYTE] := [[1...][2...]]
              TWODIM ARRAY [4 ARRAY [2 WORD]] := [[0...]...]
              MESSAGE ARRAY [* BYTE] := 'THIS IS A MESSAGE'
                  (sizeof=17)
              ONEDIM3 ARRAY [* INTEGER] := [25535,0,(-4)]
                  (sizeof=6)
              THREEDIM ARRAY [3 2 3 SHORT_INTEGER]
```

The following examples declare variables by specifying the type as a user-defined type.

```
      TYPE
              BUFFER ARRAY [128 BYTE]
              MATRIX ARRAY [8 8 BYTE]

      INTERNAL
              CHARBUF BUFFER := [' '...]
              CHESSBOARD MATRIX
```

A component of an array variable is denoted by the variable followed by a list of indices.

```
   array_variable    => array_designator '[' array_index+ ']'

   array_designator  => array_identifier
                     => pointer_variable
                     => record_variable
                     => array_variable

   array_index       => arithmetic_expression
```

The base type of each index in the list must be WORD, INTEGER, BYTE or SHORT_INTEGER. Notice that the component of an array of arrays (e.g., TWODIM[I]) is itself an array. The indices of an array must conform with its declaration, so that neither TWODIM[I,J] nor MATRIX[1][2] are valid with the above declarations.

Some valid array denotations are:

```
      CHARBUF[10]
      CHESSBOARD[ROW COLUMN]
      TWODIM[I][J]
```

7.2.2 RECORD VARIABLES AND FIELD DESIGNATORS

A record variable is a variable whose base type is RECORD. Several record identifiers may appear in a single declaration, and may optionally be initialized if declared GLOBAL or INTERNAL. Each record field is initialized in left to right order from the values given in the initial list. There are two ways to initialize a record: with a single constructor if there is only one record identifier, or with a list of constructors enclosed in square brackets if there is more than one record identifier in a single declaration. In the first case, for a constructor containing N elements, the first N fields are initialized. (Having more constants than the number of record fields is flagged as an error.) In the second case, the elements of each record are initialized to the specified values within the corresponding constructor in a manner similar to the first case. The declaration of a record variable may either use a record type identifier as the type, or may instead define the record template in the record variable declaration itself.

```
      record_variable_declaration
                    => identifier record_type
                          [ ':=' constructor ]
                    => identifier identifier+ record_type
                          [ ':=' '[' constructor* ['...'] ']' ]
```

A component (field) of a record variable is denoted by an expression called a field designator. The field designator consists of the record designator (which specifies the particular record being accessed) and a field identifier (which specifies which field is being accessed).

```
record_variable     => record_designator
                                 '.' field_identifier

record_designator   => record_identifier
                    => pointer_variable
                    => array_variable
                    => record_variable
```

Examples:

```
TYPE
  PATIENT RECORD [AGE, HEIGHT, WEIGHT BYTE
                  BIRTH RECORD [DAY, MO, YR BYTE]
                  SEX BYTE
                  ROOM WORD
                 ]

INTERNAL
  FEMALE ARRAY [100 PATIENT] := [[?,?,?,[],'F']...]
         (only the SEX field of each record is initialized)
  DEAN, PROVOST PATIENT
  PROGRAMSTATUS RECORD [FLAGS BYTE
                        PROGRAM_COUNTER WORD] := [%80,0]
```

Some valid record denotations are:

```
DEAN.ROOM
PROVOST.BIRTH.YR
FEMALE[I].BIRTH.DAY
PROGRAMSTATUS.FLAGS
```

7.3 REFERENCED VARIABLES

Referenced variables are variables which are pointed to by some pointer variable. The base type of a pointer variable is type pointer. The defined type of a pointer variable is a combination of the number of levels of indirection (i.e., the number of '↑' appearing in the declaration), along with the defined type to which it is declared to point (see 6.3).

A pointer to a component of a structure is declared by specifying that the pointer points to the type of the desired component. Thus, the pointer variable is not restricted to point only within the array or record; rather, it can point to any variable of the specified type. In contrast, a pointer to a record or an array structure itself is declared by specifying the record or array type. Such a pointer is restricted to point to the beginning of any record or array of the specified type. Thus the compiler can ensure that any field references (for records) or indices (for arrays) are computed from the base address.

The only operations defined on pointers are the tests for equality and ordering (based on the underlying machine-dependent addressing scheme), the pointer operator '↑' (which yields the variable referred to by the pointer), the address operator '#' which yields the address of the pointer variable, and the INC and DEC operators (which yield a pointer to the next and previous values in memory of the type pointed to).

A pointer variable is declared as a simple variable (see 7.1) and may be initialized with a type-compatible value. If p is a pointer variable which points to data type T, p denotes that variable and its pointer value, whereas p↑ denotes the variable of type T referenced by p. If p involves more than one level of indirection, then to get the value to which p ultimately points, as many '↑' as appear in the declaration of p must be appended to p.

```
pointer_variable     => pointer_designator '↑'

pointer_designator   => pointer_identifier
                     => array_variable
                     => record_variable
                     => pointer_variable
```

For example, the following set of declarations form a structure for a hash table. HASH_PTR points to some "bucket" (i.e., an element of SYM_BUCKETS) where a bucket is the head of a linked list of names which hash to that bucket. Each element of SYM_BUCKETS points to the head of a list of TABLE_ENTRYs in the array SYMBOL_TABLE. Given a bucket by the hash function, searching down the linked list of names for a given name is accomplished via the NEXT field of the record using the pointer variable TABLE_PTR.

```
TYPE
        STRING RECORD [LENGTH BYTE
                       CHARS ↑BYTE]
        ENTRY_PTR ↑TABLE_ENTRY
        TABLE_ENTRY RECORD [NAME STRING
                            NEXT ENTRY_PTR]
        STRPTR ↑STRING
        NAMES ARRAY [100 TABLE_ENTRY]
        BUCKETS ARRAY [100 ENTRY_PTR]

INTERNAL
        CHARSTR STRING
        CHARSTR_PTR STRPTR
        SYMBOL_TABLE NAMES
        SYM_BUCKETS BUCKETS
        HASH_PTR ↑ENTRY_PTR
        TABLE_PTR ENTRY_PTR := NIL
```

Some valid variable denotations are:

```
        CHARSTR.LENGTH                (type = BYTE)
        CHARSTR_PTR↑.LENGTH           (type = BYTE)
        CHARSTR.CHARS↑                (type = BYTE)
        SYMBOL_TABLE[1].NAME.CHARS    (type = ↑BYTE)
        SYM_BUCKETS[1]↑.NAME.CHARS    (type = ↑BYTE)
        HASH_PTR↑                     (type = ENTRY_PTR)
        HASH_PTR↑↑                    (type = TABLE_ENTRY)
```

Notice that the variable designator CHARSTR_PTR↑ functions semantically the same as CHARSTR, since they are both record variables of type STRING. Similarly, for arrays and pointers to arrays, the pointer can be used to index into the array. For example, with the declaration:

```
INTERNAL
        SYM_LENGTH BYTE
        SYM_TAB_PTR ↑NAMES
```

Some valid assignments and expressions are:

