PL/I Language

Programmer's Guide

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The PL/I Language Programmer's Guide was prepared using the Digital Research TEX-80 Text formatter and printed in the United States of America.

- First Edition: September 1982
- Second Edition: May 1983

Foreword

Digital Research PL/I is an implementation of PL/I based on American National Standard X3.74, PL/I General Purpose Subset (Subset G). Digital Research PL/I is a complete software development system for both applications and system programming.

Digital Research has implemented PL/I for both 8-bit and 16-bit microprocessors. At the source-code level, the 16-bit implementations are upward compatible with the 8-bit implementations.

Digital Research PL/I runs under any of the Digital Research family of operating systems. It also runs under the IBM Personal Computer Disk Operating System Version 1.1. This manual assumes you are already familiar with your operating system, and minimizes references to any specific system.

The PL/I Language Programmer's Guide is a tutorial introduction to the features and faculties of PL/I. It should be used in conjunction with the PL/I Language Reference Manual which is the formal specification of the language, its syntax and semantics.

This manual is divided into two parts. The first part, Sections 1 through 6, presents a brief introduction to the PL/I language, with emphasis on block structure, data types, and its various executable statements. Section 5 gives guidelines for developing a readable programming style. Section 6 explains the operation of the system as a whole, and introduces you to the mechanics of compiling, linking, and executing programs,

The second part, Sections 7 through 18, contains detailed sample programs that illustrate the useful facilities of the language, including Input/Output processing, string and list processing, scientific computation, and business applications. There is also a discussion about directly accessing certain routines in the Run-time Subroutine Library, and writing programs that use overlays. Each section presents general concepts, and then a detailed discussion of one or more example programs to illustrate the concepts.

The best way to learn any programming language is to study working examples. To learn PL/I, you should study these example programs along with the associated text, and cross-check the material with the PL/I Language Reference Manual when necessary. Once you understand the operation of a particular program, you can modify the program to enhance its operation and further your experience with the language.

Table of Contents

Tables, Figures, and Listings

Tables

Figures

Listings

1 Introduction

1.1 What is PL/I?

Digital Research PL/I is a programming language that you can use to write either applications or system-level programs. It is formally based on American National Standard X3.74, PL/I General Purpose Subset (Subset G). Subset G has the formal structure of the full language, but in some ways it is a new language, and in many ways an improved language compared to its parent.

Digital Research PL/I is easy to learn and use. It is a highly portable language because its design generally ensures hardware independence. It is also more efficient and cost effective, because programs written in PL/I are easier to implement, document, and maintain.

1.2 Using This Manual

This manual is designed to help you learn PL/I by studying sample programs. If you have never programmed in a structured, high-level language such as PL/I, you should read Sections 1 through 4 first. These sections provide you with a brief introduction to the language. PL/I has features that are similar to other programming languages, but it also has its own unique constructs and syntax.

Sections 1 through 4 outline the fundamental structure and features of PL/I in an informal and conceptual framework. This summary can help you become familiar with the overall capabilities of PL/I and encourage you to use its full power.

Sections I through 4 are not a complete tutorial on PL/I programming in general. If you find the overview is not sufficiently detailed, you might want to read some of the books listed in Appendix E of the PL/I Language Reference Manual. You should also refer to the material in Sections 1 through 4 of the PL/I Language Reference Manual.

If you are already an experienced PL/I programmer, you might want to begin with Section 6, which describes how to compile and link programs.

1.3 Notation

The following notational conventions appear throughout this document:

Words in capital letters are PL/I keywords or the names of PL/I programs that are described in the text.

Words in lower-case letters or in a combination of lower-case letters and digits separated by a hyphen represent variable information for you to select. These words are described or defined more explicitly in the text.

- Example statements are given in lower-case.
- The vertical bar | indicates alternatives.
- / represents a blank character.
- Square brackets [ ] enclose options.

- Ellipses … indicate that the immediately preceding item can occur once or any number of times in succession.

Except for the special characters listed above, all other punctuation and special characters represent the actual occurrence of those characters.

In text, the symbol CTRL represents a control character. Thus, CTRL-C means control-C. In a PL/I source program listing or any listing that shows example console interaction, the symbol represents a control character.

- The acronym BIF refers to one of the PL/I built-in functions
- Throughout this manual, program listings have brackets on the left side to illustrate and emphasize the block structure of the language.
- References to material in the PL/I Language Reference Manual are noted at the end of each section. The acronym LRM denotes Language Reference Manual. For example,

References: LRM Section 3.1.1

- In this manual, CP/M& refers to any of the Digital Research family of 8 and 16-bit operating systems. DOS refers to the IBM Personal Computer Disk Operating System Version 1.1.
- Listings of sample programs in this manual use the device names $CON and $LST. This is standard for CP/M. However, under a different operating system, the device names may be different. This does not affect the way the program runs.
- In this document, the use of color in examples denotes user interaction with the computer.

End of Section 1

2 The PL/I Language

Every PL/I program consists of one or more statements from three general categories:

- structural statements
- declarative statements
- executable statements

These categories are not mutually exclusive, but provide a convenient starting point. The following sections describe and illustrate the statements in each general category.

2.1 Structural Statements

Structural statements are the foundation of any program because they define the logical units in a program. These logical units are called blocks. When a program executes, control always flows from one logical unit to another. Logical units can contain other logical units, causing control to flow into and out of the units. You use structural statements to specify the hierarchical and logical structure in a program.

2.2 Declarative Statements

Declarative statements always occur in a logical unit defined by a structural statement, and determine the environment of a logical unit. The environment is the name and type of all the data variables available in a logical unit. Use declarative statements to specify the context of the variables you want to manipulate in a logical unit.

2.3 Executable Statements

Executable statements manipulate storage, transfer the flow of control between logical units, control the flow of data to and from I/O devices, and perform calculations. Both structural statements and declarative statements serve only to create a context for executable statements.

Listing 2-1 on the following page shows a PL/I program that illustrates statements from each category. You need not fully to understand the program or the syntax of each statement at this point, but you can see the program consists of distinct blocks of statements. Each block is a logical unit of control.

```
sample:
    procedure options(main);
    declare
        c character(10) varying;

    do;
        put skip list('Input: ')
        get list(c);
        c = upper(c); /* function reference
        put skip list('Output: ',c);
    end;
```

```
    begin;
        declare
            c float binary(24);

        put skip list('Input:
        get list(c);
        call output(c); /* subroutine invocation
    end;

    upper:
        procedure(c) returns(character(10) varying);
        declare
            c character(10) varying;

        return(translate(c,'ABCDEFGHIJKLMNOPQRSTUVWXYZ',
            'abcdefghijklmnopqrstuvwxyz'));
    end upper;

    output:
        procedure(c);
        declare
            c float binary(24);

        put skip edit(c) (column(20),e(10,2));
    end output;
end sample;
```

Listing 2–1. SAMPLE PL/I Program

Every PL/I program must have a main procedure block. Although you can separately develop and compile external procedures that can be linked to and called from a main procedure, there can be only one main procedure block in a program. In Listing 2-1, the first two statements, together with the last statement, determine the outermost, or main block of the program.

2.4 PL/I Blocks

In PL/I a block can have its own local environment, and possibly an environment inherited from a containing block. A containing block is any block that contains another block. For example, in Listing 2-1 the DO-group inherits the environment of the main procedure block. However, the BEGIN block has its own local environment, even though it is contained in the main procedure block.

In PL/I there are two types of blocks:

- PROCEDURE blocks
- BEGIN blocks

You can nest either type of block. This means that you can put one block inside another, but the blocks cannot overlap. The essential difference between a PROCEDURE block and a BEGIN block is the way that PL/I executes each block in the overall program.

PL/I executes BEGIN blocks as they are encountered in the normal sequence of statements in the program. A BEGIN block ends when its

corresponding END statement is encountered or when control passes outside the block. When control reaches a BEGIN block, the statements inside the block execute sequentially. Usually, when control leaves the block, it simply passes to a containing block or goes to the next sequential block.

PL/I ignores PROCEDURE blocks as they are encountered in the usual sequence of statements in the program. Control only passes to and enters a PROCEDURE block when the program invokes the procedure with a CALL statement or a function reference. A PROCEDURE block is active when the statements inside the block are executing. When the statements inside the procedure finish executing, the PROCEDURE block returns control to the point of the call.

For this reason, you can place a procedure anywhere in a program. It is good programming practice to put all procedures at the bottom of the main program. This makes debugging and maintaining a program easier.

2.5 Procedures

Every procedure consists of a procedure name, procedure header, the procedure body of zero or more statements, and an end statement. Figure 2-1 shows the components of the main procedure in the SAMPLE program.

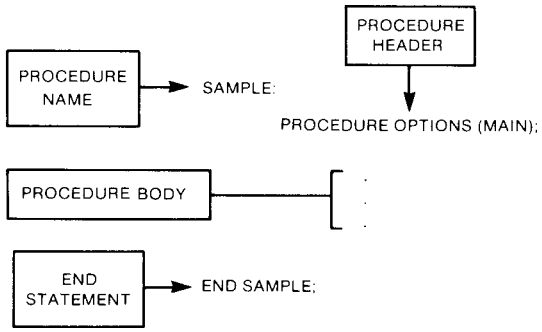


Figure 2–1. PL/I Procedure Components

If you nest procedures, they inherit the environment of containing blocks. However, any variable that you declare in a containing block can be redeclared, with local attributes, in the nested procedure.

There are two general types of procedures in PL/I:

- subroutine procedures
- function procedures

You use the CALL statement to invoke a subroutine procedure. A subroutine procedure performs a specific task, and optionally returns values to the invoking procedure.

You invoke a function procedure by making a function reference. A function reference is simply using the name of the function in a statement. PL/I evaluates the function reference and replaces it with a scalar value at the point of the reference.

Procedures are either internal or external in relation to the main procedure. An internal procedure is contained in the body of the main procedure, while external procedures are written and compiled

separately from the main program. To make an external procedure known to the main procedure, you must declare the procedure name as an entry constant (see Section 3.1.3). You must also link the external procedure to the main procedure after both are compiled. All the procedures in the SAMPLE program are internal to the main procedure.

2.6 DO-groups

The DO-group is similar to the BEGIN block. There are several forms of the DO-group, and they are executable statements because they influence the flow of control. However, they are also considered structural statements because they define logical units.

Listing 2-1 illustrates the simplest form of the DO-group. It looks like a BEGIN block, but there is a crucial difference. Although a DO-group binds all the statements in its body into one logical unit, it cannot define a new environment. A DO-group cannot define new variables whose environment is limited to the body of the DO-group.

A DO-group can bind only executable statements. However, a BEGIN block can bind both declarative statements and executable statements. The environment of a DO-group is determined by the environment of the block where it occurs.

References: LRM Sections 2.1 to 2.19, 8.1 to 8.2

End of Section 2

3 Declarations

You use declarative statements to specify the data items you want to manipulate with the executable statements in your program. PL/I has a rich variety of data types. In addition to arithmetic and string data, PL/I supports pointer, label, and entry data, which are generally not available in other languages. Table 3-1 shows the PL/I data types divided into categories and subcategories.

Category	**Subcategory**
Arithmetic	FIXED BINARY
	FLOAT BINARY
	FIXED DECIMAL
String	CHARACTER
	BIT
Control	Label Variable
	Label Constant
	Entry Variable
	Entry Constant
Pointer	POINTER
File	File Variable
	File Constant
Data Aggregates	Arrays
	Structures
Procedures	Subroutines
	Functions

Table 3–1 PL/I Data Types

All declarative statements specify either data constants or data variables. You must explicitly declare all data variables in a DECLARE statement, but data constants are usually declared implicitly by their occurrence in an executable statement. A PL/I variable is defined by an identifier name. The name can consist of up to thirty-one alphanumeric characters or underscores. The first character must be a letter.

Usually, declarative statements, whether explicit or implicit, result in a specific allocation of storage for the data item declared. The compiler determines the amount of storage required for the type of data, and associates the item with this storage. BASED variables are an exception because they do not necessarily force an allocation of storage (see Section 4.5).

3.1 Scalar Data

There are two main kinds of data: scalar, or single, data items, and aggregate, or multiple, data items. Scalar data types are the fundamental data types of the language.

3.1.1 Arithmetic Data

You use arithmetic data for direct numerical calculation. PL/I provides several types of arithmetic data, so you can match the data to the application.

3.1.1.1 FIXED BINARY

You can use FIXED BINARY data to represent integers. PL/I internally represents this data type in two's complement binary form. The precision of a FIXED BINARY number is the number of bits used to represent it, independent of the sign. PL/I uses from 1 to 15 bits, so it can represent integers in the range from -32768 to +32767.

3.1.1.2 FLOAT BINARY

You can use FLOAT BINARY data to represent very small or very large numbers. FLOAT BINARY data has a binary fractional part (called the mantissa) , a binary exponent, and a sign. PL/I supports both single-precision and double-precision FLOAT BINARY numbers. The precision of a FLOAT BI14ARY number is the number of bits in the mantissa.

Single-precision numbers can have from 1 to 24 bits, while the exponent part is always represented by 8 bits. The maximum range of single-precision FLOAT BINARY numbers in decimal is approximately 10-39 to 1038.

Double-precision numbers can have from 24 to 53 bits, while the exponent has 11 bits. The maximum range of double-precision FLOAT BINARY numbers in decimal is approximately 10-308 to 10 308

3.1.1.3 FIXED DECIMAL

You can use FIXED DECIMAL data to represent numbers with a fixed decimal point. You can also use FIXED DECIMAL data to represent integers. Internally, PL/I represents FIXED DECIMAL data in binary coded decimal (BCD) digits.

FIXED DECIMAL numbers have both a precision and scale factor. The precision is the total number of decimal digits used to represent the number. The scale factor is the number of decimal digits to the right of the decimal point.

In PL/I, the precision of a FIXED DECIMAL number can vary from one to fifteen, while the scale factor can vary from zero to fifteen. This arithmetic data type is particularly useful for commercial calculations, which require exact representations of dollars and cents and cannot accept the truncation errors of binary arithmetic.

You declare an arithmetic data variable in a declaration statement of one of the following forms, where p is the precision and q is the scale factor.

Statement:

```
DECLARE identifier FIXED BINARY[(p)];
```

Example:

```
declare index-counter fixed binary(7);
```

Statement:

```
DECLARE identifier FLOAT BINARY[(p)];
```

Example:

```
declare pi float binary(53);
```

Statement:

```
DECLARE identifier FIXED DECIMAL[(pf,ql)];
```

Example:

```
declare base_pay fixed decimal(5,2);
```

Note: The precision and scale factor are optional. If you omit them, PL/I supplies default values.

You should use binary arithmetic for most numerical work, because it is faster and uses the least storage. If you are doing scientific work, PL/I has a complete library of built-in mathematical functions which includes the trigonometric and the hyperbolic functions.

3.1.2 String Data

The ability to manipulate string variables is one of the most useful features of PL/I. PL/I has a complete set of built-in functions that you can use to manipulate string data. You declare a string variable to be either a bit string or a character string in a declaration of one of the following forms:

Statement:

```
DECLARE identifier CHARACTER[(n)];
```

Example:

```
declare alphabet character(26);
```

Statement:

```
DECLARE identifier CHARACTER[(n)] VARYING;
```

Example:

```
declare state character(20) varying;
```

Statement:

```
DECLARE identifier BIT[(n)];
```

Example:

```
declare flag bit(l);
```

The VARYING attribute means that the character string can vary in length, but cannot exceed the value of n. For CHARACTER variables, the value of n can be between 0 and 254. If you want to manipulate longer strings, you can use one-dimensional arrays.

Character-string constants are implicitly declared by their occurrence in a program. You indicate a character-string constant by enclosing it in single apostrophes. If you want to include an apostrophe in the string, you must precede it with an extra apostrophe. PL/I also allows you to include control characters in a character string.

The following are examples of character strings:

```
'Ada Lovelace'
'^g ^g Input Error'
'Can''t Read Previous Line'
```

Bit-string variables cannot have the VARYING attribute, and the length of a bit string cannot exceed sixteen. PL/I allows you to specify bit-string constants in several different formats. Each format corresponds

to a different base, which is the number of bits used to represent the item. The formats for bit-string constants are

- base 2 (B or B1 format)
- base 4 (B2 format)
- base 8 (B3 format)
- base 16 (B4 format)

In each of the formats, you write the bit-string constant as a string of numeric digits for the desired base, enclosed in single apostrophes and followed by the format type. The following are examples of the four formats:

```
'101111'B    equals 101111
'101111'B1   equals 101111
'233'B2      equals 101111
'57'B3 equals 101111
'2F'B4 equals 00101111
```

3.1.3 Control Data

There are two types of control data:

- LABEL data
- ENTRY data

LABEL data allows you to reference individual statements in your program. PL/I not only allows individual statements to have labels, it also allows you to declare label variables. This means that you can manipulate labels in your program like any other valid data items.

The value of a label variable is always a label constant, implicitly defined and declared by its occurrence as a label of a statement in the program. PL/I allows you to subscript label constants. You can also declare arrays of label variables.

You can use label variables to manipulate the flow of control between logical units of a program. It is good programming practice to do this without using GOTO'S and labels.

The following program is a whimsical example of label variables.

```
chase_your_tail:
    procedure options(main);
    declare
        wherever label;

    there:
        wherever = here;
    here:
        wherever = there;
    goto wherever;

end chase_your_tail;
```

Listing 3–1. Example of Label Variables

PL/I also supports a powerful data type called ENTRY data. ENTRY data allows you to reference procedures just like any valid data item. You

can declare an entry variable then assign it a value. The value of an entry variable is an entry constant.

Entry constants are the labels of procedures, rather than labels of executable statements. An entry constant is implicitly declared by its appearance as a label to an internal procedure.

When you declare an entry variable, you must explicitly define the type of entry constant that the variable can assume. When you explicitly declare an entry constant, you must declare it with the same attributes as the procedure it references.

The modules shown in Listing 3-1 illustrate these concepts. Listing 3-la shows an external procedure called a. Listing 3-lb shows the program CALL, that references a. In CALL, f is an entry variable that assumes three different constant values. To create a program, you compile each module separately then link them together.

```
procedure(x) returns(float); /* external procedure
    declare x float;
    return(x/2);
end a;
```

Listing 3–2 External Procedure A

```
call:
    procedure options(main);
    declare
        f(3) entry(float) returns(float) variable,
        a entry(float) returns(float); /* entry constant /*
    declare
        i fixed, x float;

    f(l) a;
    f(2) b;
    f(3) c;

    do i = 1 to 3;
        put skip list('Type X')
        get list(x);
        put list('f(',i,')=',f(i)(x));
    end;
    stop;

    b:
        procedure(x) returns(float); /* internal procedure
        declare x float;
        return (2*x + 1);
    end b;

    c:
        procedure(x) returns(float); /* internal procedure
        declare x float;
        return(sin(x));
        end c;

end call;
```

Listing 3–3 The CALL Program

3.1.4 Pointer Data

Pointer data allows you to manipulate the storage allocated to variables. The value of a pointer variable is the address of another variable.

3.1.5 File Data

File data items describe and provide access to the data associated with an external device. File data items are either file constants or variables. You must always assign a file constant to a file variable before you access the data in the file.

You declare file data in a declaration statement in one of the following forms:

Statement:

```
DECLARE identifier FILE;
```

Example:

```
declare current_transaction file;
```

Statement:

```
DECLARE identifier FILE VARIABLE;
```

Example:

```
declare f(2) file variable;
```

The executable statements used for file access determine the file attributes. (Section 4.3 describes file-handling and I/O operations.)

3.2 Data Aggregates

A data aggregate is a combination of data types that forms a data type on a higher level. There are two kinds of aggregates in PL/I:

- arrays
- structures

3.2.1 Arrays

An array is a subscripted collection of data items of the same data type. PL/I allows arrays of arithmetic values, character strings, bit strings, label constants, entry constants, pointers, files, or structures (see Section 3.2.2).

The following are examples of array declarations:

```
declare test_scores(100);
declare A(4,5);
declare A(1:4,2:5,0:10);
```

You make direct references to individual elements of an array by using a subscripted variable reference. PL/I also allows you to make cross-sectional references, with the restriction that the reference must specify a data component whose storage is connected. For example, using the following declarations:

```
declare A(5,2) fixed binary;
declare B(5,2) fixed binary;
```

you can visualize the arrays pictured in Figure 3-1:

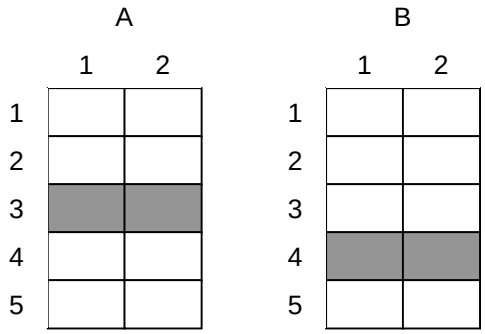


Figure 3–1. Arrays

In this example, A and B are identical in size and attributes. Therefore, an assignment such as

```
A(3) = B(4);
```

is valid because the cross-sectional reference specifies connected storage.

3.2.2 Structures

A structure is a very different type of data aggregate than an array. A structure is hierarchical, much like a tree, where the leaves of the tree, called nodes, can be various PL/I data types.

Each node of the tree, beginning with the root, has a name and a level number. The level number indicates the level of each node in relation to the root. The following example illustrates a structure declaration.

```
declare
    1 employee,
        2 name address,
            3 name,
                4 first character(10),
                4 middle initial character(l),
                4 last character(20),
            3 address,
                4 street character(40),
                4 city character(10),
                4 state character(2),
                4 zip_code character(5),
        2 position,
            3 department no character(3),
            3 job - title character(20),
        2 salary fixed decimal(8,2),
        2 number_of_dependents fixed,
        2 health_plan bit(l),
        2 date-hired character(B);
```

Listing 3–4. Example Structure Declaration

Figure 3-2 illustrates the hierarchy of levels that corresponds to the declaration.

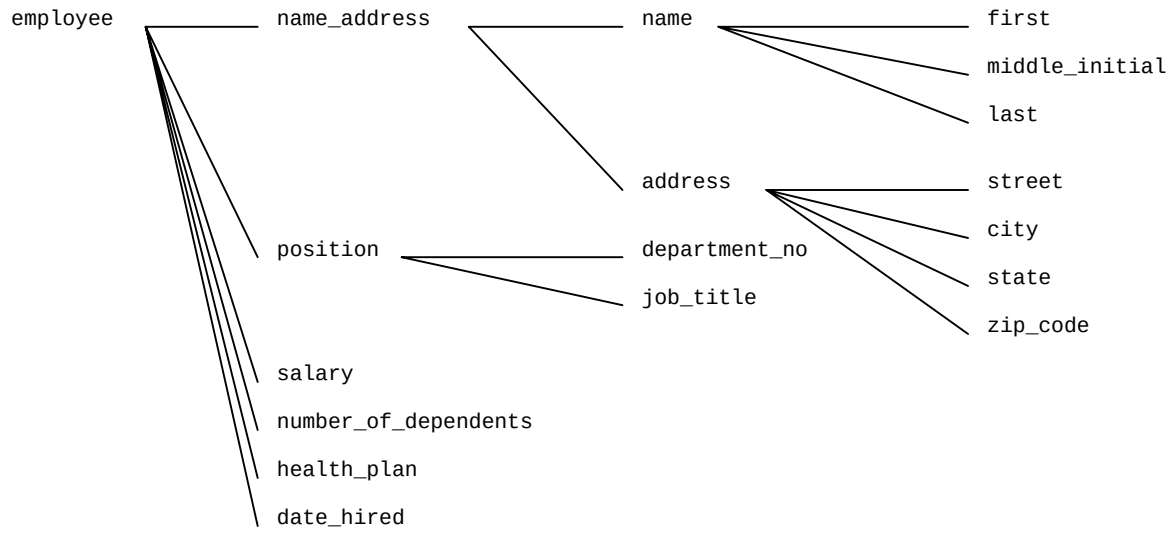


Figure 3–2. Structure Declaration Hierarchy

Nodes on each level can also determine a structure. Such a substructure is a member of the main structure. You can give the BASED attribute to the main structure with the result that all the members of the structure receive the attribute.

Structures are powerful tools because they enable you to group logically related data items that might not have the same data type. Thus, structures allow you to characterize and manipulate logical objects in your program to more closely resemble real data.

References: LRM Sections 3.1 to 3.6, 5.1 to 5.5

End of Section 3

4 Executable Statements

The category of executable statements is divided into several subcategories based on the type of function that the statement performs. The subcategories are

- assignment statements
- sequence control statements
- I/O and file-handling statements
- memory management statements
- condition processing statements
- preprocessor statements
- null statements

4.1 Assignment Statements

An assignment statement places the value of an expression into the storage location associated with a variable.

An expression is a combination of operators, operands, function references, and parentheses that control the order of evaluation of the expression.

In PL/I, the assignment statement has the form:

```
variable reference = expression;
```

An expression in PL/I can be fairly complicated. The simplest type of variable reference is instantiating the variable name, which means to assign the variable a specific value. A variable reference can also be a reference to a data aggregate, or to a component of the aggregate. If the variable is BASED, a pointer-qualified reference might be required (see Section 4.5.1).

PL/I also allows certain built-in functions such as UNSPEC and SUBSTR to appear as targets on the left side of assignment statements. When they appear as variables in this context, they are called pseudo-variables.

Expressions can be computational. This means that the expression involves arithmetic or string values of the various types and their respective operators. Expressions can also be noncomputational, involving comparisons of noncomputational data types such as labels, entry constants, and pointers.

PL/I allows computational expressions of different data types, and automatically performs conversion between the various types following a standard set of default rules. You should become familiar with the automatic conversion rules and the properties of the built-in conversion functions (see Section 4 LRM).

The following sequence of code illustrates some simple examples of assignment statements. These examples also illustrate some of the ways you can reference a variable in PL/I. Such references can also occur in expressions, although PL/I limits aggregate expressions to comparison for equality.

```
assign:
    procedure options(main);
    declare
        p pointer,
        i fixed binary(7),
        r bit(16),
        s bit(16) based,
        (u,v) float binary(24),
        A(5,2) character(2),
        B(5,2) character(2),
        C character(20),
        1 W,
            2 x fixed binary,
            2 y bit(16),
        1 Z,
            2 x fixed binary,
            2 y bit(16);

    u = u + V; /* simple assignment
    A = B; /* array aggregate assignment
    A(3) = B(3); /* cross-sectional reference
    w   z; /* structure aggregate assignment
    p       s = (r = w.y); /* pointer-qualified reference
    W.x = W.x + Z.X; /* partially-qualified aggregate reference
    unspec(w.y) = unspec(A(5,1)); /* pseudo-variable reference
    substr(C,i+1,3) = substr(C,10,3); /* pseudo-variable reference
    A(2*i+l) BM; /* variable is expression

end assign;
```

Listing 4–1. Simple Examples Of Assignment Statements

4.2 Sequence Control Statements

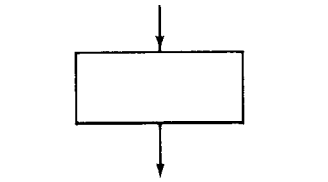
You can use sequence control statements to alter the normal sequential flow of control. In PL/I, sequence control statements perform unconditional branching, conditional branching, iteration, branch and return through procedure invocation, and a more unique construct called condition processing.