```
        SYM_TAB_PTR := # SYMBOL_TABLE
        SYM_LENGTH := SYM_TAB_PTR↑[10].NAME.LENGTH
        SYM_LENGTH := SYMBOL_TABLE[10].NAME.LENGTH
```

The last two assignments are equivalent. The first assignment exemplifies the only way in which pointers to arrays can be assigned initial values other than NIL. Note that the array variable identifier must be given without an index in this case.

7.4 SCOPE RULES

A "scope" is a region of text in which an identifier is known with a single meaning. A scope is either

a module definition, bracketed by MODULE and the matching END, or

a procedure declaration (see section 10), bracketed by PROCEDURE and the matching END, or

a record definition, bracketed by '[' and the matching ']'.

Note that procedure declarations are not allowed within other procedure declarations so that in any module there can be at most three nested levels of scoping: module level, procedure level, and record level for records declared in procedures.

A variable identifier is accessible in a scope S if it is

declared in S or in the scope of the module or procedure definition containing S, or

declared EXTERNAL in the module definition containing S, or

explicitly imported into S through a formal parameter of the procedure declaration in which S appears.

New identifiers are declared

> in a variable, procedure, type or constant declaration in the module,
>
> as record components,
>
> as formal parameters, return parameters, or local variables of a procedure declaration, or
>
> as loop labels.

New identifiers are accessible within the newly established scope. They are not accessible outside of this scope, except that field identifiers of records are accessible outside the scope when used in a field designator, which is considered to be a continuation of that scope.

The name declared by a procedure declaration is considered to be declared in the entire scope of the enclosing module definition. The formal parameters of the procedure declaration, if any, are accessible only in the scope of the procedure.

A new identifier may not be introduced which is the same as any other identifier introduced in the scope (notice that record field identifiers may use identifier names appearing in the scope outside the current level of record definition).

An identifier used in a scope and not declared in that scope is said to be free in that scope. Any identifier which is free in the scope of a procedure must be declared in the enclosing scope (i.e., the scope of the module). Thus, procedures do not explicitly import variables, as modules do via the EXTERNAL declaration.

A module scope has the property that all its possible interactions with the rest of the program can be determined by examining its import and export list (i.e., the variables declared GLOBAL or EXTERNAL), and the parameters of GLOBAL or EXTERNAL procedures (since parameters may be passed which are pointers to variables in other modules' scopes).

The value of a variable can change only

as the result of assignment to that variable or one of its components, either directly or indirectly (through a pointer to that variable), or

as a result of a procedure call in which that variable was pointed to by an actual parameter corresponding to a formal parameter of type pointer, or

as a result of a procedure call that has side-effects (i.e., the procedure modifies variables other than its own locals). If the variables modified by the procedure appear in the expression invoking the procedure, unexpected results may occur.

8. EXPRESSIONS

Expressions are constructs denoting rules of computation for obtaining values of variables and generating new values by the application of operators. Expressions may consist of operands (i.e., variables, constants, and procedures that return exactly one value of the appropriate type) and operators. In addition to the conventional arithmetic operators, several other operators are defined to facilitate the construction of relational or conditional expressions in the restricted context of an if statement (see section 9.2.1.1).

The rules of composition specify operator precedences according to six classes of operators. The unary operators have the highest precedence, then the multiplying operators, then the adding operators, then the relational operators, then ANDIF and finally, with the lowest precedence, ORIF. Sequences of operators of the same precedence are executed from left to right.

The rules of precedence are reflected by the following syntax:

```
conditional_expression    => conditional_term
                                (ORIF conditional_term)*

conditional_term          => conditional_factor
                                (ANDIF conditional_factor)*

conditional_factor        => arithmetic_expression
                                [rel_op arithmetic_expression]

arithmetic_expression     => arithmetic_term
                                (add_op arithmetic_term)*

arithmetic_term           => arithmetic_factor
                                (mult_op arithmetic_factor)*

arithmetic_factor         => unary_operator
                                arithmetic_factor
                          => constant
                          => variable
                          => '#' variable
                          => '#' text_constant
                          => NIL
                          => '(' conditional_expression ')'

rel_op                    => '=' | '<>' | '<' | '>'
                          => '<=' | '>='
```

```
add_op              => '+' | '-' | OR | XOR

mult_op             => '*' | '/' | MOD | AND

unary_operator      => unary_op | type_converter

unary_op            => '+' | '-' | ABS
                    => NOT | INC | DEC
```

Examples:

```
15
-X
A/B*C
T1[J] AND T2[J] XOR T3[J]
PTR↑.CHAR <> 'Y'
I > 10 ORIF A[I] = 0
```

The rules of precedence can be overridden since any expression enclosed within parentheses is evaluated independently from preceding or succeeding operators.

Examples:

```
2*3-4*5         = (2*3)-(4*5)       = -14
2*(3-4)*5       = ((2*(3-4))*5      = -10
60/10/2         = (60/10)/2         =   3
60/(10/2)                           =  12
4+7 AND 3       = 4+(7 AND 3)       =   7
(4+7) AND 3                         =   3
```

8.1 OPERATORS

The base types of the operands for each operator are given in the following tables along with the corresponding base type of the result. In accordance with the type compatibility conventions of PLZ, all operands must have the same defined type.

Arithmetic overflow during evaluation of an expression may be ignored.

8.1.1 BINARY OPERATORS

The three types of binary operators are:

- arithmetic operators
- logical operators
- relational operators

The arithmetic operators are valid only for operands whose base type is one of the standard arithmetic types in PLZ, namely those whose base type is WORD, BYTE, INTEGER, or SHORT_INTEGER. The base type and defined type of the result they produce is the same as the base type and defined type, respectively, of the operands. The division operator, /, truncates toward zero, so that -(A/B) = -A/B = A/-B. The MOD operator is defined as A MOD B = A-((A/B)*B), so that the sign of the result of MOD is always the sign of the left operand. The right operand of / or MOD must be non-zero, otherwise the result is undefined. The symbols and operations of the arithmetic operators are given in the following table.

ARITHMETIC OPERATORS

operator	operation
*	multiplication
/	division with truncation
MOD	modulus
+	addition
-	subtraction

The logical operators are valid for all types whose base type is one of the standard arithmetic types in PLZ. The result of the bitwise logical operation has the same base type and defined type as the base type and defined type, respectively, of the operands.

LOGICAL OPERATORS

operator	operations
AND	logical 'and'
OR	logical 'or'
XOR	logical 'exclusive or'

The relational operators are valid for all types whose base type is one of the standard arithmetic types in PLZ, as well as for all types whose base type is pointer. The symbols and operations of the relational operators are given in the following table. The comparisons are signed or unsigned according to whether the operands are signed or unsigned.

RELATIONAL OPERATORS

operator	operation
=	equal
<>	not equal
<	less than
>	greater than
<=	less than or equal
>=	greater than or equal

A relational operator may be used only in a conditional expression that controls an if statement since a data result is never generated.

8.1.2 UNARY OPERATORS

For the unary operators the base type and defined type of the result is the same as the base type and defined type, respectively, of the operand (except for type converters, see 8.1.3).

UNARY OPERATORS

operator	operation	base type of operand
+	unary plus	arithmetic
-	unary minus	arithmetic
ABS	absolute value	arithmetic
NOT	logical complement	arithmetic
INC	the value of the pointer plus the length of the base type to which it points	pointer
DEC	the value of the pointer minus the length of the base type to which it points	pointer
SIZEOF	determine number of bytes of storage occupied by operand	any type (result is a constant value)
#	address of variable	any type (result has base type pointer)

The SIZEOF operator can be applied to any static variable (see 5.3) or type or constant identifier and produces a constant value which is the number of bytes of storage occupied by the operand. This value is useful for communicating with storage allocators or I/O procedures.

Examples:

```
TYPE
    MATRIX ARRAY[8 4 WORD]
INTERNAL
    CLARA ARRAY [* BYTE] := 'NETTE'
    DISKSTREAM RECORD [FILE_DESC WORD
                       POSITION WORD
                       BUFFER ARRAY [256 WORD]
                      ]
          .
          .
          .
      SIZEOF MATRIX/SIZEOF WORD     (value is 32)
      SIZEOF CLARA                  (value is 5)
      SIZEOF DISKSTREAM.BUFFER      (value is 512)
```

The address operator '#' can be applied to any type of variable, and produces a value which is equivalent to a pointer to that type. If only an array identifier is given, then the pointer value is an array pointer type; however, if an index is also given, then the pointer value is to the array component's type. The index expression may be either constant or variable. If only a record identifier is given, then the pointer value is a record pointer type; however, if a field name is also given, then the pointer value is to the record field's type. If the variable is a pointer designator, then the resulting pointer value has the type "pointer to the type of the pointer designator". Thus '#' effectively cancels a single pointer operator '↑'.

Examples:

```
TYPE
    Ary ARRAY [5 BYTE]
    Rec RECORD [F1 WORD  F2 ↑BYTE]

INTERNAL
    I        BYTE
    BUFFER   Ary
    R        Rec
    BUFPTR   ↑Ary
    ROOT     ↑Rec
     .
     .
     .
    #I           (pointer to BYTE)
    #BUFFER      (pointer to ARRAY Ary)
    #BUFFER[I]   (pointer to BYTE)
    #R           (pointer to RECORD Rec)
    #R.F1        (pointer to WORD)
    #R.F2        (pointer to pointer to BYTE)
    #ROOT        (pointer to pointer to RECORD Rec)
    #ROOT↑.F1    (pointer to WORD)
    #ROOT↑.F2    (pointer to pointer to BYTE)
    #ROOT↑.F2↑   (pointer to BYTE)
```

The address operator '#' can also be applied to a text_constant (see 5.3) and produces a value which is equivalent to a pointer to the sequence of 8-bit values. This value is type-compatible with any pointer variable which is defined to point to a variable whose base type is BYTE or SHORT_INTEGER.

Examples:

```
TYPE
    CHAR  BYTE
    MESSAGE ↑CHAR
EXTERNAL
    PRINT PROCEDURE (↑BYTE)
    PUTMESSAGE PROCEDURE (MSG MESSAGE, SIZE WORD)
INTERNAL
    GREETINGS ↑BYTE
    .
    .
    .
    GREETINGS := #'HELLO%R'
    PRINT (GREETINGS)
    PUTMESSAGE (#'WHAT IS YOUR NAME?',18)
```

8.1.3 TYPE CONVERTERS

In recognition of the fact that controlled breaches of the type system are sometimes necessary, PLZ provides a class of unary operators called type converters. Type converters may be either the standard type identifiers BYTE, SHORT_INTEGER, WORD or INTEGER, or a user-defined type identifier. The unary operator takes a value of its operand type and produces a value of the converter type after any necessary conversion of the machine representation of the operand expression.