4.2.1 Iteration

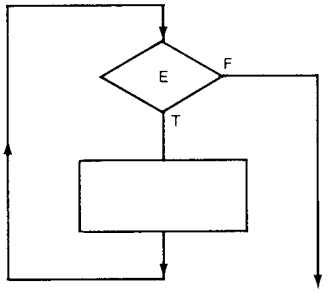
PL/I provides an extensive variety of iteration control in the various forms of the DO statement. For example, you can perform iteration not only with an arithmetic control variable, but also with a pointer control variable that is moving through a linked list of pointers.

The following diagrams illustrate the basic forms of the DO statement and the flow of control that they induce. The values e1, e2, e3, and e4 represent any scalar expressions.

```
DO;
  .
  .
  .
END;
```



```
DO WHILE(e);
     .
     .
     .
END;
```




```
DO i = el REPEAT(e2);
    .
    .
    .
END;
```

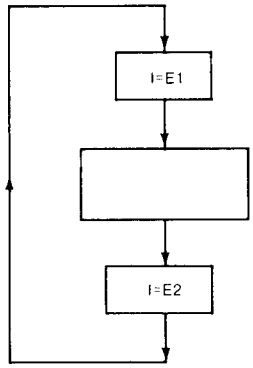
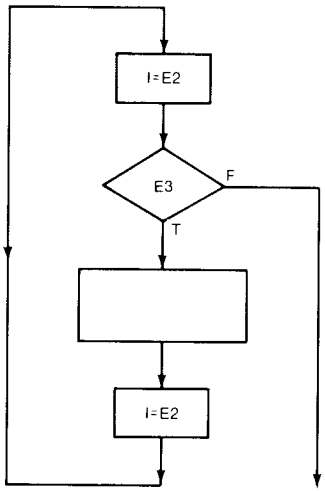


Figure 4–1. Forms of the DO Statement

```
DO i = el REPEAT(e2) WHILE(e3);
   .
   .
   .
END;
```




```
DO i = el TO e2 BY e3 WHILE(e4);
   .
   .
   .
END;
```

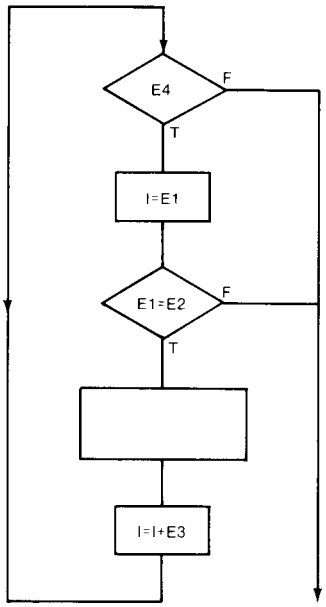


Figure 4-1. (continued)

4.2.2 Procedure Invocation

A branch and return occurs as the result of a procedure invocation. As we have seen, in PL/I there are two types of procedures: subroutine procedures and function procedures. There are two corresponding forms of invocation.

You invoke a subroutine procedure with a CALL statement, but you invoke a function procedure by using its name in an expression. You call a subroutine procedure for a specific reason, such as altering the value of variables passed to the procedure, or input and output. You always invoke a function procedure in an expression to return a scalar data item. In PL/I, both types of procedures can be recursive, which means they can call themselves.

There is an important distinction between a procedure definition and a procedure invocation. A procedure definition is a declarative statement; a procedure invocation is an executable statement. The data items you pass to the procedure when you invoke it are called the arguments. The arguments are distinguished from the parameters you give in the procedure definition. Thus, the arguments are the parameters as they are known in the invoking block, while the parameters are the corresponding parameters as they are known in the invoked block, the procedure.

4.2.3 Parameter Passing

In PL/I, you can pass parameters by reference or by value. You pass them by reference if the arguments and the parameters share storage. You pass them by value if the value of the parameter is held as a local copy of the value of the argument.

Under PL/I rules, the parameter and argument always share storage if they have identical attributes. If the argument is an expression, or if its data attributes do not match those of the corresponding parameter, then the parameter is passed by value. PL/I passes the parameter by value if you enclose the parameter in parentheses in the procedure header statement of the procedure definition.

A procedure is an independent logical unit that performs a specific function. If you carefully define the specific function that the procedure performs and the parameters that it expects from the invoking environment, you can divide the design, coding, and debugging of the overall program into separate units.

If you pass a parameter by reference to conserve storage, be aware that the invoked procedure can change the value of a variable outside its local environment. If you want to assure that the procedure does not change a variable outside its local environment, then you must pass the parameters by value and use extra storage.

Parameter passing is a trade-off between the amount of storage available on your system and the level of modularity and isolation you want in your program. There are three alternatives for parameter passing, characterized as the high, middle, and low road. The skeletal program in Listing 4-1 illustrates the concepts they represent.

In the low road, you pass by reference but pay close attention to the possible side effects that can result. The advantage of this method is that it conserves storage.

In the middle road, you pass by value, enclosing the argument in parentheses at the point of invocation in the CALL statement or function reference.

In the high road, you declare a duplicate variable for each parameter in the procedure definition. You then assign the corresponding parameter to its duplicate, and use the duplicate as a local copy in the procedure. Equally you can enclose the parameter in parentheses in the procedure header. The high road is least efficient in its use of storage.

```
main:
    procedure options(main);
    declare
```

```
        a float binary;

    call low-sub(a); /* pass by reference
    call middle-sub((a)); /* pass by value
    call high-sub(a); /* pass by reference

    low sub:
        procedure(x);
        declare
            x float binary;

    end low-sub;

    middle-sub:
        procedure(x);
        declare
            x float binary;

    end middle-sub;

    high_sub:
        procedure(x);
        declare
            (x,my_x) float binary;
        my-x = x; /* reassign using local variable

    end high_sub;
end main;
```

Listing 4–2. Parameter Passing

4.2.4 Conditional Branch

PL/I provides a conditional branch in the form of an IF statement. The conditional branch has one of the following forms:

```
IF condition THEN group
IF condition THEN group-1 ELSE group-2
```

where the condition is a scalar expression that PL/I evaluates and reduces to a single value, and the groups are either single statements, DO-groups, or BEGIN blocks.

You can nest IF statements, in which case PL/I matches each ELSE with the innermost unmatched IF-THEN pair. However, you can use null statements following an ELSE to force an arbitrary matching of ELSE statements with IF-THEN pairs. (See Section 4.7, "Null Statements.")

4.2.5 Unconditional Branch

PL/I provides an unconditional branch in the form of a GOTO statement. The unconditional branch has one of the forms:

```
GOTO  label constant;
GOTO  label-variable;
```

Because PL/I is block-structured, certain rules apply to the use of the GOTO. The target label must be in the same block containing the GOTO, or in a containing block. You cannot transfer control to an inner block.

4.3 I/O and File-handling Statements

The executable I/O statements provide PL/I with a device- independent input/output system that allows a program to transmit data between memory and external devices. To understand the I/O statements, you must first know about files and their attributes.

The collection of data elements that you transmit to or from an external device is called the data set. The corresponding internal file constant or variable is called a file.

As with other data items, you must declare files before you use them in a program. A file declaration has the form:

```
DECLARE file-id FILE [VARIABLE];
```

where file id is the file identifier. If you do not include the optional 7VARIABLE attribute, the declaration defines a file constant. With the VARIABLE attribute, the declaration defines a file variable that can take on the value of a file constant through an assignment statement. You must assign a file constant to a file variable before you can perform any I/O operations.

4.3.1 Opening Files

PL/I requires that a file be open before performing any I/O operations on the data set. You can open a file explicitly by using the OPEN statement, or implicitly by accessing the file with the following I/O statements:

- GET EDIT
- PUT EDIT
- GET LIST
- PUT LIST
- READ
- WRITE
- READ Varying
- WRITE Varying

The general form of the OPEN statement is

```
OPEN FILE(file-id) [file-attributes];
```

where file-id is the file identifier that appears in a FILE declaration statement, and file-attributes denotes one or more of the following:

- STREAM RECORD
- PRINT
- INPUT/OUTPUT/UPDATE
- SEQUENTIAL/DIRECT
- KEYED
- TITLE

- ENVIRONMENT
- PAGESIZE
- LINESIZE

Multiple attributes on the same line are conflicting attributes, so you can only specify one attribute. The first attribute listed is the default attribute. All the attributes are optional; you can specify them in any order.

A STREAM file contains variable length ASCII data. You can visualize it as a stream of ASCII character data, organized into lines and pages. Each line in a STREAM file is determined by a linemark, which is a line-feed or a carriage return/line-feed pair. Each page is determined by a pagemark, which is a form-feed. Generally, you must convert the data in a STREAM file from character form to pure binary form before using it. Some text editors automatically insert a line-feed following each carriage return, but files that PL/I creates can contain line-feeds without preceding carriage returns. In this case, PL/I senses the end of the line when it encounters the line-feed.

A RECORD file contains binary data. PL/I accesses the data in blocks determined by a declared record size, or by the size of the data item you use to access the file. A RECORD file must also have the KEYED attribute, if you use FIXED BINARY keys to directly access the fixed-length records.

The PRINT attribute applies only to STREAM OUTPUT files. PRINT indicates that the data is for output on a line printer.

For an INPUT file, PL/I assumes that the file already exists when it executes the OPEN statement. When it executes the OPEN statement for an OUTPUT file, PL/I also creates the file. If the file already exists, PL/I first deletes it, then creates a new one.

You can read from and write to an UPDATE file. PL/I creates an UPDATE file, if it does not exist, when executing the OPEN statement. An UPDATE file cannot have the STREAM attribute.

You access SEQUENTIAL files sequentially from beginning to end, but you access DIRECT files randomly using keys. PL/I automatically gives DIRECT files the RECORD attribute. PL/I also requires you to declare all UPDATE files with the DIRECT attribute, so you can locate the individual records.

A KEYED file is simply a fixed-length record file. The key is the relative record position of the record within the file based upon the fixed record size. You must use keys to access a KEYED file. PL/I automatically gives KEYED files the RECORD attribute.

The TITLE(c) attribute defines the programmatic connection between an internal filename and an external device or a file in the operating system's file system. If you omit the TITLE attribute, PL/I assigns the default title file id.DAT, where file-id is the file identifier specified in the OPFFN statement.

The character string c can specify a physical device such as a console or printer (see Section 10.2, LRM) . If the character string c specifies a disk file, it must be in the form,

```
d:filename.typ;password
```

where the drive code d, the filetype, and the password are all optional. You must specify a filename. The filename cannot be an ambiguous wildcard reference.

You can also specify $1 or $2 for both the filename and filetype. $1 gets the first default name from the command line, $2 gets the second default name.

The ENVIRONMENT attribute defines fixed record sizes for RECORD files, internal buffer sizes, the file open mode, and the level of password protection. You can open a file in one of three modes: Locked, Read-Only, or Shared. Locked is the default mode, and means that no other user can access the file while it is open. Read-Only means that other users can access the file, but only to read it.

Shared mode means that other users can also simultaneously open and access the file. You can use the built-in LOCK and UNLOCK functions to lock and unlock individual records in the file, so there are no collisions with other users.

If you assign a password to a file, you can also assign the level of protection that the password provides. The levels of protection are: Read, Write, and Delete. Read means that you must supply the password to read the file. Write means that you can read the file, but you must supply the password to write to the file. Delete means that you can read the file or write to it, but you cannot delete the file without the password.

Note: File password protection and record locking/unlocking for individual records is not available in all implementations. See Appendix A in the LRM.

The LINESIZE attribute applies only to STREAM files, and defines the maximum number of characters in the input or output line length. The PAGESIZE attribute applies only to STREAM OUTPUT files, and defines the number of lines per page on output.

4.3.2 File Attributes

PL/I controls all file transactions through an internal data structure called the File Parameter Block (FPB). The FPB contains information about the file, such as whether it is open or closed, the external device or file associated with the file, the current line and column, or record being accessed, and the internal buffer size. The FPB also contains a File Descriptor that describes the file's attributes. These attributes in turn describe the allowable methods of access. Table 4-1 summarizes the valid attributes that you can assign to a file, either through an explicit OPEN statement, or implicitly by an I/O access statement.

Table 4–1 PL/I Valid File Attributes

STREAM INPUT ENVIRONMENT TITLE LINESIZE
STREAM OUTPUT ENVIRONMENT TITLE LINESIZE PAGESIZE
STREAM OUTPUT PRINT ENVIRONMENT TITLE LINESIZE PAGESIZE
RECORD INPUT SEQUENTIAL ENVIRONMENT TITLE
RECORD OUTPUT SEQUENTIAL ENVIRONMENT TITLE
RECORD INPUT SEQUENTIAL KEYED ENVIRONMENT TITLE
RECORD OUTPUT SEQUENTIAL KEYED ENVIRONMENT TITLE

RECORD INPUT DIRECT KEYED ENVIRONMENT TITLE
RECORD OUTPUT DIRECT KEYED ENVIRONMENT TITLE
RECORD UPDATE DIRECT KEYED ENVIRONMENT TITLE

4.3.3 Implied Attributes

If you do not open a file with explicit attributes, PL/I determines the attributes from the type of I/O statement you use to access the file. Table 4-2 summarizes the attributes implied by each of the I/O statements. In the following table, f is a file constant, x is scalar or aggregate data type that is not CHARACTER VARYING, and k is a FIXED BINARY key value.

Table 4–2 File Attributes Associated With I/O Access

I/O Statement	Implied Attributes
GET FILE(f) LIST	STREAM INPUT
PUT FILE(f) LIST	STREAM OUTPUT
GET FILE(f) EDIT	STREAM INPUT
PUT FILE(f) EDIT	STREAM OUTPUT
READ FILE(f) INTO(v)	STREAM INPUT
WRITE FILE(f) FROM(v)	STREAM OUTPUT
READ FILE(f) INTO(x)	RECORD INPUT SEQUENTIAL
READ FILE(f) INTO(x) KEYTO(k)	RECORD INPUT SEQUENTIAL KEYED ENVIRONMENT(Locked,Fixed(i))
READ FILE(f) INTO(x) KEY(k)	RECORD INPUT DIRECT KEYED ENVIRONMENT(Locked,Fixed(i)) RECORD UPDATE DIRECT KEYED ENVIRONMENT(Locked,Fixed(i))
WRITE FILE(f) FROM(x)	RECORD OUTPUT SEQUENTIAL
WRITE FILE(f) FROM(x) KEYFROM(k)	RECORD OUTPUT DIRECT KEYED ENVIRONMENT(Locked,Fixed(i)) RECORD UPDATE DIRECT KEYED ENVIRONMENT(Locked,Fixed(i))

4.3.4 Closing Files

The CLOSE statement disassociates the file from the external data set. The form of the CLOSE statement is

```
CLOSE FILE(file-id);
```

where file id is a file constant for which PL/I clears the internal buffers, records all the data on the disk, and closes the file at the operating system level. You can subsequently reopen the same file using the OPEN statement. PL/I automatically closes all open files at the end of the program or upon execution of a STOP statement.

4.3.5 File Access Methods

PL/I supports two methods of file access:

- STREAM I/O
- RECORD I/O

There are three different kinds of STREAM I/O:

- LIST-directed uses the GET LIST and PUT LIST statements, which transfer a list of data items without any format specifications.
- Line-directed uses the READ and WRITE statements, which allow you to access variable-length CHARACTER data in an unedited form. These statements might not be available in other implementations of PL/I.
- EDIT-directed uses the GET EDIT and PUT EDIT statements, which allow formatted access to character data items.

EDIT-directed I/O is similar to list-directed I/O except that it writes data into particular fields of the output line, as described by a list of format items. The data list specifies a number of values to write in fixed fields defined by the format-list.

The format-list can contain two kinds of format items: data format items and control format items. PL/I pairs each element of the data list with an item in the format-list. The format item determines how PL/I interprets the data element. PL/I executes control format items as they are encountered in the format-list.

You can precede any format item with a positive integer constant value, not exceeding 254, that determines the number of times to apply the format item or group of format items.

4.3.6 Data Format Items

The following examples show the various format items you can use in a GET EDIT or PUT EDIT statement.

A[(w)]

The A format reads or writes the next alphanumeric field whose width is specified by w, with truncation or blank padding on the right. If you omit w, the A format uses the size of the converted character data as a field width.

B[n1[(w)]

The B format reads or writes bit-string values. n is the number of bits used to represent each digit. w is the field width that you must include on input.

E(w[,d])

The E format reads or writes a data item into a field of w characters in scientific notation, with maximum precision allowed in the field width. w must be at least 8.

F(w[,d])

The F format reads or writes fixed-point arithmetic values with a field width of w digits, and d optional digits to the right of the decimal point.

4.3.7 Control Format Items

LINE(ln)

Moves to the line specified by ln in the data stream before writing the next data item.

COLUMN(nc)

Moves to column position specified by nc in the data stream before reading or writing the next data item. This can flush the current line.

PAGE

Performs a page eject for PRINT files.

SKIP[(nl)]

Skips nl lines before reading or writing the next data item.

X(n)

Advances n blank characters into the data stream before reading or writing the next data item.

R(fmt)

Specifies a remote format. This means that the format is specified elsewhere in a FORMAT statement.

4.3.8 Predefined Files

PL/I has two predefined file constants called SYSIN, the console keyboard, and SYSPRINT, the console output display. These files do not need to be declared unless you make an explicit reference to them in an OPEN or I/O statement.

SYSIN has the default attributes:

```
STREAM INPUT ENVIRONMENT(Locked,Buff(128)) TITLE('$CON') LINESIZE(80)
PAGESIZE(0)
```

SYSPRINT has the default attributes:

```
STREAM PRINT ENVIRONMENT(Locked,Buff(128)) TITLE('$CON') LINESIZE(80)
PAGESIZE(0)
```

4.4 Condition-processing Statements

PL/I has several features that make it ideal for applications programming. One of these features is its capability for condition processing. In most languages, the program cannot recover from run time error conditions, such as an invalid data conversion—control reverts to the operating system.

PL/I has various features that allow you to intercept run-time errors, program a response, and recover control. These features are collectively called condition processing.

PL/I provides condition processing with these executable statements:

- ON
- REVERT
- SIGNAL

4.4.1 The ON Statement

You use the ON statement to intercept and program a response to a run-time condition signaled by the system, or by the execution of a SIGNAL statement. The ON statement is an executable statement that defines the response. It has the form:

```
ON condition-name on-body;
```

where condition-name is one of the major condition categories, with or without a subcode (see Section 4.4.4). The on-body is a PL/I statement or statement group that you process when the condition occurs.

If the subcode is not present, then PL/I processes the ON statement when any of the subcode conditions occur. This is equivalent to subcode 0. The file conditions must have a file reference describing the file for which the condition is signaled.

4.4.2 The REVERT Statement

You use the REVERT statement to disable the ON condition set by the ON statement. This is important because you can have only sixteen ON conditions set without overflowing the condition code area. If overflow happens, the PL/I run-time system stops processing. The form of the REVERT statement is

```
REVERT condition-name;
```

PL/I automatically reverts an ON condition set in a given block when control leaves the environment of that block.

4.4.3 The SIGNAL Statement

The SIGNAL statement allows you to activate the response for a condition. The form of the SIGNAL statement is

```
SIGNAL condition-name;
```

4.4.4 Condition Categories

The condition categories describe the various conditions that the run-time system can signal or that your program can signal by executing a SIGNAL statement.

There are nine major condition categories with subcodes, some of which are system-defined, and some of which you can define yourself. Table 4-3 shows the predefined subcodes.

Table 4–3 PL/I Condition Categories and Subcodes

Type	**Meaning**
ERROR	
ERROR(0)	Any ERROR subcode
ERROR(l)	Data conversion
ERROR(2)	I/O Stack overflow
ERROR(3)	Function argument invalid
ERROR(4)	I/O Conflict
ERROR(5)	Format stack overflow
ERROR(6)	Invalid format item
ERROR(7)	Free space exhausted
ERROR(8)	Overlay error, no file
ERROR(9)	Overlay error, invalid drive
ERROR(10)	Overlay error, size
ERROR(11)	Overlay error, nesting

Type	Meaning
ERROR(12)	Overlay error, disk read error
ERROR(13)	Invalid OS call
ERROR(14)	Unsuccessful Write
ERROR(15)	File Not Open
ERROR(16)	File Not Keyed
FIXEDOVERFLOW	
FIXEDOVERFLOW(0)	Any FIXEDOVERFLOW subcode
OVERFLOW	
OVERFLOW(0)	Any OVERFLOW subcode
OVERFLOW(l)	Floating-point operation
OVERFLOW(2)	Float precision conversion
UNDERFLOW	
UNDERFLOW(0)	Any UNDERFLOW subcode
UNDERFLOW(l)	Floating-point operation
UNDERFLOW(2)	Float precision conversion
ZERODIVIDE	
ZERODIVIDE(0)	Any ZERODIVIDE subcode
ZERODIVIDE(l)	Decimal divide
ZERODIVIDE(2)	Floating-point divide
ZERODIVIDE(3)	Integer divide
ENDFILE	
UNDEFINEDFILE	
KEY	
ENDPAGE	

In addition to these predefined system condition subcodes, you can define certain subcodes for a specific application, test for the desired condition, and then use the SIGNAL statement to signal the condition.

4.4.5 Condition Processing Built-in Functions

PL/I provides certain built-in functions to help handle conditions when they occur. These functions are

- ONCODE
- ONFILE
- ONKEY
- PAGENO
- LINENO

The ONCODE function returns the subcode of the most recently signaled condition, or zero if no condition has been signaled.

The ONFILE function returns the internal filename of the file involved in an I/O operation that signaled a condition.

The ONKEY function returns the value of the last key involved in an I/O operation that signaled a condition.

The PAGENO and LINENO functions return the current page number and line number for a PRINT file named as the parameter.

4.5 Memory Management Statements

Every variable in a PL/I program has a storage-class attribute. The storage class determines how and when PL/I allocates storage for a variable, and whether the variable has its own storage or shares storage with another variable.

PL/I supports four different storage classes:

- AUTOMATIC (the default in PL/I)
- BASED
- PARAMETER
- STATIC

PL/I treats AUTOMATIC storage as STATIC storage, except in procedures marked as RECURSIVE. The compiler allocates storage for STATIC variables prior to execution, and the storage remains allocated as long as the program is running. You can use the INITIAL attribute to assign initial constant values to STATIC data items.

If a variable appears in a parameter list, the compiler assigns it the PARAMETER storage class. Storage for parameters is allocated by the calling procedure when it passes the parameters to the called procedure. (See Appendix A in the LRM.)

Note: Only STATIC variables can have the INITIAL attribute, to be compatible with the ANSI Subset G PL/I standard.

Storage-class attributes are properties of scalars, arrays, major structure variables, and file variables. You cannot assign storage class attributes to entry names, file constants, or members of data aggregates.

4.5.1 BASED Variables and Pointers

The compiler does not allocate storage for variables with the BASED storage class. A based variable is a variable that describes storage that you must access with a pointer. The pointer is the location where the storage for the based variable begins, and the based variable itself determines how PL/I interprets the contents of the storage beginning at that location. Thus, the pointer and the based variable taken together are essentially equivalent to a nonbased variable.

You can visualize a based variable as a template that overlays the storage specified by its base. Thus, a based variable can refer to storage allocated for the based variable itself, or to storage allocated for other variables.

The format of the BASED variable declaration is

```
DECLARE name BASED[(pointer-reference)];
```

For example,

```
      declare A(5,5) character(10) based;
      declare bit-vector bit(8) based(p);
```

where the pointer reference is an unsubscripted POINTER variable, or a function call, with zero arguments, that returns a POINTER value.

A pointer-qualified reference can be either implicit or explicit. When you declare a variable as BASED without a pointer reference, then each reference to the variable in the program must include an explicit pointer qualifier of the form:

```
pointer-exp -> variable
```

When you declare a variable as BASED with a pointer reference, then you can reference it without a pointer qualifier. The run-time system reevaluates the pointer reference at each occurrence of the unqualified variable using the pointer expression given in the variable declaration.

The following code sequence illustrates the concept of based variables.

```
declare
      p pointer,
      a character(128),
      b(128) character(l) based(p),
      c(0:127) bit(8) based(p),
      d(64) bit(16) based(p),
      e(8,0:15) bit(8) based(p);

p = addr(a);
```

In this example, after pointer p is set to the address of a, each of the variables b, c, d, and e refers to the same 128 bytes of storage occupied by the variable a, although they do so in different ways. Thus, the variables b, c, d, and e overlay the variable a.

There is one important point to consider here. The overlays illustrated above depend on the method a particular processor uses to internally represent and store the data items. Such code makes a program implementation-dependent. For example, in implementations other than PL/I, the internal representation of an array could include some header bytes in addition to the bytes used to represent the data elements. In each case, you must investigate the internal representation before using based variables to overlay other data types.

4.5.2 The ALLOCATE Statement

The ALLOCATE statement explicitly allocates storage for a BASED variable. The ALLOCATE statement takes the form:

```
ALLOCATE based variable SET(pointer variable);
```

For example,

```
allocate input_buffer set(buffer_ptr);
```

The run-time system obtains sufficient memory for the based variable from the free storage area and then sets the pointer variable to the address of this memory segment.

4.5.3 The FREE Statement

The FREE statement releases the storage allocated to a BASED variable. The FREE statement takes the form:

```
FREE [pointer variable] based variable;
```

For example,

```
free inputbuffer;
```

Note: The pointer variable reference is optional if you declared the based variable with a pointer reference.

The following code sequence illustrates the use of the ALLOCATE and FREE statements.

```
declare
    (p,q,r) pointer,
    a character based,
    b fixed based(r);

allocate a set(p);
allocate b set(r);
allocate a set (q)

free p a;
free q a;
free b;
```

4.6 Preprocessor Statements

Preprocessor statements allow you to include other files and modify the source program at compile time.

The %INCLUDE statement copies PL/I source from another file at compile time. The %INCLUDE statement is useful for filling in declarations that are repeated throughout a program. The %INCLUDE statement takes the form:

```
%INCLUDE 'filespec';
```

For example,

```
%include 'fcb.dcl';
```

The %REPLACE statement allows you to replace identifiers by literal constants throughout the text of a PL/I program at compile time. The %REPLACE statement takes the form:

```
%REPLACE identifier BY literal constant;
```

You can put more than one identifier-constant pair in a single %REPLACE statement by separating the pairs with commas.

For example,

```
%replace
true by '1'b,
false by '0'b;
```

4.7 Null Statements

The null statement does not perform any action. Its form is simply:

You can use the null statement as the target of a THEN or ELSE clause in an IF statement. In the following example,

```
if x > average then
       goto print_it;
else;
```

no action takes place when x is less than or equal to average, and the sequence of execution continues at the statement following the ELSE. As another example, consider this statement:

```
on endpage(report-file);
```

Here, no action takes place when PL/I processes the ON-unit for ENDPAGE, and the I/O statement that signaled the condition continues.

You can also use null statements to give more than one label to the same executable statement. For example,

```
A:;
B: statement-1;
statement-2;
```

References: LRM Sections 2.7 to 2.9, 2.15, 7, 8, 9, 10.1 to 10.3, 10.7 to 10.8, 11.1, 11.3

End of Section 4

5 Programming Style

PL/I is a free-format language. You can write programs without regard to column positions and specific line formats. Each line can be up to 120 characters long terminated by a carriage return, and logically connected to the next line in sequence. The compiler simply reads the source program from the first through the last line, disregarding line boundaries.