```
type_converter     => BYTE
                   => WORD
                   => INTEGER
                   => SHORT_INTEGER
                   => type_identifier
```

The effects of type conversion on the machine representation of the various simple types are given in the table below.

EFFECTS OF TYPE CONVERSION

Converter Base Type	Operand Base Type: byte	word	short integer	integer	pointer
byte	=	t	=	t	t
word	r	=	r	=	w
short integer	=	t	=	t	t
integer	r	=	s	=	w
pointer	r	r	s	r	=

= : no effect
r : argument is right-justified in a field of zero bits
s : argument's sign is preserved (sign extension)
t : truncation, producing low order 8 bits only
w : truncation, producing low order 16 bits only

It is important to realize that the numeric interpretation of a value's representation may change even though the bit pattern itself is unchanged. For example, if an INTEGER is converted to a WORD, the same bit pattern that was interpreted as a two's complement signed number is now interpreted as an unsigned positive number.

Examples:

```
INTERNAL
        SMALLNUM  SHORT_INTEGER
        COUNT     INTEGER
        INDEX     WORD
           .
           .
           .
        COUNT := INTEGER SMALLNUM
        INDEX := WORD (COUNT + 1)
```

Because the normal type-checking mechanism of the compiler is inhibited when type conversion is used, unexpected results may occur when a value with a differing machine representation is bound to a variable. This is particularly true when mixing pointer and non-pointer variables, since a pointer is necessarily a machine-dependent value. Good programming practice suggests that the effect of type conversion should be kept localized by not passing type-converted values across procedure or module boundaries if possible.

Occasionally it is convenient to use several different data structures as a template for the same underlying machine representation. A type converter can be used for this purpose, as in the following example:

```
TYPE
        STRING RECORD [LEN BYTE
                       CHARS ARRAY [255 BYTE]]
        PERSON RECORD [NAME ARRAY [10 BYTE]
                        AGE WORD]
        STRPTR ↑STRING
        PERPTR ↑PERSON
INTERNAL
        S STRPTR
        P PERPTR
        BUFFER ARRAY [1000 BYTE]
           .
           .
           .
        S := STRPTR #BUFFER[0]
        IF S↑.LEN > 128 THEN ...
           .
           .
           .
        P := PERPTR #BUFFER[0]
        IF P↑.NAME[0] = 'A' THEN ...
```

8.2 PROCEDURE INVOCATION

A procedure invocation specifies the evaluation of a procedure. It consists of the identifier designating the procedure and may include a list of actual parameters. The actual parameters are assigned ("bound") to the corresponding formal parameters declared in the procedure declaration (see 10). The correspondence is established by the positions of the parameters in the lists of the actual and formal parameters, respectively. Parameters are passed to the procedure by value only; i.e., the formal parameter is treated as a local declaration of a variable whose value is assigned from the actual parameter list upon entry to the procedure.

Each actual parameter must be an arithmetic expression, possibly containing other procedure invocations. The corresponding formal parameter represents a local variable of the called procedure, and the value of the expression becomes the initial value of this variable.

The type of the actual parameter must be the same type as the formal parameter. Since the value of a parameter may be a pointer to a variable, call by reference can be accomplished by declaring the formal parameter to be of type pointer to a particular type, and then passing the address of a variable of the same type.

The procedure when used in an expression must return exactly one value of the correct type.

```
procedure_invocation    => procedure_identifier
                              [actual_parm_list]

actual_parm_list        => '(' parameter* ')'

parameter               => arithmetic_expression
```

Example:

Given the following procedure and variable declarations,

```
INTERNAL
    P PROCEDURE (IN1 BYTE,IN2 ↑BYTE)
      RETURNS (VAL BYTE)
      :
      END P

    MASK Y Z BYTE
    ZPTR ↑BYTE
```

some valid expressions are:

```
Y + P(Z,ZPTR)
P(Y,#Z) AND MASK
128 + P(2*P(Y+3,ZPTR),#Z)
```

9. STATEMENTS

Statements denote algorithmic actions, and are said to be executable.

```
statement => simple_statement
          => structured_statement
```

9.1 SIMPLE STATEMENTS

A simple statement is a statement of which no part constitutes another statement.

```
simple_statement => assignment_statement
                 => procedure_statement
                 => return_statement
                 => loop_control_statement
```

9.1.1 ASSIGNMENT STATEMENT

The assignment statement serves to replace the current value of a variable by a new value specified as an expression.

```
assignment_statement => variable assign_op
                            arithmetic_expression

assign_op            => ':=' | '+=' | '-='
```

The variable and the expression must be of the same type. The form

```
VAR += EXP
```

is similar to

```
VAR := VAR + EXP
```

while the form

```
VAR -= EXP
```

is similar to

```
VAR := VAR - EXP
```

Notice that VAR is evaluated only once in the '+=' and '-=' constructs.

Examples:

```
PTR := INC PTR
RECT.AREA := RECT.LENGTH * RECT.WIDTH
GO_AHEAD := STILL_RUNNING AND NO_ERRORS
COUNTDOWN -= 1
CUSTOMER↑.BALANCE += DEPOSIT + INTEREST * DEPOSIT
```

9.1.2 PROCEDURE STATEMENT

The procedure statement causes the execution of the procedure denoted by a procedure identifier and the assignment of any returned values. If the declaration of the procedure includes a RETURNS list, the procedure statement is written as a special form of the assignment statement. In this case, the number and type of variables in the list must be the same as the number and type of variables on the left-hand side of the procedure statement.

```
procedure_statement
            => [variable variable+ ':=']
                 procedure_invocation

procedure_invocation
            => procedure_identifier [actual_parm_list]
```

Examples:

```
BIG := MAX(X,Y)
INITIALIZE
DAY,MO,YEAR := GET_DATE
PRINT_CHAR(DIGIT+'0')
```

9.1.3 RETURN STATEMENT

The return statement causes execution to leave a procedure body and return to the statement following the procedure call in the calling procedure. No return statement is necessary immediately before the END of a procedure since one is implicit.

```
      return_statement => RETURN
```

9.1.4 LOOP CONTROL STATEMENTS

There are two kinds of loop control statements: the exit and repeat statements. The exit statement causes execution to continue at the first statement following the innermost DO...OD block which contains the exit statement, whereas the repeat statement causes execution to continue at the first statement of the innermost DO...OD block which contains the repeat statement. Furthermore, the exit and repeat statements may be qualified by a label identifier indicating a specific enclosing DO..OD block to which execution is to proceed (see 9.2.2).

```
   loop_control_statement
                         => exit_statement
                         => repeat_statement

   exit_statement        => EXIT [FROM label]

   repeat_statement      => REPEAT [FROM label]
```

Examples:

```
      EXIT
      REPEAT FROM ILOOP
```

9.2 STRUCTURED STATEMENTS

Structured statements are constructs composed of other statements that are executed either conditionally (conditional statements) or repeatedly (loop statements). The syntax of PLZ enables the elimination of the compound statement, since statements that are to be executed sequentially in the context of a structured statement are bracketed by the delimiters of that structured statement.

```
structured_statement => conditional_statement
                     => loop_statement
```

9.2.1 CONDITIONAL STATEMENTS

A conditional statement selects for execution one or more of its component statements.

```
conditional_statement  => if_statement
                       => select_statement
```

9.2.1.1 IF STATEMENT

The if statement specifies that the statements between the symbols THEN and ELSE (or FI, if there is no ELSE clause) are to be executed only if a certain conditional expression is true. If it is false, then either no statement is to be executed, or, if present, the statements between the symbols ELSE and FI are to be executed.