In exchange for this freedom of expression, you should adhere to some stylistic conventions, so that your programs can be easily read and understood by other programmers. A professional program not only produces the correct output, but is consistent in form and divided into logical segments that are easy to comprehend. A logically structured program is also much easier to debug. A well constructed program is appreciated for its form and its function.

There are many stylistic conventions in use by individual programmers. The following rules illustrate one set of conventions that are used throughout the examples in this guide. Listing 5-1 illustrates the conventions presented in this section.

5.1 Case

You can write PL/I programs in either upper- or lowercase. Internally, the PL/I compiler translates all characters, outside of string quotes, to uppercase. Using the use of lowercase throughout programs generally improves readability.

5.2 Indentation

Use indentation throughout your program to set off various declarations and statements. To simplify indentation, the compiler expands tabs (CTRL-I characters) to every fourth column position. Some text editors expand tabs to multiples of eight columns, so the line appears wider during the edit and display operations. The compiler issues the TRUNC (truncate) error if the expanded line length exceeds 120 columns.

Program statements start at the outer block level in the first column position. Each successive block level, initiated by a DO group, BEGIN, or PROCEDURE block, starts at a new indentation level, four spaces or one tab stop. Give statements in a group the same indentation level, with procedure names and labels on a single line by themselves.

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information required to understand the overall purpose and operation of your program. They also simplify the task of maintaining and updating the code without introducing errors.

```
This program computes the largest of three
/* FLOAT BINARY numbers x, y, and z.

test:
procedure options(main);
    declare
        (a,b,c) float binary;
    put list ('Type Three Numbers:
    get list (a,b,c);
    put list ('The Largest Value is',max3(a,b,c));

/* this procedure computes the largest of x, y, and z
    max3: procedure4x,y,z) returns(float binary);
        declare
            (x,y,z,max) float binary;

        if x > y then
            x > z then
                if max = x;
                else
                    max = z;
            else
                if y > z then
                    max = y;
                else
                    max = z;
        return(max);
    end max3;
end test;
```

Listing 5–1. PL/1 Stylistic Conventions

References: PL/I Command Summary

End of Section 5

6 Using the System

Developing a PL/I program is a 3-step process:

1. Write the source file using any suitable text editor.
2. Compile the source file and generate the relocatable object file.
3. Link the relocatable object file with the Run-time Subroutine Library to generate an executable command file.

PL/I is a compiled language. Consequently, if you make any change to the source file, you must recompile the program. Try to divide large programs into several small modules, compile each module separately, then link them together. Small programs compile faster and use less storage for the Symbol Table.

Figure 6-1 illustrates the development process.

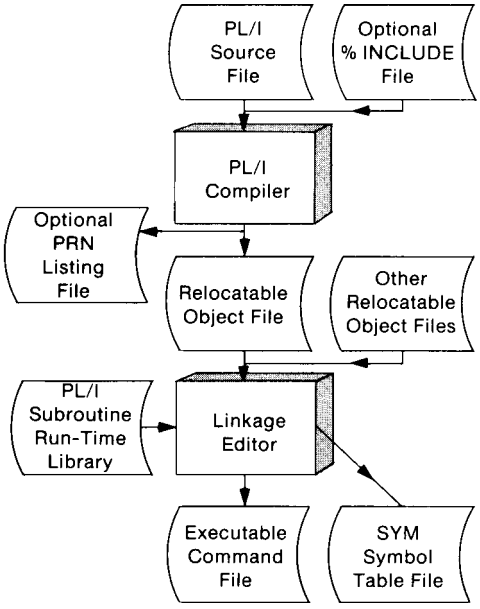


Figure 6–1. PL/I Program Development

6.1 PL/1 System Files

When you receive your PL/I system, you should first make copies of all the distribution disks. If you are unsure how to do this, read your operating system documentation.

The contents of the distribution disks varies with the implementation. The file RELNOTES.PRN on the Sample Program Disk describes the contents of the files for your particular implementation.

Note: You have certain responsibilities when making copies of Digital Research programs. Be sure you read your licensing agreement.

After you make back-up disks, load your compiler disk and type a DIR command:

```
A>dir
```

The directory contains several types of files, as shown in Table 6-1.

Table 6–1 PL/I System Files

Type	Definition
CMD	Executable command file (8086 implementations) , for example, DEMO.CMD
COM	Executable command file (8080 implementations) , for example, DEMO.COM
DAT	Default data filetype
DCL	%INCLUDE file (data declarations)
EXE	Executable command file (under IBM DOS) , for example, DEMO.EXE
IRL	Indexed Relocatable File, for example PLILIB.IRL
L86	Library file (8086 implementations), for example, PLILIB.L86
OBJ	Relocatable object code file (8086 implementations), for example, DEMO.OBJ
OVL	PL/I Compiler Overlays (8080 implementations) , PLI0, PLI1, and PLI2
OVR	PL/I Compiler Overlays (8086 implementations) , PLI0, PLI1, and PLI2
PLI	PL/I source programs, for example, DEMO.PLI
PRN	Printer disk file; compiled program listing on disk. Also used for readable documentation file
REL	Relocatable object code file (8080 implementations), for example, DEMO.REL
SYM	Symbol Table File, for example DEMO.SYM

Note: The only files that contain printable characters are the PLI source programs, PRN printer listing files, and the SYM symbol table files.

6.2 Invoking the Compiler

You invoke the PL/I compiler using a command of the general form:

```
pli filespec [$options]
```

where filespec designates the program to compile and can include an optional drive specification. For example,

```
d:myfile.pli
```

You need not specify the filetype because the compiler assumes type PLI.

$options represent a list of parameters that you can optionally include in the command line when compiling a program. These parameters enable the various compiler options as shown in Table 6-2 on the following page.

In each case, the single-letter option follows the $ symbol in the command line. You can specify a maximum of seven options following the dollar sign. The default mode using no options compiles the program but produces no source listing and sends all error messages to the console.

Table 6–2 PL/I Compiler Options

Option	Action Enabled
A	Abbreviated listing. Disables the listing of parameters and %INCLUDE statements during the compiler's first pass.
B	Built-in subroutine trace. Shows the Run-time Subroutine Library functions that are called by your PL/I program.
D	Disk file print. Sends the listing file to disk, using the filetype PRN.
I	Interlist source and machine code. Decodes the machine language code produced by the compiler in a pseudo-assembly language form.
K	Same as A.
L	List source program. Produces a listing of the source program with line numbers and machine code locations (automatically set by the I switch).
N	Nesting level display. Enables a pass 1 trace that shows exact balance of DO, PROCEDURE, and BEGIN statements with their corresponding END statements.
O	Object code off. Disables the output of relocatable object code normally produced by the compiler.
P	Page mode print. Inserts form-feeds every 60 lines, and sends the listing to the printer.
S	Symbol Table display. Shows the program variable names, along with their assigned, defaulted, and augmented attributes.

6.3 Compiler Operation

The PL/I compiler reads source program files and generates a relocatable, native code object file as output. PL/I is a 3-pass compiler, with each pass a separate overlay. Pass 1 collects declarations, and builds a Symbol Table used by subsequent passes. Pass 2 processes executable statements, augments the Symbol Table, and generates intermediate language in tree-structure form. Both passes analyze the source text using recursive descent.

Pass 3 performs the actual code generation, and includes a comprehensive code optimizer that processes the intermediate tree

structures. Alternate forms of an equivalent expression are reduced to the same form, and expressions are rearranged to reduce the number of temporary variables. There is also a special-forms recognizer that detects and matches approximately three hundred tree structures of special interest. Special-forms recognition allows the compiler to generate concise code sequences for many common statements.

Note: All the compiler overlays (PLI0, PLI1, and PLI2) must be on the default drive.

As the compiler proceeds through the first two passes, it displays the messages:

```
NO ERROR(S) IN PASS 1
NO ERROR(S) IN PASS 2
```

If there are errors, the compiler lists each line containing an error with the line number to the left, a short error message, and a ? below the position in the line where the error occurs.

At the end Pass 3, the compiler displays the message,

```
CODE SIZE = nnnn
DATA AREA = nnnn
FREE SYMS = nnnn
END COMPILATION
```

where nnnn are hexadecimal numbers representing the amount of storage used for the code and data, as well as the amount of Transient Program Area (TPA) left for Symbol Table space.

If the number of error messages is excessive and you want to make corrections before proceeding, you can halt the compilation by pressing any key. The compiler responds with the message:

```
STOP PL/I (Y/N)?
Enter Y to halt the compilation.
```

Note: Under DOS, you stop a program by pressing CTRL-Break, which immediately returns control to the operating system. Therefore, you will not see the message output by PL/I.

If you use the N option, the compiler lists the program line number on the left, followed by a letter a through z that denotes the nesting level for each line. The main program level is a, and each nested BEGIN advances the level by one letter, while each nested PROCEDURE advances the level by two letters.

If you use the L option, the compiler lists the relative machine code address for each line as a four-digit hexadecimal number. This address is useful for determining the amount of machine code generated for each statement and the relative machine code address for each line of the program. The compiler prints the source language statement on the line following the relative machine code value.

Listings 6-la and 6-lb show two compilations of a program called DEMO that is on your sample program disk.

```
1 a demo:
2 b     procedure options(main);
3 b
4 b     declare
5 b         name character(20) varying;
6 b
```

```
    7 b
    8 b      put skip(2) list('PLEASE ENTER YOUR FIRST NAME: ');
    9 b      get list(name);
    10 b     put skip(2) list('HELLO ', name,' WELCOME TO PL/I');
    11 b
    12 b end demo;
```

Listing 6–1. Compilation of DEMO Using $N Option

```
    1 a 0000 demo:
    2 a 0006 procedure options(main);
    3 a 0006
    4 c 0006 declare
    5 c 0006     name character(20) varying;
    6 c 0006
    7 c 0006
    8 c 0006 put skip(2) list('PLEASE ENTER YOUR FIRST NAME: ');
    9 c 0022 get list(name);
    10 c 003C    put skip(2) list('HELLO ', name,' WELCOME TO PL/I');
    11 c 006C
    12 a 006C end demo;
```

Listing 6–2. Compilation of DEMO Using $L Option

6.4 The DEMO Program

You can start learning to use the PL/I system by compiling the program called DEMO. The source file for DEMO is on your PL/I sample program disk, so you do not have to write the code. To display the source file, use the TYPE command, as follows:

To compile the DEMO program, enter the command:

```
A>pli demo
```

Now examine your directory and find the object file that contains the relocatable machine code produced by the compiler. The machine code produced by the compiler is not directly executable, so you have to link the object file with the Run-time Subroutine Library (RSL) with the command:

```
A>link demo
```

Now examine your directory and find the command file and the Symbol Table file produced by the linkage editor. You can load the Symbol Table file under SID-80 or SID-86 for debugging.

6.5 Running DEMO

To run the compiled program, enter the name of the command file,

```
A>demo
```

The operating system loads the DEMO program, which begins processing and prompts you with the message,

```
PLEASE ENTER YOUR FIRST NAME:
```

Console input is free-field and incorporates the full line-editing facilities of the operating system. When you enter your name, DEMO gives an appropriate response. Listing 6-2 shows interaction with DEMO.

```
A>demo
PLEASE ENTER YOUR FIRST NAME: Larry
HELLO Larry, WELCOME TO PL/I
A>
```

Listing 6–3. Interaction with the DEMO Program

Various run-time errors can halt processing if the program does not explicitly intercept them. In this case, PL/I displays the message in the following form:

```
error-condition (code), file-option, auxiliary-message
Traceback: aaaa bbbb cccc dddd # eeee ffff gggg hhhh
```

The error-condition is one of the standard PL/I condition categories (see Section 4.4.4). Code is an error subcode identifying the origin of the error.

PL/I prints the file option when the error involves an I/O operation, and takes the form,

```
File: internal=external
```

where internal is the internal program name that references the file involved in the error, and external is the external device or filename associated with the file. PL/I prints the auxiliary message whenever the preceding information is insufficient to identify the error.

The traceback portion lists up to eight elements of the internal stack. In the preceding general form, element aaaa corresponds to the top of the stack, while hhhh corresponds to the bottom of the stack. If the stack depth exceeds eight elements, the # character separates the four topmost elements on the left from the four lowermost elements on the right.

Listing 6-3 is an example of the diagnostic form. In this case, the console input is an end-of-file (CTRL-Z) character. Entering a CTRL-Z signals the ENDFILE condition for the SYSIN file. This is standard console input. In this example, the external device connected to the SYSIN file is the console, denoted by CON.

```
A>demo
PLEASE ENTER YOUR FIRST NAME: ^Z
END OF FILE (1), File: SYSIN=CON
Traceback: 07BE 0769 012E 4COO # 0702 0322 8090 012E
A>
```

Listing 6–4. Error Traceback for the DEMO Program

6.6 Error Messages and Codes

PL/I can detect two kinds of errors: compilation errors and run-time errors. The Compiler marks each compilation error with an error message following the line containing the error, with a ? character near the position of the error in the line. The ? might follow the actual error position by a few columns. In some cases, an error on one line can lead to errors on subsequent lines.

PL/I categorizes errors as either recoverable or non-recoverable. Most compile-time errors are recoverable, and the Compiler continues processing the source file. However, some compile-time errors are non-

recoverable. The Compiler stops processing and control immediately returns to the operating system.

The run-time system detects errors while the program is running. Most run-time errors are recoverable if intercepted by an ON-unit. However, some run-time errors are non- recoverable. The program stops and control immediately returns to the operating system.

In general, the error messages are implementation-dependent. See Appendix E in the LRM for the complete list.

End of Section 6

7 Using Different Data Types

PL/I programs allow you to use different data types to suit different applications. In programs throughout the manual, you should note how and why each type of data is used in a particular situation.

7.1 The FLTPOLY Program

Listing 7-1 shows a program for evaluating a polynomial expression. The program begins by reading three values, x, y, and z, from the console, and then uses the values to evaluate the polynomial expression:

$p(x,y,z) = x^2 + 2y + z$

The main part of the program is bounded by a single DO-group. On each successive iteration, the program reads the values of x, y, and z from the standard SYSIN, console, file. The program then writes the value produced by p(x,y,z) to the SYSPRINT file, again, the console file. Finally, if all the input values are zero, the program executes the STOP statement and ends the indefinite loop.

The program uses the %REPLACE statement on line 8 to define the literal value of true as the bit-string constant, '1'b. The compiler substitutes this value whenever it encounters the name true. Thus, the compiler interprets the DO-group beginning on line 13 as,

```
do while ('1'b);

end,:
```

which loops until it executes the contained STOP statement. Using %REPLACE statements to define constants can improve the readability of your programs.

```
 1 a
 2 a /* This program evaluates a polynomial expression
 3 a /* using FLOAT BINARY data.
 4 a
 5 a fltpoly:
 6 b procedure options(main);
 7 b
 8 b %replace
 9 b     true by '1'b;
10 b declare
11 b    (x,y,z) float binary(24);
12 b
13 c do while(true);
14 c    put skip(2) list('Type x,y,z: '};
15 c    get list(x,y,z);
16 c
17 c    if x=0 & y=0 & z=0 then
18 c        stop;
19 c
20 c    put skip list('       2');
21 c    put skip list('      x  + 2y + z =',p(x,y,z));
22 c end;
23 b
24 b P:
25 c    procedure (x,y,z) returns (float binary(24));
```

```
    26 c     declare
    27 c         (x,y,z) float binary;
    28 c     return (x * x + 2 * y + z);
    29 c end P;
    30 b
    31 b end fltpoly;
```

Listing 7–1. Polynomial Evaluation Program (FLOAT BINARY)

Listing 7-2 shows the console interaction with the FLTPOLY program. The initial values for x, y, and z are: 1.4, 2.3, and 5.67, but on the next loop, the input takes the form:

```
      ,4.5,,
```

This form changes the value of y only. Thus, on this loop, the values of x, y, and z are 1.4, 4.5, and 5.67. The third input line changes y and z, while the fourth line changes x only.

```
A>fltpoly

Type x,y,z: 1.4, 2.3, 5.67

       2
      x + 2y + z = 1.223000E+01

Type x,y,z: , 4.5,,

       2
      x + 2y + z = 1.663000E+01

Type x,y,z: , 4.0,-3.7

       2
      x + 2y + z = 1.427000E+01

Type x,y,z: 2.3,,,

       2
      x + 2y + z = 3.559999E+00

Type x,y,x: 0,0,0

A>
```

Listing 7–2. Interaction with FLTPOLY Program

7.2 The DECPOLY Program

Listing 7-3 shows the DECPOLY program, which is essentially the same program as Listing 7-1. The difference between the two programs is that FLTPOLY uses FLOAT BINARY data items, while DECPOLY uses FIXED DECIMAL items. FLOAT BINARY computations execute significantly faster than their FIXED DECIMAL equivalents, but single-precision FLOAT BINARY computations involve truncation errors, and produce an answer with only about 7 decimal places of accuracy.

```
    1 a
    2 a /* This program evaluates a polynomial expression
    3 a /* using FIXED DECIMAL data.
    4 a
```

```
 5 a decpoly:
 6 b procedure options(main);
 7 b
 8 b %replace
 9 b     true by '1'b;
10 b declare
11 b    (x,y,z) fixed decimal(15,4);
12 b
13 c do while(true);
14 c    put skip(2) list('Type x,y,z: ');
15 c    get list(x,y,z);
16 c
17 c    if x=0 & y=0 & z=0 then
18 c        stop;
19 c
20 c        put skip list('       2');
21 c        put skip list('      x + 2y + z =',p(x,y,z));
22 c end;
23 b
24 b P:
25 c procedure (x,y,z) returns (fixed decimal(15,4));
26 c declare
27 c    (x,y,z) fixed decimal(15,4);
28 c    return (x * x + 2 * y + z);
29 c end P;
30 b
31 b end decpoly;
```

Listing 7–3. Polynomial Evaluation Program (FIXED DECIMAL)

Listing 7-4 shows the console interaction with the DECPOLY program. The initial input values for x, y, and z are: 1.4, 2.3, and 5.67. These are the same values used for the FLTPOLY program, but notice the difference in the output. The second loop changes the values of y and z, and the third loop changes all three values.

```
A>decpoly

Type x,y,z: 1.4, 2.3, 5.67

       2
      x + 2y + z = 12.2300

Type x,y,z: , .0006, 7,

       2
      x + 2y + z = 8.9612

Type x,y,z: 723.445, 80.54, 0

       2
      x + 2y + z = 523533.7480

Type x,y,z: 0,0,0

A>
```

Listing 7–4. Interaction with DECPOLY Program

Experiment with these two programs by comparing the results when you enter the same values in each one. Understanding how PL/I internally treats the different data types helps you choose the right type of data to suit the application.

References: LRM Section 3.1, 11.1, Appendix A

End of Section 7

8 STREAM and RECORD File Processing

The example programs in this section illustrate STREAM and RECORD file processing using the various I/O statements.

8.1 File Copy Program

Listing 8-1 shows a general purpose, file-to-file copy program. The program first defines and opens two file constants called input file and output - file. It then begins executing a continuous loop that reads data from input-file and copies it to output-file.

Both OPEN statements define STREAM files with internal buffers of 8192 bytes each. In the first OPEN statement, PL/I supplies the default attribute INPUT, while the second OPEN statement explicitly specifies an OUTPUT file. Otherwise, it would also default to an INPUT file.

This program shows the special use of READ and WRITE statements to process STREAM files. The READ statement on line 19 reads a STREAM file into buff, a character string of varying length. It reads each line of input up to and including the next carriage return line-feed into buff, and sets the length of buff to the amount of data read, including the carriage return line-feed character. The WRITE statement performs the opposite action. It sends the data to a STREAM file from buff. The output file receives all characters from the first position through the length of buff.

The program terminates by reading through the input file until it reaches the end-of-file (CTRL-Z) character. PL/I automatically closes all open files, and writes the internal buffers onto the disk, thus preserving the newly created output file.

```
 1 a
 2 a   /* This program copies one file to another using
 3 a   /* buffered I/O.
 4 a
 5 a   copy:
 6 b        procedure options(main);
 7 b             declare
 8 b                  (input_file,output_file) file;
 9 b
10 b             open file (input_file) stream
11 b             environment(b(8192)) title('$1.$1');
12 b
13 b             open file (output_file) stream output
14 b             environment(b(8192)) title('$2.$2');
15 b             declare
16 b                  buff character(254) varying;
17 b
18 c             do while ('1'b)
19 c                  read file (input_file) into (buff);
20 c                  write file (output_file) from (buff);
21 c             end;
22 b   end copy;
```

Listing 8–1. COPY (File-to-File) Program

Listing 8-2 shows a sample execution of the copy program using the following command line:

```
A>copy copy.pli $con
```

In this case, the input file is COPY.PLI the original source file, while the output file is the system console. Thus, the program simply lists COPY.PLI at the terminal.

The TITLE options connect the internal filenames to external devices and files. The command line has two parts: the command itself, and the command tail, which can contain two filenames.

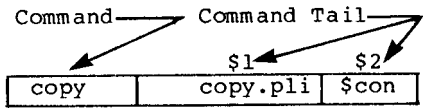


Figure 8–1. Default Filenames in the Command Tail

The OPEN statement on line 10 takes the first default name, including the drive in the command tail (denoted by $1.$l), and assigns it to the internal file constant called input file. Similarly, the second OPEN statement on line 13 takes the second default name including the drive in the command tail (denoted by $2.$2) , and assigns it to the internal file constant called output-file.

For example, the command,

```
A>copy a:x.dat c:u.new
```

copies the file X.DAT from drive a to the new file U.NEW on drive c. The input file must exist, but PL/I erases the output file if it exists, and recreates it.

```
A>copy copy.pli $con
   1 a
   2 a   /* This program copies one file to another using
   3 a   /* buffered I/O.
   4 a
   5 a   copy:
   6 b        procedure options(main);
   7 b        declare
   8 b             (input_file,output_file) file;
   9 b
  10 b        open file (input-file) stream
  11 b             environment(b(8192)) title('$l.$l');
  12 b
  13 b        open file (output_file) stream output
  14 b             environment(b(8192)) title('$2.$2');
  15 b        declare
  16 b             buff character(254) varying;
  17 b
  18 c        do while('l'b);
  19 c             read file (input_file) into (buff);
  20 c             write file   (output_file) from (buff);
  21 c        end;
  22 b   end copy;

END OF FILE (3), File: INPUT=COPY.PLI
Traceback : 044B 03AF 0155
A>
```

Listing 8–2. Interaction with the COPY Program

8.2 Name and Address File

The two programs in Listings 8-3 and 8-6 manage a simple name and address file. The CREATE program produces a STREAM file containing individual names and addresses that are subsequently accessed by the RETRIEVE program.

8.2.1 The CREATE Program

The CREATE program in Listing 8-3 contains a data structure that defines the name, address, city, state, zip code, and phone number format. This data structure is not in the source file CREATE.PLI. It is contained in a separate file named RECORD.DCL, and CREATE uses an %INCLUDE statement to read and merge this file with the source file. Both files are on your sample program disk. The + symbols to the right of the source line number in the listing indicate that the code comes from an %INCLUDE file. The actual line in the source program appears as follows:

```
      create:
            procedure options(main);

            %include 'record.dcl';
```

The file specified in the %INCLUDE statement can be any valid filename. The compiler simply copies the file at the point of the %INCLUDE statement, and then continues.

The OPEN statement, line 29, does not specify the PRINT attribute. This means the output file is in a form suitable for later input using a GET LIST statement.

```
  1 a
  2 a   /* This program creates a name and address file. The
  3 a   /* data structure for each record is in the %INCLUDE
  4 a   /* file RECORD.DCL.
  5 a
  6 a   create:
  7 b       procedure options(main);
  8 b
  9+b       declare
 10+b           1 record,
 11+b                2 name character(30) varying,
 12+b                2 addr character(30) varying,
 13+b                2 city character(20) varying,
 14+b                2 state character(10) varying,
 15+b                2 zip fixed decimal(6),
 16+b                2 phone character(12) varying;
 17 b       %replace
 18 b           true by '1'b,
 19 b           false by '0'b;
 20 b
 21 b       declare
 22 b           output file,
 23 b           filename character(14) varying,
 24 b           eofile bit(l) static initial(false);
 25 b
 26 b       put list ('Name and Address Creation Program, File Name:
 27 b       get list (filename);
 28 b
```

```
 29 b       open file(output) stream output title(filename);
 30 b
 31 c       do while (^eofile);
 32 c           put skip(3) list('Name:
 33 c           get list(name);
 34 c           eofile = (name = 'EOF');
 35 c           if ^eofile then
 36 d               do;
 37 d                   /* write prompt strings to console
 38 d                   put list('Address:
 39 d                   get list(addr);
 40 d                   put list('City, State, Zip:
 41 d                   get list(city, state, zip);
 42 d                   put list('Phone:
 43 d                   get list(phone);
 44 d
 45 d           /* data in memory, write to output file
 46 d                   put file(output)
 47 d                   list(name,addr,city,state,zip,phone);
 48 d                   put file(output) skip;
 49 d               end;
 50 c       end;
 51 b       put file(output) skip list('EOF');
 52 b       put file(output) skip;
 53 b
 54 b   end create;
```

Listing 8–3. CREATE Program

Listing 8-4 shows the console interaction with the CREATE program. You specify the output file as names.dat in the first input line. The GET LIST statement, line 33, accepts input delimited by blanks and commas, unless the delimiters are included in single apostrophes. Thus, CREATE takes the input line,

```
'John Robinson
```

as a single string value with PL/I automatically inserting the implied closing apostrophe at the end of the line. The last entry includes the three input values,

```
Unknown, 'Can"t Find', 99999
```

that CREATE assigns to the variables city, street, and state. Because the first value does not begin with an apostrophe, the I/O system scans the data item until the next blank, tab, comma, or end of-line occurs. The second data item begins with an apostrophe, and this causes the I/O system to consume all input through the trailing balanced apostrophe, and reduce all embedded double apostrophes to a single apostrophe. The last value, 99999, is assigned to a decimal number, and must contain only numeric data. You can use the command,

```
A>type names.dat
```

to display the STREAM file that the program creates. Listing 8-5 shows the output resulting from each input entry.

```
A>create
Name and Address Creation Program, File Name: names.dat

Name: 'Arthur Jackson'
Address: '100 W. 3rd St.'
```

```
City, State, Zip: 'Fresno', 'Ca.', 93706
Phone: '529-1277'

Name: 'Donna Harris'
Address: 12999 Sierra Rd.'
City, State, Zip: 'Chico', 'Ca.', 95926
Phone: '635-3570'

Name: 'John Robinson
Address: 1805 Franklin St.'
City, State, Zip: 'Monterey', 'Ca.', 93940
Phone: '649-1000'

Name: 'Virginia Wilson'
Address: '?'
City, State, Zip: Unknown, 'Can"t Find', 99999
Phone: '?'

Name: 'EOF'

A>
```

Listing 8–4. Interaction with the CREATE Program

```
A>type names.dat
'Arthur Jackson' '100 W. 3rd St.' 'Fresno' 'Ca.'    93706 '529-1277' 'Donna
Harris' '2999 Sierra Rd.' 'Chico' 'Ca.'      95926 '635-3570' 'John Robinson'
'805 Franklin St.' 'Monterey' 'Ca.'    93940 '649-1000' 'Virginia Wilson' '?'
'Unknown' 'Can''t Find'   99999 '?'

'EOF'

A>
```

Listing 8–5. Output from the CREATE Program

8.2.2 The RETRIEVE Program

The RETRIEVE program shown in Listing 8-6 reads the file created by CREATE, and displays the name and address data upon user request. The compiler includes the same RECORD.DCL file used in the CREATE program, shown in Listing 8-3.