```
if_statement => IF conditional_expression THEN
                   statement*
                [ELSE
                   statement*]
                FI
```

Note that the only time an expression which contains a relational operator (see 8.1.1) may appear is in the if statement. The relational operators do not generate a data value; nevertheless, the compiler can generate code to determine whether the comparison is true or false and thus execute the correct set of statements in the if statement.

The ANDIF and ORIF operators may be used to compose several relational expressions, allowing partial evaluation of the conditional expression. If the left operand of ANDIF is false, then the right operand is not evaluated. If the left operand of ORIF is true, then the right operand is not evaluated. The precedence of the ANDIF, ORIF and relational operators is described in section 8.1. For example:

```
IF PTR = NIL ORIF PTR↑.VAL = KEY THEN EXIT
ELSE PTR := PTR↑.NEXT
FI

IF ELEMSIZE > 0 ANDIF TBLSIZE/ELEMSIZE > 2 THEN
   SUBDIVIDE(TABLE)
FI
```

Notice that in the first example, PTR should not be used to reference a record field when its value is NIL, while a division by zero is avoided in the second example.

Examples:

```
IF A[I] > A[J] THEN
    TEMP := A[I]
    A[I] := A[J]
    A[J] := TEMP
FI

IF I <= 5 THEN
    PROCESS(1)
ELSE
    IF I <= 8 THEN
        PROCESS(2)
    ELSE
        IF I < 13 THEN
            PROCESS(3)
        ELSE
            PROCESS(4)
        FI
    FI
FI


IF PRIORITY = 0 ORIF
   WAIT_ON_IO=TRUE ANDIF EMPTY(READYQ)=FALSE THEN
      RUN(TCB[I])
ELSE
      DO !BUSY WAIT!
      OD
FI
```

9.2.1.2 SELECT STATEMENT

The select statement is an extension of the if statement and consists of an expression (the selector) and a list of select elements of the form

```
      CASE constant_expression+ THEN statement*
```

where the constant expressions may be given in any order. It specifies that the statements of the one select element, whose list of constant expressions contains the current value of the selector, are to be executed. Thus, constant expressions evaluating to the same constant may not appear in different select elements. An ELSE clause can be used to identify those statements which should be executed if none of the constant expressions equals the current value of the selector. If none of the constant expressions equals the selector and there is no ELSE clause, no statements in the body of the select statement are executed. Each element is terminated by the next select element. The ELSE clause, if present, is terminated by the select statement terminator FI.

```
      select_statement => IF arithmetic_expression
                          select_element+
                          [ELSE statement*]
                          FI

      select_element   => CASE select_expression+ THEN
                             statement*

      select_expression
                       => constant_expression
```

Examples:

```
IF SYMTYPE[NEXT_SYMBOL]
CASE 1 THEN SCANDIGIT
              VAL := STR_TO_INT(STARTPTR, ENDPTR)
CASE 2 THEN SCANID
CASE 3 THEN SCANOP
CASE TAB, BLANK THEN SCANDELIM
CASE ',' ';' ':' THEN SCANPUNCTUATION
ELSE ILLEGAL
FI
```

```
IF COMMANDLETTER
CASE ESC THEN QUIT RETURN
CASE 'P', 'p' THEN PASTE (CURSOR1, CURSOR2)
CASE 'C', 'c' THEN CUT (CURSOR1, CURSOR2)
CASE 'I', 'i' THEN
              UPDATE (CURSOR1)
              IF CURWINDOW
              CASE COMMANDW    THEN EXPANDNAME('I')
                                    INPUT(KEYBOARD)
              CASE USERW       THEN INPUT(KEYBOARD)
                                    IF EOF=TRUE THEN
                                         ERROR(EMPTY)
                                    FI
              CASE RECOVERYW   THEN UPDATE(CURSOR2)
                                    UNDO
              FI
ELSE ERROR(UNRECOGNIZED)
FI
```

9.2.2 LOOP STATEMENT

The only framework provided for repetitive statements in PLZ is the loop statement. The statements between the symbols DO and OD are executed repeatedly until control is diverted through a loop control statement. The exit, repeat, or return statements are the only way to change the flow of execution through the statements delimited by the symbols DO and OD. The exit and repeat statements may, of course, appear in conditional statements, thus providing the capability to effect the well-known FOR, WHILE, and UNTIL constructs.

A DO statement does not introduce a new scope; no new identifiers can be declared.

```
loop_statement => [label] DO statement* OD

label          => identifier
```

Examples:

```
!Nested "FOR" loops, with a 2-level exit!
   I := 1
   ILOOP: DO
      IF I > LIMI THEN EXIT FI
      J := 1
      JLOOP: DO
         IF J > LIMJ THEN EXIT FI
         IF A[I,J] = TERMINATOR THEN EXIT FROM ILOOP FI
         J := J+1
      OD
      I := I+1
   OD
   !When we get here, either a[i,j] = terminator, or
    i > limi and j > limj!

!WHILE COND DO...loop!
DO
   IF COND = FALSE THEN EXIT FI
    .
    .
OD
```

```
!REPEAT...UNTIL COND loop!
DO
 .
 .
   IF COND = TRUE THEN EXIT FI
OD

!non-repetitive sequence!
DO
    .
    .
    .
   EXIT
OD

!infinite loop!
DO
OD



!Use REPEAT FROM to find a matching row!
   I := 0
   MATCH_ROW := 0
   ILOOP: DO
      I += 1
      IF I > LIMI THEN EXIT FI
      J := 0
      JLOOP: DO
         J += 1
         IF J > COMPLIST_SIZE THEN
            EXIT
         FI
         IF A[I,J] <> COMPLIST[J] THEN
            REPEAT FROM ILOOP
         FI
      OD
      !We get here only if j > complist_size,
       i.e., a[i,j] = complist [j], for all j
       such that 1 <= j <= complist_size!
      MATCH_ROW := I
      EXIT
   OD
      !Either i > limi and no rows matched
       (match_row = 0), or 1 <= i <= limi and
       match_row = i!
```

10. PROCEDURE DECLARATIONS

A procedure declaration serves to define an executable part of a program, and to associate an identifier with it so that it can be activated by procedure statements or procedure invocations in expressions.

The procedure heading specifies the identifier naming the procedure, the formal parameter identifiers (if any), and the identifiers whose values are to be returned (if any). The formal parameters are also referred to as "in" parameters since their values are considered input values to the procedure, while the term "out" parameters refers to the returned values which are considered output values of the procedure. All such identifiers are considered local to the procedure body. The base type of a parameter may be any simple type. Thus arrays and records may not be passed, but pointers to these structures are allowed as parameters.

Procedures may return values of any assignable type (see 9.1.2). The value or values returned are the current values of the identifiers specified in the RETURNS list of the procedure heading at the time that a RETURN or END statement is executed. The RETURN statement itself does not specify the value to be returned.

A procedure declaration may also include LOCAL variable declarations which associate identifiers with storage that is dynamically allocated on each procedure entry. Thus recursion and re-entrant procedures are possible, and the storage usage of a program may vary during execution so that a program can be designed to use less data storage than one whose allocation is completely static. Local variables may be of any type and their scope is local to the containing procedure. Local variables may not be initialized since they are allocated each time the procedure is entered.

A procedure is activated by the evaluation of a procedure invocation. If the procedure returns a single value, then its invocation may be used either in an expression or in a procedure statement. If it returns either no values or more than one value, the procedure invocation may appear only in a procedure statement (see sections 8.2 and 9.1.2).

Occurrence of a procedure identifier in an expression or a procedure statement within its declaration implies the recursive execution of the procedure.

All procedures must be declared before they are used. If two procedures are mutually recursive (that is, a procedure calls another procedure, which in turn results in the invocation of the first procedure), then it is not possible to give both declarations before their usage in the same module. This problem may be overcome by placing the declarations in separate modules, using the appropriate GLOBAL and EXTERNAL declaration classes for the procedures.

```
procedure_declaration
                  => procedure_identifier
                         PROCEDURE [formal_parm_list]
                            [RETURNS formal_parm_list]
                         locals*
                         [ENTRY
                            statement*]
                         END procedure_identifier

formal_parm_list => '(' formal_parm* ')'

formal_parm      => identifier+ simple_type

locals           => LOCAL
                         (identifier+ type)*
```

Notice that the keyword ENTRY is used to separate the declarations of parameters and local variables from the executable sequence of statements that constitutes the body of the procedure.

Example:

```
      TYPE
          TABLE ARRAY [30 BYTE]
          TABLEPTR ↑TABLE
      INTERNAL
          CH RESULT BYTE
          T  TABLE
          TPTR TABLEPTR := #T  !Initialize pointer to table!