The main DO-group in the RETRIEVE program, between lines 30 and 59, reads two string values corresponding to the lowest and highest names to print on each iteration. The embedded DO-group between lines 41 and 57 reads the entire input file and lists only those names between the lower and upper bounds.

The RETRIEVE program, similar to the CREATE program, reads the name of the source file from the console. However, RETRIEVE opens and closes this source file each time it receives a retrieval request from the console.

The OPEN statement on line 38 sets the internal buffer size of the input file to 1024 bytes. After processing the file, RETRIEVE executes the CLOSE statement on line 58 and flushes all internal buffers. Thus, RETRIEVE sets the input file back to the beginning on each retrieval request.

```
   1 a      retrieve:
```

```
 2 b          procedure options(main);
 3 b          /* name and address retrieval program */
 4 b
 5+b          dcl
 6+b              1 record,
 7+b                2 name  character(30) varying,
 8+b                2 addr  character(30) varying,
 9+b                2 city  character(20) varying,
10+b                2 state character(10) varying,
11+b                2 zip   fixed decimal(6),
12+b                2 phone character(12) varying;
13 b
14 b          %replace
15 b              true  by '1'b,
16 b              false by '0'b;
17 b
18 b          dcl
19 b              (sysprint, input) file;
20 b
21 b          dcl
22 b              filename character(14) varying,
23 b              (lower, upper) character(30) varying,
24 b              eofile bit(1);
25 b
26 b          open file(sysprint) print title('$con');
27 b          put list('Name and Address Retrieval, File Name: ');
28 b          get list(filename);
29 b
30 c              do while(true);
31 c              lower = 'AAAAAAAAAAAAAAAAAAAAAAAAAAAAAA';
32 c              upper = 'zzzzzzzzzzzzzzzzzzzzzzzzzzzzzz';
33 c              put skip(2) list('Type Lower, Upper Bounds: ');
34 c              get list(lower,upper);
35 c              if lower = 'EOF' then
36 c                  stop;
37 c
38 c              open file(input) stream input environment(b(1024))
39 c                  title(filename);
40 c              eofile = false;
41 d                  do while (^eofile);
42 d                  get file(input) list(name);
43 d                  eofile = (name = 'EOF');
44 d                  if ^eofile then
45 e                      do;
46 e                      get file(input)
47 e                          list(addr,city,state,zip,phone);
48 e                      if name >= lower & name <= upper then
49 f                          do;
50 f                          put page skip(3)
51 f                              list(name);
52 f                          put skip list(addr);
53 f                          put skip list(city,state);
54 f                          put skip list(zip);
55 f                          put skip list(phone);
56 f                          end;
57 e                      end;
58 d                  end;
59 c              close file(input);
```

```
  60 c              end;
  61 b          end retrieve;
```

Listing 8–6. RETRIEVE Program

Listing 8-7 shows user interaction with the RETRIEVE program. Again, the input file is names.dat, and exists on the disk in the form produced by CREATE. The input values,

```
      B,E
```

set lower to B and upper to E and cause RETRIEVE to list only Donna Harris. The second console input line sets lower to B and upper to K. This causes RETRIEVE to list Donna Harris and John Robinson. The comma in the next input value sets the lower bound at AAA ... A and the upper bound as K. Thus RETRIEVE lists Arthur Jackson, Donna Harris, and John Robinson. The last entry consists only of a comma pair, leaving the lower bound as the sequence AAA...A and the upper bound at zzz ... z. These two bounds include the entire alphabetic range, so that RETRIEVE displays the entire list 'of names and addresses. Finally, entering EOF ends the program.

Line 26 of Listing 8-6 opens the SYSPRINT file with the PRINT attribute and title of CP/M. It is good programming practice to open all files with explicit attributes. In this case the statement is redundant because when PL/I executes the PUT LIST statement on line 27, it supplies the same attributes to the file by default.

```
A>retrieve
Name and Address Retrieval, File Name: names.dat

Type Lower, Upper Bounds: B,E

Donna Harris
2999 Serra Rd.
Chico Ca.
    95926
635-3570

Type Lower, Upper Bounds: B,K

Donna Harris
2999 Serra Rd.
Chico Ca.
    95926
635-3570

John Robinson
805 Franklin St.
Monterey Ca.
    93940
649-1000

Type Lower, Upper Bounds:     K

Arthur Jackson
100 w. 3rd St.
Fresno Ca.
    93706
529-1277
```

```
Donna Harris
2999 Serra Rd.
Chico Ca.
    95926
635-3570

John Robinson
805 Franklin St.
Monterey Ca.
    93940
649-1000

Type Lower, Upper Bounds:

Arthur Jackson
100 W. 3rd St.
Fresno Ca.
    93706
529-1277

Donna Harris
2999 Serra Rd.
Chico Ca.
    95926
635-3570

John Robinson
805 Franklin St.
Monterey Ca.
    93940
649-1000

Virginia Wilson

Unknown Can't Find
    99999

Type Lower, Upper Bounds; EOF,,

A>
```

Listing 8–7. Interaction with the RETRIEVE Program

8.3 An Information Management System

The next four sample programs provide a model for an information management system. These programs manage a file of employee names, addresses, wage schedules, and wage reporting mechanisms. Each of these programs is simple, but together they contain all the elements of a more advanced data base management system. They demonstrate the power of the PL/I programming system, while providing the basis for custom application programs.

First, the ENTER program establishes the data base. A second program, called KEYFILE, reads this data base and prepares a key file for direct access to individual records in the data base. A third program, called UPDATE, interacts with the user at the console and allows access to the

data base for retrieval and update. Finally, the REPORT program reads the data base to produce a report.

8.3.1 The ENTER Program

Listing 8-8 shows the ENTER program. The ENTER program interacts with the user at the console and constructs the initial data base. The basic input loop between lines 40 and 53 prompts the user for an employee name, age, and hourly wage. ENTER fills, the employee data structure with this information. In the example, line 48 fills the address fields with default values defined in the structure on lines 24 through 33. You can terminate the console input by entering EOF.

The employee record contains several fields whose total length is 101 bytes. You can use the $S compiler option to verify this value. The OPEN statement on line 37 specifies a fixed record size of 128 bytes, so you can expand the records later. Each record of the emp file holds exactly one employee data structure.

The OPEN statement gives emp the KEYED attribute, and makes each record the fixed size specified in the ENVIRONMENT option. The OPEN statement also specifies the buffer size as 8000 bytes, which PL/I automatically rounds off to 8192 bytes. The program fills each employee record from the console input and writes the record to the employee file named in the command line, with the file type EMP, line 38.

The WRITE statement is in a separate subroutine, named WRITEIT, starting on line 55. Placing the code in a separate subroutine helps reduce the size of the program because the program calls WRITEIT at two different points, lines 45 and 52.

Listing 8-9 shows the user interaction with the ENTER program as several employee records are entered. Entering EOF ends the program, closes the file plantl.emp, and records the data on the disk.

```
 1 a      enter:
 2 b          proc options(main);
 3 b
 4 b          %replace
 5 b              true  by '1'b,
 6 b              false by '0'b;
 7 b
 8 b          dcl
 9 b              1 employee static,
10 b                2 name     char(30) varying,
11 b                2 addr,
12 b                  3 street char(30) varying,
13 b                  3 city   char(10) varying,
14 b                  3 state  char(7)  varying,
15 b                  3 zip    fixed dec(5),
16 b                2 age      fixed dec(3),
17 b                2 wage     fixed dec(5,2),
18 b                2 hours    fixed dec(5,1);
19 b
20 b          dcl
21 b               1 default static,
22 b                 2 street char (30) varying
23 b                   initial('(no street)'),
24 b                 2 city   char(10) varying
25 b                   initial('(no city)'),
```

```
  26 b                 2 state  char(7)  varying
  27 b                   initial('(no st)'),
  28 b                 2 zip    fixed dec(5)
  29 b                   initial(00000);
  30 b          dcl
  31 b              emp file;
  32 b
  33 b          open file(emp) keyed output environment(f(100),b(8000))
  34 b              title ('$1.EMP');
  35 b
  36 c              do while(true);
  37 c              put list('Employee: ');
  38 c              get list(name);
  39 c              if name = 'EOF' then
  40 d                  do;
  41 d                  call write();
  42 d                  stop;
  43 d                  end;
  44 c              addr = default;
  45 c              put list ('  Age, Wage: ');
  46 c              get list (age,wage);
  47 c              hours = 0;
  48 c              call write();
  49 c              end;
  50 b
  51 b          write:
  52 c              procedure;
  53 c              write file(emp) from(employee);
  54 c              end write;
  55 b          end enter;
```

Listing 8–8. The ENTER Program

```
A>enter plantl
Employee: Jackson
    Age, Wage: 25, 6.75
    Employee: Harris
    Age, Wage: 30, 9.00
    Employee: Robinson
    Age, Wage: 41, 15.00
    Employee: Wilson
    Age, Wage: 27, 7.50
    Employee: Smith
    Age, Wage: 25,
    Employee: Jones
    Age, Wage: F I
    Employee: EOF
A>
```

Listing 8–9. Interaction with the ENTER Program

8.3.2 The KEYFILE Program

Listing 8-10 shows the KEYFILE program, which constructs a key file by reading the data base file created by ENTER. The key file is a sequence of entries consisting of an employee name followed by the key number corresponding to that name. In this case, the key file is also a STREAM file, so you can display it at the console. Line 16 opens the $1.EMP file with the KEYED attribute, specifies each record to be 128 bytes

long, and sets a buffer size of 10000 bytes. Line 19 opens the key file named keys as a STREAM file with LINESIZE(60) and a TITLE option that appends KEY as the filetype.

On line 23, the KEYFILE program reads successive records, extracts the key with the KEYTO option, and writes the name and key to both the console and to the key file. The sample interaction in Listing 8-11 illustrates the output from KEYFILE using the plantl.emp data base. Each key value extracted by the READ statement is the relative record number corresponding to the position of the record in the file.

After executing the KEYFILE program, you can use the command

```
A>type plantl.key
```

to display the actual contents of the plantl.key file as shown in Listing 8-12.

```
 1 a      keypr:
 2 b          proc options(main);
 3 b
 4 b          /* create key from employee file */
 5 b
 6 b          dcl
 7 b              1 employee static,
 8 b                2 name char(30) varying;
 9 b
10 b          dcl
11 b              (input, keys) file;
12 b
13 b          dcl
14 b              k fixed;
15 b
16 b          open title('$1.emp') keyed
17 b            env(f(100),b(10000)) file(input);
18 b
19 b          open file (keys) stream output
20 b              linesize (60) title('$1.key');
21 b
22 c              do while('1');
23 c              read file(input) into(employee) keyto(k);
24 c              put skip list(k,name);
25 c              put file(keys) list(name,k);
26 c              if name = 'EOF' then
27 c                  stop;
28 c              end;
29 b          end keypr;
```

Listing 8–10. The KEYFILE Program

```
A>keyfile plantl

    0 Jackson
    1 Harris
    2 Robinson
    3 Wilson
    4 Smith
    5 Jones
    6 EOF
A>
```

Listing 8–11. Interaction with the KEYFILE Program

```
A>type plantl.key
'Jackson'    0 'Harris'   1 'Robinson' 2
'Wilson' 3 'Smith'    4 'Jones'    5 1EOF'
A>
```

Listing 8–12. Contents of the Key File

8.3.3 The UPDATE Program

The UPDATE program in Listing 8-13 allows you to access the data base created by ENTER and indexed through the file created by KEYFILE. The UPDATE program first reads the key file, a STREAM file, into a data structure called keylist. Keylist cross references the employee name with the corresponding key value in the data base. Lines 20 to 23 declare the data structure that holds these cross-reference values, and lines 37 to 40 fill in the data

Note: Line 39 is not a multiple assignment statement, but rather a definition of a Boolean expression for the variable, eolist.

UPDATE opens the emp file on line 31. The OPEN statement assigns the file the DIRECT attribute, that allows both READ and WRITE operations with the individual records identified by a key value. You then enter an employee name as matchname, and the DO-group between lines 47 and 61 directly accesses the individual records in the data base.

The direct access takes place as follows. Line 48 searches the list of names read from the key file. If there is a match, the READ with KEY statement on line 50 brings the employee record into memory from the emp file. The program displays and updates various fields from the console, and then rewrites the record to the data base with the WRITE with KEYFROM statement on line 58. UPDATE ends execution when you enter an EOF.