          VERIFY PROCEDURE (CHAR BYTE, PTR TABLEPTR)
                 RETURNS (RSLT BYTE)
              ! Check whether CHAR is in TABLE
                pointed to by PTR !

              LOCAL
                   INDEX BYTE
              ENTRY
                 INDEX := 0
                 DO
                    IF INDEX = 30 THEN RSLT := FALSE EXIT FI
                    IF CHAR = PTR↑[INDEX] THEN
                               RSLT := TRUE EXIT
                    FI
                    INDEX += 1
                 OD
             END VERIFY
```

A call to VERIFY looks like:

```
      RESULT := VERIFY (CH, TPTR)
```

The declaration of an EXTERNAL procedure contains only the procedure heading, since the actual executable body is defined in another module where the procedure is declared GLOBAL. Since references to the formal parameter names do not occur in an EXTERNAL procedure declaration, the names may optionally be omitted, however the types are required. For example, in the recommended form:

```
      EXTERNAL
      GETSEQ PROCEDURE (UNIT BYTE
                        BUFPTR ↑BYTE
                        NUMBYTES WORD)
             RETURNS   (RETBYTES WORD
                        RCODE BYTE)
```

could also be written:

```
      EXTERNAL
      GETSEQ PROCEDURE (BYTE ↑BYTE WORD)
             RETURNS   (WORD BYTE)
```

```
restricted_procedure_declaration
                        => procedure_identifier
                              PROCEDURE [parameter_type_list]
                              [RETURNS parameter_type_list]

parameter_type_list => '(' restricted_parm* ')'

restricted_parm     => identifier* simple_type
```

The following example demonstrates the use of recursion and the ordering of procedure declarations before their usage.

```
EXTERNAL
   PUTCH PROCEDURE (CH BYTE)
   PUTSTRING PROCEDURE (START ↑BYTE, COUNT BYTE)

INTERNAL

! print non-negative decimal integer
  with leading zeros suppressed !

   NPRINT PROCEDURE (N INTEGER)
      ENTRY
         IF N>0 THEN
            NPRINT(N/10)
            PUTCH(BYTE(N MOD 10)+'0')
         FI
      END NPRINT

GLOBAL
   PRINTDEC PROCEDURE (N INTEGER)
      ENTRY
         IF N>0 THEN NPRINT(N)
         ELSE
            IF N=0 THEN PUTCH('0')
            ELSE PUTCH('-')
               IF N=-32768 THEN
                  PUTSTRING(#'32768',5)
               ELSE
                  NPRINT(ABS N)
               FI
            FI
         FI
      END PRINTDEC
```

11. PROGRAMS AND MODULES

A PLZ program consists of a sequence of modules to be linked together by the available linking facility. The name of a GLOBAL procedure should be supplied to the linking facility to specify the entry point of a PLZ program. The parameters to this procedure are defined by the particular system where the program is executed.

A PLZ module consists of a sequence of variable and procedure declarations (i.e., executable statements appear only inside procedure declarations). In addition to parameter passing between procedures, the sharing of data (or procedures) between modules may be achieved by declaring a variable (procedure) to be GLOBAL in one module and declaring references to that variable (procedure) within other modules as EXTERNAL. Data (procedures) which are declared INTERNAL to a module may be referenced only within that module.

A SAMPLE PROGRAM

The following program accepts text from the console (each "token" is a string of characters separated by a blank) and produces an alphabetized list of all the tokens input up to a return character. The algorithm uses a binary tree of tokens where the left subtree of each token is alphabetically less than the given token, and the right subtree has all the tokens whch are greater than or equal. The printing routine recursively traverses the tree to output the alphabetized list.

The program consists of three modules: the main treesort module, a storage allocator module and an I/O module which is not shown. The two I/O procedures getseq (which reads a sequence of bytes) and putseq (which writes a sequence of bytes) are declared as EXTERNAL to the corresponding modules.

```
treesort module

constant
      TRUE := 1
      FALSE := 0
      CONOUT := 2              ! console output unit !

type
      node record [name ↑byte
                   left, right ↑node]

external
      alloc_node  procedure
                  returns (newnode ↑node)
      input_token procedure
                  returns (notdone byte)
      putseq procedure (unit byte, bufptr ↑byte, numbytes word)
              returns (retbytes word, rcode byte)

internal

      putchar procedure (unit, ch byte)
         local length word
                retcode byte
         entry
                length, retcode :=
                        putseq (unit, #ch, 1)
         end putchar

global
      root ↑node := NIL        ! initialize root of tree !

! output string delimited by blank !

      print procedure (bufptr ↑byte)
         entry
                do
                        if bufptr↑ = ' ' then
                                putchar (CONOUT, '%r')
                                exit
                        else    putchar (CONOUT, bufptr↑)
                                bufptr := inc bufptr
                        fi
                od
         end print
```

```
internal

! recursive symmetric order traversal routine !

      treeprint procedure (currentnode ↑node)
         entry
                 if currentnode↑.left <> NIL then
                         treeprint (currentnode↑.left) fi
                 print (currentnode↑.name)
                 if currentnode↑.right <> NIL then
                         treeprint (currentnode↑.right) fi
         end treeprint




! string comparison -- returns TRUE if strl <= str2 !

lessequal procedure (strl, str2 ↑byte)
          returns (order byte)
   entry
         do
         if strl↑ <> str2↑ then
                 if strl↑ <= str2↑ then
                         order := TRUE return
                 else
                         order := FALSE return
                 fi
         else
                 if strl↑ = ' ' then
                         order := TRUE return
                 else
                         strl := inc strl
                         str2 := inc str2
                 fi
         fi
         od
   end lessequal
```

```
! The workhorse procedure:  traverse tree to find
  appropriate place to insert node.  Names which are
  alphabetically less  are found in the left subtree !

insert procedure
   local newnode, currentnode ↑node
   entry
         newnode := alloc_node
         if newnode <> NIL then
            if root <> NIL then         ! is tree empty? !
               currentnode := root
               do
                 if lessequal(newnode↑.name,currentnode↑.name)
                                                   = TRUE then
                     if currentnode↑.left <> NIL then
                            currentnode := currentnode↑.left
                     else
                            currentnode↑.left := newnode exit
                     fi
                 else
                     if currentnode↑.right <> NIL then
                            currentnode := currentnode↑.right
                     else
                            currentnode↑.right := newnode exit
                     fi
                 fi
               od
            else
                  root := newnode ! first node in tree !
            fi
         fi
   end insert




! The main procedure inputs tokens and inserts nodes in the
  tree.  When a CR is entered, the alphabetized tree is
  printed !

global
      main procedure
         entry
              do
                 if input_token = TRUE then insert
                 else exit
                 fi
              od
              if root <> NIL then treeprint(root) fi
         end main

end treesort
```

```
storage module

! contains the storage allocator for nodes and the
  input_token  procedure !

constant
      TRUE := 1
      FALSE := 0
      MAXNODES := 100
      MAXCHARS := 1500
      CONIN := 1                    ! console input unit !
      CR := '%r'                    ! CR character !
type
      node record [name ↑byte
                   left, right ↑node]
external
      print procedure (bufptr ↑byte)
      getseq procedure (unit byte, bufptr ↑byte, numbytes word)
              returns (retbytes word, rcode byte)
internal
      tree array [MAXNODES node]
      nextnode ↑node := #tree[0]
              ! initialize pointer to first node to be
                allocated and initialize count of
                available nodes !
      avail short_integer := MAXNODES

      token ↑byte     ! pointer to start of current token !
              ! buffer for name strings and index into it !
      stringspace array [MAXCHARS byte]
      nextchar word := 0
      nospacemsg array [* byte] := 'NO_MORE_SPACE '

global

      ! Allocates a node, installs token and initializes
        branches, returning pointer to node.  Outputs
        error message if none are available -- no
        deallocation !

      alloc_node procedure
              returns (newnode ↑node)
         entry
              if avail <> 0 then
                  newnode := nextnode
                  newnode↑.name := token
                  newnode↑.left := NIL
                  newnode↑.right := NIL
                  avail -= 1
                  nextnode := inc nextnode
              else
                  newnode := NIL
                  print (#nospacemsg[0])
              fi
         end alloc_node
```

```
! reads characters from the console until either a blank
  or a CR, returning notdone = FALSE if a CR, and token
  pointing to start of string delimited by blank !

      input_token procedure
              returns (notdone byte)
         local length word
                 retcode byte
         entry
                 token := #stringspace[nextchar]
                 do   ! get 1 character at a time !
                   length, retcode :=
                       getseq (CONIN, #stringspace[nextchar], 1)
                   if stringspace[nextchar] = ' ' then
                      nextchar += 1
                      notdone := TRUE
                      exit
                   else
                      if stringspace[nextchar] = CR then
                           stringspace[nextchar] := ' '
                           notdone := FALSE exit ! replace CR !
                      fi
                   fi
                   if nextchar >= MAXCHARS then
                      print (#nospacemsg[0])
                      notdone := FALSE
                      exit
                   else
                     nextchar += 1
                   fi
               od
         end input_token

end storage
```

12. IMPLEMENTATION NOTES

This section discusses general implementation conventions and restrictions for parts of the PLZ/SYS language which should be emphasized.

12.1 IDENTIFIERS AND KEYWORDS

Identifiers may vary in capitalization. The PLZ rule is that each time an identifier is used, it must be written the same way it was declared (see 4).

Keywords such as GLOBAL or RETURN may be written in either entirely capital letters or entirely lower case, thus either GLOBAL or global is acceptable, but GloBaL would be taken to be an identifier, not a keyword.

12.2 REPRESENTATION OF POINTERS

The representation of a pointer in memory is independent of the type of variable to which it points. By their very nature, address quantities are machine-dependent values. Thus PLZ/SYS programs which are intended to be transportable to various machines should limit their use of pointers to assignment, parameter-passing, and equality tests and avoid arithmetic operations or assigning constant values to pointer variables through type conversions.

The representation of the pointer value NIL is implementation dependent, so portable programs should avoid the use of comparisons other than equality and inequality. The INC and DEC operators are not valid when applied to NIL since the size of the variable pointed to is not defined.

12.3 STRUCTURE ALIGNMENT

Some machines require that data variables be aligned on certain address boundaries, and therefore record fields may not necessarily be assigned contiguous memory locations. The SIZEOF operator may be used to determine the total number of bytes occupied by a record, which will always be rounded up to a value which falls on the alignment boundary. The alignment boundary of a record is taken to be the maximum alignment boundary of its fields, which depends on the particular machine. Thus programs which are to be portable to other translators or machines should not assume any particular allocation of record fields.

PLZ/SYS does guarantee that elements of a one-dimensional array are allocated sequential memory locations starting from the base address of the array. This allows elements to be accessed by using pointers which are usually more efficient than array indices on most machines. The user is cautioned that compiler implementations are not required to generate code to check that array indices are in bounds for the declared size of an array, nor is it required that code be generated to check that the INC or DEC operators applied to a pointer to an element in an array yields an address still within the bounds of the array.

12.4 UNARY OPERATORS IN LISTS

PLZ has the characteristic that a list of numbers such as "4,-2,1" has the perhaps unexpected interpretation of being only two distinct values (2 and 1), since the comma is equivalent to a blank throughout PLZ and thus the first two numbers evaluate to the single expression 4-2. This interpretation is due to a combination of the lack of any delineation between elements in a list other than delimiters, and the ambiguity of using the same symbol "-" for both unary and binary minus (the same is true for "+"). While this will usually cause only minor problems in either parameter lists or array indices since the compiler checks for the correct number of values, unexpected results may occur in either a list of initialization values or in a list of select expressions following the keyword CASE. There are at least two simple solutions to avoid this problem: use 0-N instead of -N whenever it appears in a list of values, or enclose the expression in parentheses as in "4,(-2),1".

12.5 ONE-PASS COMPILATION

PLZ has been designed to permit one-pass translation. To this end, identifiers must be declared before they are used. However, this restriction is relaxed for identifiers following '↑' in declarations of pointer variables or definitions of pointer types. The following excerpt from 7.3 illustrates this:

```
TYPE
    ENTRY_PTR ↑TABLE_ENTRY
    TABLE_ENTRY RECORD [NAME STRING
                        NEXT ENTRY_PTR]
```

APPENDIX

PLZ/SYS GRAMMAR

```
module                  => module_identifier MODULE
                           declarations*
                           END module_identifier

declarations            => constants
                        => types
                        => globals
                        => internals
                        => externals

constants               => CONSTANT
                              constant_definition*

types                   => TYPE
                              type_definition*

globals                 => GLOBAL
                              var_or_proc_declaration*

internals               => INTERNAL
                              var_or_proc_declaration*

externals               => EXTERNAL
                              restricted_var_or_proc_declaration*

constant_definition     => identifier
                              ':=' constant_expression

constant_expression     => constant_term
                              (add_op constant_term)*

constant_term           => constant_factor
                              (mult_op constant_factor)*

constant_factor         => unary_op constant_factor
                        => constant
                        => '(' constant_expression ')'

constant                => number
                        => character_constant
                        => constant_identifier
                        => SIZEOF static_variable
                        => SIZEOF type_identifier
                        => SIZEOF constant_identifier

character_constant      => ''' character_text [character_text] '''

type_definition         => identifier type
```

```
type                        => simple_type
                            => structured_type

simple_type                 => BYTE
                            => WORD
                            => INTEGER
                            => SHORT_INTEGER
                            => pointer_type
                            => simple_type_identifier

pointer_type                => '↑' type
                            => pointer_type_identifier

structured_type             => array_type
                            => record_type

array_type                  => ARRAY '[' constant_expression+ type ']'
                            => array_type_identifier

record_type                 => RECORD '[' field_declaration+ ']'
                            => record_type_identifier

field_declaration           => identifier+ type

var_or_proc_declaration => variable_declaration
                            => procedure_declaration

restricted_var_or_proc_declaration
                            => identifier+ type
                            => restricted_procedure_declaration

variable_declaration        => identifier simple_type
                                   [ ':=' initial_value ]
                            => identifier identifier+ simple_type
                                   [ ':=' '[' initial_value*
                                                      ['...'] ']' ]
                            => identifier structured_type
                                   [ ':=' constructor ]
                            => identifier identifier+ structured_type
                                   [ ':=' '[' constructor*
                                                      ['...'] ']' ]
                            => identifier ARRAY '[' '*' simple_type ']'
                                   ':=' '[' initial_value+ ']'
                            => identifier ARRAY '[' '*' simple_type ']'
                                   ':=' text_constant+

constructor                 => '[' initial_component* ['...'] ']'

initial_component           => initial_value
                            => constructor

initial_value               => type_converter initial_value
                            => (INC|DEC) initial_value
                            => constant_expression
                            => '#' static_variable
                            => '#' text_constant
                            => NIL
                            => '?'
```

```
text_constant             => character_sequence

static_variable           => simple_identifier
                          => array_identifier
                          => record_identifier
                          => static_array_variable
                          => static_record_variable

static_array_variable     => static_array_designator
                                '[' constant_expression+ ']'

static_array_designator   => array_identifier
                          => static_record_variable
                          => static_array_variable

static_record_variable    => static_record_designator
                                '.' field_identifier

static_record_designator
                          => record_identifier
                          => static_array_variable
                          => static_record_variable

procedure_declaration     => procedure_identifier
                                PROCEDURE [formal_parm_list]
                                   [RETURNS formal_parm_list]
                                locals*
                                [ENTRY
                                   statement*]
                                END procedure_identifier

formal_parm_list          => '(' formal_parm* ')'

formal_parm               => identifier+ simple_type

locals                    => LOCAL
                                (identifier+ type)*

restricted_procedure_declaration
                          => procedure_identifier
                                PROCEDURE [parameter_type_list]
                                [RETURNS parameter_type_list]

parameter_type_list       => '(' restricted_parm* ')'

restricted_parm           => identifier* simple_type
```

```
statement                 => assignment_statement
                          => if_statement
                          => select_statement
                          => loop_statement
                          => exit_statement
                          => repeat_statement
                          => return_statement
                          => procedure_statement

assignment_statement      => variable assign_op
                                arithmetic_expression

assign_op                 => ':=' | '+=' | '-='

if_statement              => IF conditional_expression THEN
                                statement*
                             [ELSE statement*]
                             FI

select_statement          => IF arithmetic_expression
                             select_element+
                             [ELSE statement*]
                             FI

select_element            => CASE constant_expression+ THEN
                                statement*

loop_statement            => [label] DO
                                statement*
                             OD

label                     => identifier

exit_statement            => EXIT [FROM label]

repeat_statement          => REPEAT [FROM label]

return_statement          => RETURN

procedure_statement       => [variable variable+ ':=']
                                procedure_invocation

procedure_invocation      => procedure_identifier
                                [actual_parm_list]

actual_parm_list          => '(' parameter* ')'

parameter                 => arithmetic_expression
```

```
conditional_expression  => conditional_term
                              (ORIF conditional_term)*

conditional_term        => conditional_factor
                              (ANDIF conditional_factor)*

conditional_factor      => arithmetic_expression
                              [rel_op arithmetic_expression]

arithmetic_expression   => arithmetic_term
                              (add_op arithmetic_term)*

arithmetic_term         => arithmetic_factor
                              (mult_op arithmetic_factor)*

arithmetic_factor       => unary_operator arithmetic_factor
                        => constant
                        => variable
                        => '#' variable
                        => '#' text_constant
                        => NIL
                        => '(' conditional_expression ')'

rel_op                  => '=' | '<>' | '<' | '>' | '<=' | '>='

add_op                  => '+' | '-' | OR | XOR

mult_op                 => '*' | '/' | MOD | AND

unary_operator          => unary_op
                        => type_converter

unary_op                => '+' | '-' | ABS | NOT | INC | DEC

type_converter          => BYTE
                        => WORD
                        => SHORT_INTEGER
                        => INTEGER
                        => type_identifier
```

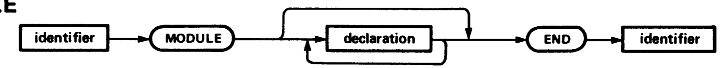
```
variable                  => identifier
                          => procedure_invocation
                          => array_variable
                          => record_variable
                          => pointer_variable

array_variable            => array_designator
                                '[' arithmetic_expression+ ']'

array_designator          => variable

record_variable           => record_designator '.' field_identifier

record_designator         => variable

pointer_variable          => pointer_designator '↑'

pointer_designator        => variable
```

PLZ/SYS LEXICAL GRAMMAR

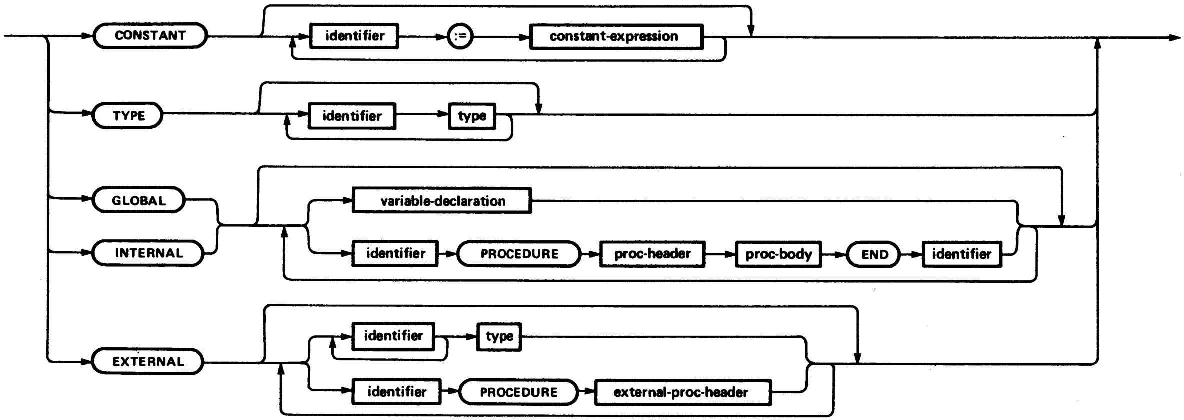
```
PLZ_text                 => separator* [id_constant_text]
                               (separator+ id_constant_text)*

id_constant_text         => identifier
                         => word_symbol
                         => literal_constant

separator                => delimiter_text
                         => special_symbol

identifier               => letter (letter | digit | '_')*

literal_constant         => number
                         => character_sequence

delimiter_text           => delimiter
                         => comment

number                   => integer
                         => hex_number

integer                  => digit+

hex_number               => '%' hex_digit+

character_sequence       => ''' character_text+ '''

character_text           => character
                         => special_character_text

character                => any_character_except_%_or_'

special_character_text   => '%' special_character
                         => '%' hex_digit hex_digit

special_character        => 'R' | 'L' | 'T' | 'P' | 'Q' | '%'
                         => 'r' | 'l' | 't' | 'p' | 'q'

comment                  => comment_initiator comment_char*
                               comment_terminator

comment_char             => any_character_except_comment_terminator

comment_initiator        => '!'

comment_terminator       => '!'

letter                   => 'A' | 'B' | ... | 'Z'
                         => 'a' | 'b' | ... | 'z'
```

```
digit                   => '0' | '1' | ... | '9'

hex_digit               => digit
                        => 'A' | 'B' | ... | 'F'
                        => 'a' | 'b' | ... | 'f'

special_symbol          => '+' | '-' | '*' | '/' | '='
                        => '<' | '>' | '<=' | '>=' | '<>'
                        => '.' | '%' | '↑' | ':=' | '+='
                        => '-=' | '#" | '[' | ']' | '(' | ')'
                        => '?' | '...'

word_symbol             => ABS | AND | ANDIF | ARRAY | BYTE
                        => CASE | CONSTANT | DEC | DO | ELSE
                        => END | ENTRY | EXIT | EXTERNAL | FI
                        => FROM | GLOBAL | IF | INC | INTEGER
                        => INTERNAL | LOCAL | MOD | MODULE | NIL
                        => NOT | OD | OR | ORIF | PROCEDURE
                        => RECORD | REPEAT | RETURN | RETURNS
                        => SHORT_INTEGER | SIZEOF | THEN
                        => TYPE | WORD | XOR

delimiter               => ',' | ';' | ':' | space
                        => tab | formfeed | linefeed
                        => carriage_return
```

MODULE

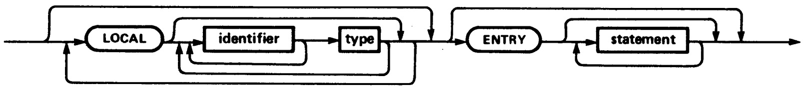


DECLARATION



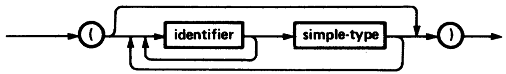
PROC-HEADER

PROC-BODY

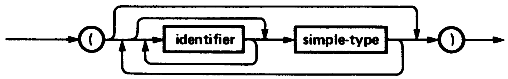


EXTERNAL-PROC-HEADER

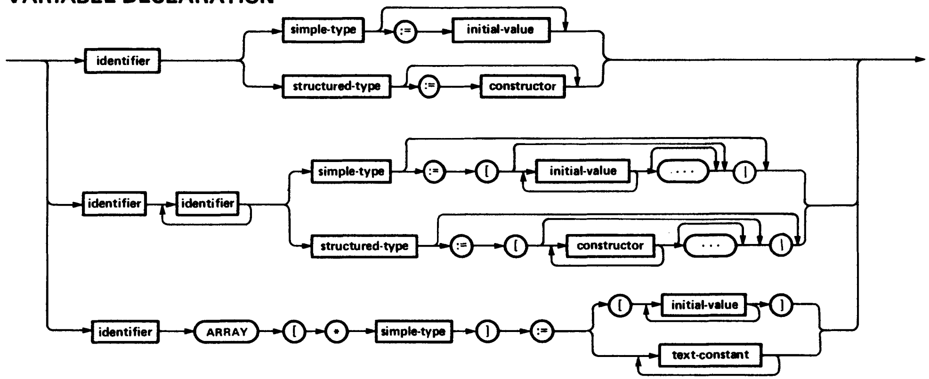
PARM-LIST



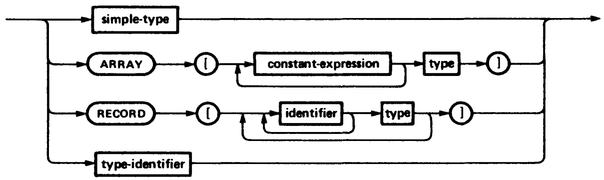
EXTERNAL-PARM-LIST



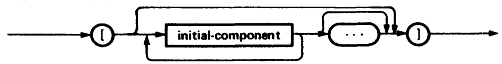
VARIABLE-DECLARATION



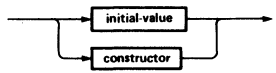
TYPE



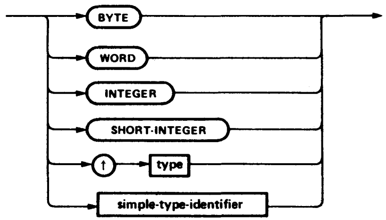
CONSTRUCTOR



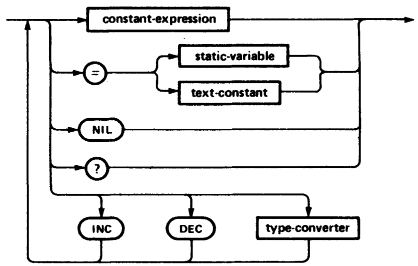
INITIAL-COMPONENT



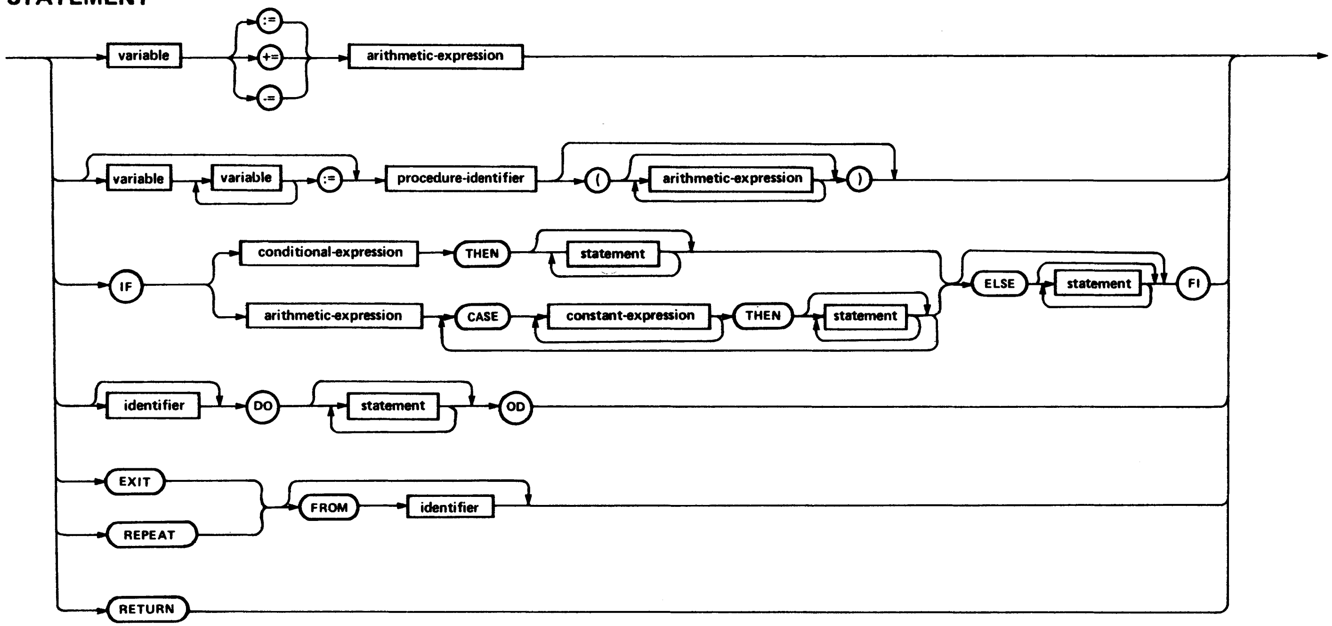
SIMPLE-TYPE



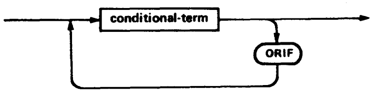
INITIAL-VALUE



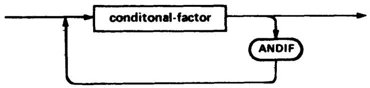
STATEMENT


variable
:=
+=
-=
arithmetic-expression
variable
variable
:=
procedure-identifier
(
arithmetic-expression
)
IF
conditional-expression
THEN
statement
arithmetic-expression
CASE
constant-expression
THEN
statement
ELSE
statement
FI
identifier
DO
statement
OD
EXIT
REPEAT
FROM
identifier
RETURN

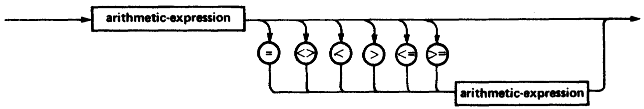
CONDITIONAL-EXPRESSION



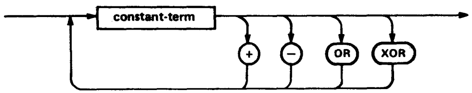
CONDITIONAL-TERM



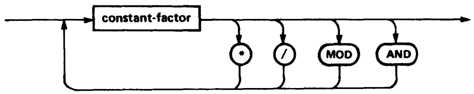
CONDITIONAL-FACTOR



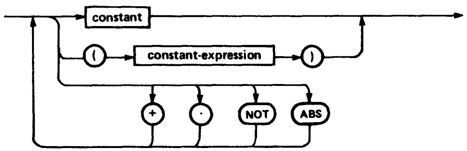
CONSTANT-EXPRESSION



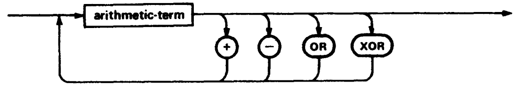
CONSTANT-TERM



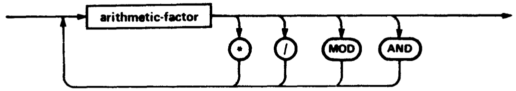
CONSTANT-FACTOR



ARITHMETIC-EXPRESSION



ARITHMETIC-TERM



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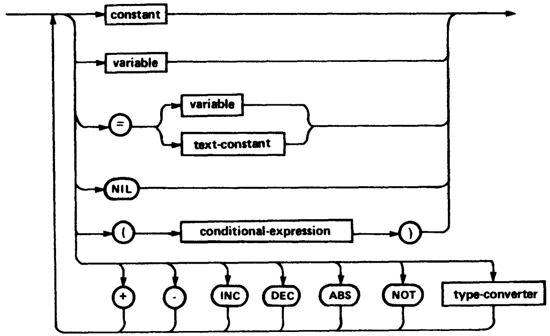
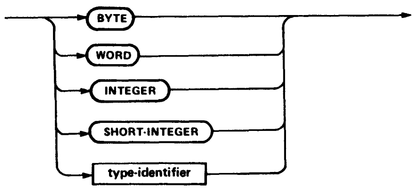
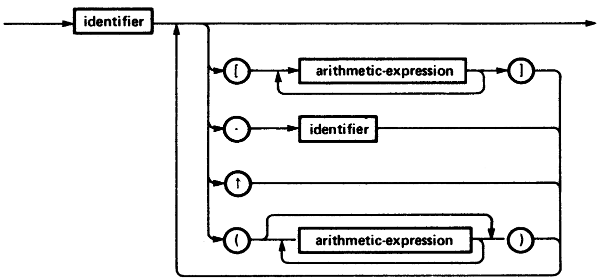


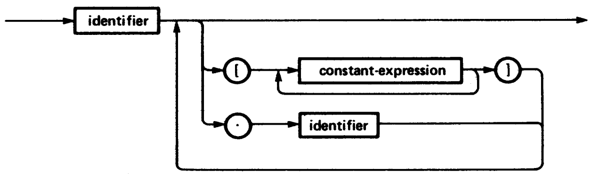
TYPE-CONVERTER



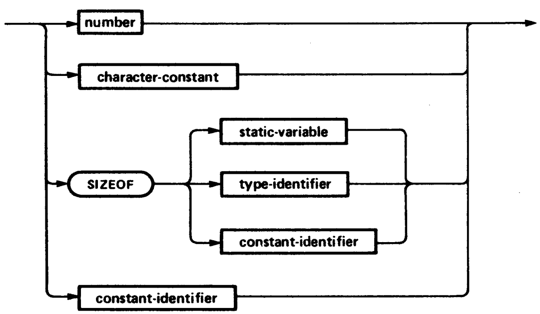
VARIABLE



STATIC-VARIABLE

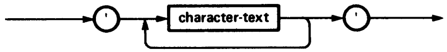


CONSTANT

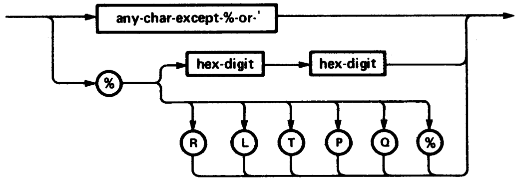


CHARACTER-CONSTANT

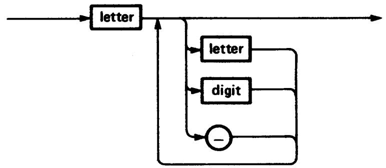
TEXT-CONSTANT



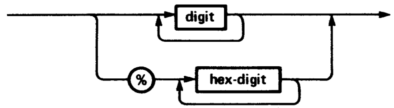
CHARACTER-TEXT



IDENTIFIER



NUMBER



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