Listing 8-14 shows three successive update sessions during which various addresses and work times are updated. In each session, you enter the employee name, access and display the record, and optionally, update the fields. The GET LIST statement is useful here. To change a value, you simply type the new value in the field position. If you do not want to change a value, entering a comma delimiter leaves the field unchanged.

```
  1 a     update:
  2 b         proc options(main);
  3 b         dcl
  4 b             1 employee static,
  5 b               2 name     char(30) var,
  6 b               2 addr,
  7 b                 3 street char(30) var,
  8 b                 3 city   char(10) var,
  9 b                 3 state  char(7)  var,
 10 b                 3 zip    fixed dec(5),
 11 b               2 age      fixed dec(3),
 12 b               2 wage     fixed dec(5,2),
 13 b               2 hours    fixed dec(5,1);
 14 b         dcl
 15 b             (emp, keys) file;
 16 b         dcl
 17 b             1 keylist (100),
 18 b               2 keyname char(30) var,
```

```
 19 b                2 keyval  fixed binary;
 20 b          dcl
 21 b              (i, endlist) fixed,
 22 b              eolist bit(1) static initial('0'b),
 23 b              matchname char(30) var;
 24 b
 25 b          open file(emp) update direct env(f(100))
 26 b              title ('$1.EMP');
 27 b
 28 b          open file(keys) stream env(b(4000)) title('$1.key');
 29 b
 30 c              do i = 1 to 100 while(^eolist);
 31 c              get file(keys) list(keyname(i),keyval(i));
 32 c              eolist = keyname(i) = 'EOF';
 33 c              end;
 34 b
 35 c              do while('1'b);
 36 c              put skip list('Employee: ');
 37 c              get list(matchname);
 38 c              if matchname = 'EOF' then
 39 c                  stop;
 40 d                  do i = 1 to 100;
 41 d                  if matchname = keyname(i) then
 42 e                      do;
 43 e                      read file(emp) into(employee)
 44 e                          key(keyval(i));
 45 e                      put skip list('Address: ',
 46 e                          street, city, state, zip);
 47 e                      put skip list('         ');
 48 e                      get list(street, city, state, zip);
 49 e                      put list('Hours:',hours,': ');
 50 e                      get list(hours);
 51 e                      write file(emp) from (employee)
 52 e                          keyfrom(keyval(i));
 53 e                      end;
 54 d                  end;
 55 c              end;
 56 b          end update;
```

Listing 8–13. The UPDATE Program

```
A>update plantl

Employee:        Jackson

Address:             (no street) (no city) (no state)    0
    '100 W. 3rd St.', 'Fresno', 'Ca.', 93706
Hours:           0.0 : 40.0
Employee:                Harris
Address:             (no street) (no city) (no state)    0
    '2999 Serra Rd.', 'Chico', 'Ca.', 95926
Hours:           0.0 : 46.0
Employee:                EOF

A>update plantl
Employee: Harris

Address: 2999 Serra Rd. Chico Ca. 95926
wool
```

```
Hours:       46.0 :   48.0

Employee:        Wilson

Address:     (no street)  (no city)    (no state)   0
    sell
Hours:       0.0 :    35.5

Employee: EOF
A>update plantl

Employee:        Wilson

Address:             (no street) (no city) (no state)    0
    1556 Palm Ave.', 'Burbank', 'Ca.', 91L507
Hours:       35.5
Employee:        ROF
A>
```

Listing 8–14. Interaction with the UPDATE Program

8.3.4 The REPORT Program

Listing 8-15 shows the REPORT program. The REPORT program uses the updated employee file to produce a list of employees along with their paycheck values. The REPORT program also accesses the employee file, but it reads the file sequentially to produce the desired output. The main DO-group between lines 35 and 51 reads each successive employee record and constructs a title line of the form,

```
[name]
```

followed by a dollar amount. REPORT uses the STREAM form of the WRITE statement, lines 41 and 50, to produce the output line. Line 40 includes the embedded control characters ^M and ^J at the end of buff to cause a carriage return and line-feed when writing the buffer. The REPORT program then computes the pay value and assigns it to the CHARACTER VARYING string called buff, on line 44. In this assignment, PL/I performs an automatic data conversion from FIXED DECIMAL to CHARACTER, with leading blanks. REPORT also scans the leading blanks, replacing them by a dollar sign dash sequence to align the output, and writes the data to the report file.

Listings 8-16 and 8-17 show the output from the REPORT program. In the first case, the command,

```
A>report plantl $con
```

sends the report to the console for review. In the second case, the command,

```
A>report plantl plantl.prn
```

sends the output to the disk file plantl.prn. You can then examine the contents of the file with the command:

```
A>type plantl.prn
```

```
  1 a      report:
  2 b          procedure options(main);
  3 b
```

```
 4 b          dcl
 5 b              1 employee static,
 6 b                2 name     character(30) varying,
 7 b                2 addr,
 8 b                  3 street character(30) varying,
 9 b                  3 city   character(10) varying,
10 b                  3 state  character(7)  varying,
11 b                  3 zip    fixed dec(5),
12 b                2 age      fixed dec(3),
13 b                2 wage     fixed dec(5,2),
14 b                2 hours    fixed dec(5,1);
15 b
16 b          dcl
17 b              dashes character(15) static initial
18 b                  ('$--------------'),
19 b              buff character(20) varying;
20 b
21 b          dcl
22 b              i fixed,
23 b              (grosspay, withhold) fixed dec(7,2);
24 b
25 b          dcl
26 b              (repfile, empfile) file;
27 b
28 b          open file(empfile) keyed env(f(100),b(4000))
29 b              title ('$1.EMP');
30 b
31 b          open file(repfile) stream print title('$2.$2')
32 b              environment(b(2000));
33 b
34 b          put list('Set Top of Forms, Type Return');
35 b          get skip;
36 b
37 c              do while('1'b);
38 c              read file(empfile) into(employee);
39 c              if name = 'EOF' then
40 c                  stop;
41 c              put file(repfile) skip(2);
42 c              buff = '[' !! name !! ']^m^j';
43 c              write file(repfile) from (buff);
44 c              grosspay = wage * hours;
45 c              withhold = grosspay * .15;
46 c              buff = grosspay - withhold;
47 d                  do i = 1 to 15
48 d                      while (substr(buff,i,1) = ' ');
49 d                  end;
50 c              i = i - 1;
51 c              substr(buff,1,i) = substr(dashes,1,i);
52 c              write file (repfile) from(buff);
53 c              end;
54 b
55 b          end report;
```

Listing 8–15. The REPORT Program

```
A>report plantl $con
Set Top of Forms, Press Return

(Jackson]
```

```
$ ---- 229.50

[Harris]
$ ---- 351.90

[Robinson]
$ ------ 0.00

[Wilson]
$ ---- 226.32

[Smith]
$ ------ 0.00

[Jones]
$ ------ 0.00
A>
```

Listing 8–16. REPORT Generation to the Console

```
A>report plantl plantl.prn
Set Top of Forms, Press Return

A>type plantl.prn

[Jackson]
$ ---- 229.50

[Harris]
$---- 351.90

(Robinson]
$ ------ 0.00

(Wilson]
$ ---- 226.32

[Smith]
$ ------ 0.00

[Jones]
$ ------ 0.00
```

Listing 8–17. REPORT Generation to a Disk File

References: LRM Sections 10.1, 10.8, 11.2, 12

End of Section 8

9 Label Constants, Variables, and Parameters

Each of the programs presented so far ends execution either by encountering an end-of-file condition with a corresponding ENDFILE traceback, or by using a special data value that signals the end-of data condition. The EPOLY program detects the end-of-data condition by checking for the special case where all three input values, xf Y, and z, are zero.

Fortunately, PL/I provides more elegant ways to sense the end-of data condition. In fact, sensing the end-of-data condition is just one of many facilities under the general heading of condition processing. Most often, handling these conditions involves labeled statements. You need some background in label processing before you take up the general topic of condition processing in Section 10.

9.1 Labeled Statements

It is an axiom of programming to avoid labeled statements and GOTOs because of the unstructured programs that result. Programs containing many labeled statements are often difficult for other programmers to comprehend. Such programs become unreadable, even to the author, as the program grows in size.

PL/I encourages good structure by providing a comprehensive set of control structures in the form of iterative DO-groups with REPEAT and WHILE options. These control structures preclude the necessity for labeled statements in the general programming schema. You should use these control structures whenever possible, and limit the use of labeled statements to condition processing and locally defined, computed GOTOs.

Judicious use of labeled statements is appropriate in condition processing. The occurrence of an error, such as a mistyped input data line, is easily handled by transferring program control to a label in an outer block, where recovery takes place. This method of understanding the program flow is simpler than the usual system of flags, tests, and return statements.

9.2 Program Labels

Program labels, like other PL/I data types, fall into two broad categories: label constants and label variables. A label constant appears literally within the source program, and its value does not change when the program runs. A label variable has no initial value, and you must assign it the value of a label constant through a direct assignment statement, or through the parameter assignment implicit in a subroutine call.

The following code sequence is an example of a label constant preceding a PL/I statement.

```
on error(l)
begin;
put skip list('Bad Input, Try Again');
goto retry;
end;
```

```
retry: get list(name);
```

The statement on error(l) sets a trap for a particular condition. If the condition arises due to an invalid input, then control transfers to the BEGIN block, which outputs an error message, and then transfers control back to the labeled statement. If there is no error on input, control transfers to the next statement following the GET LIST statement.

9.3 Computed GOTO

In PL/I, a label constant can contain a single positive or negative literal subscript. A subscripted label constant corresponds to the target of an n-way branch, that is, a computed GOTO. The following code sequence shows a specific example.

```
            get list(x);
            goto q(x);
      q(-l):
            y = fl(x);
            goto endq;
      q(0):
            y = f2(x);
            goto endq;
      q(2):;
      q(3):
            y = f3(x);
      endq:
            put skip list('f(x)=',y);
```

This code implicitly defines four label constants: q(-l), q(0), q (2) , and q(3). The compiler automatically defines an internal label constant vector,

```
q(-1:3) label constant
```

to hold the values of these label constants.

The preceding statement is not a valid PL/I statement, but indicates what the compiler does internally when it encounters such statements in the source code. Also, when using such constructs, do not transfer control to a subscript that does not have a corresponding label-constant value. In the preceding case, a branch to q(l) produces undefined results.

9.4 Label References

A reference to a label constant can be either local or nonlocal. A local reference to a label constant means that the label occurs as the target of a GOTO statement only in the PROCEDURE or BEGIN block that contains the GOTO. A nonlocal reference to a label constant means that the label occurs on the right side of an assignment to a label variable, as an argument to a subroutine, or as the target of a GOTO statement in an inner nested PROCEDURE or BEGIN block.

Although there is no functional difference between processing a local ly-r eferenced and nonlocally-referenced label constant, a nonlocal reference requires additional space and time. For this reason, PL/I assumes that a subscripted label constant will be only locally

referenced. If program control transfers to a subscripted label constant from outside the current environment, undefined results can occur.

As an example, consider the following code sequence:

```
      main:
            procedure options(main);
            P1:
                  procedure;
                        goto lab1;
                        goto lab2;
                  P2:
                        procedure;
                              goto lab2;
                  end P2;
                  lab1:;
                  lab2:;
            end P1;
      end main;
```

The label constant lab1 is only locally referenced in the procedure P1, while lab2 is the target of both a local reference in PI and a nonlocal reference in P2.

9.5 Example Program

Listing 9-1 shows a nonfunctional program that illustrates the use of various label constants and variables. The label constants in the LABELS program are c(l), c(2), c(3), lab1, and lab2. They are defined by their literal occurrence in the program. The label variables are x, y, z, and g, and are defined by the declarations on lines 10 and 38.

At the start of execution, the label variables have undefined values. The program first assigns the constant value lab1 to the variable x. Label variable y then indirectly receives the constant value lab1 through the assignment on line 12. As a result, all three GOTO statements on lines 14, 15, and 16 are functionally equivalent. Each statement transfers control to the null statement following the label lab1 on line 32.

The subroutine call on line 18 shows a different form of variable assignment. Lab2 is an argument sent to the procedure P, and assigned to the formal label variable g. In this program, the subroutine call transfers program control directly to the statement labeled lab1.

The DO-group beginning on line 20 initializes the variable label vector z to the corresponding constant label vector values of c. Due to this initialization, the two computed GOTO statements, starting on line 25, have exactly the same effect.

```
   1 a
   2 a   /* This is a nonfunctional program. Its purpose is
   3 a   /* to illustrate the concept of label constants and
   4 a   /* variables.
   5 a
   6 a   Labels:
   7 b        procedure options(main);
   8 b        declare
   9 b            i fixed,
  10 b            (x, y, z(3)) label;
```

```
 11 b       x = labl;
 12 b       y = X;
 13 b
 14 b       goto labl;
 15 b       goto X;
 16 b       goto Y;
 17 b
 18 b       call P(lab2);
 19 b
 20 c       do i = 1 to 3;
 21 c           Z(i) = c(i);
 22 c       end;
 23 b
 24 b       i = 2;
 25 b       goto Z(i);
 26 b       goto c(i);
 27 b
 28 b       c(l)
 29 b       c(2):;
 30 b       c(3):;
 31 b
 32 b       labl:;
 33 b       lab2:;
 34 b
 35 b       P:
 36 c           procedure (g);
 37 c           declare
 38 c               g label;
 39 c           goto g;
 40 c       end P;
 41 b
 42 b       end Labels;
```

Listing 9–1. An Illustration of Label Variables and Constants

References: LRM Sections 3.3, 8.5, 8.6

End of Section 9

10 Condition Processing

Condition processing is an important facility of any production programming language. The language should allow a program to intercept and handle run-time error conditions with program-defined actions, and then continue.

For example, a common condition occurs when a program is reading input data from an interactive console, and you inadvertently enter a value that does not conform to the data type of the input variable. The PL/I run-time system signals a conversion error, and in the absence of any program-defined action, ends the program with a traceback. If this premature termination occurs after hours of data entry, it causes a considerable amount of wasted effort. This is unacceptable in a production environment.

10.1 Condition Categories

PL/I provides nine categories of conditions. They are

- ERROR
- FIXEDOVERFLOW
- OVERFLOW
- UNDERFLOW
- ZERODIVIDE
- ENDFILE
- UNDEFINEDFILE
- KEY
- ENDPAGE

The first five categories include all arithmetic error conditions and miscellaneous conditions that can arise during I/O setup and processing. They also include conversion errors between the various data types. The last four categories apply to a specific file that the I/O system is accessing. Each condition has an associated subcode that provides information about the source of the condition.

10.2 Condition Processing Statements

The ON, REVERT, and SIGNAL statements implement condition processing in PL/I. The ON statement defines the actions that take place upon encountering a condition. The REVERT statement disables the ON statement. The SIGNAL statement allows your program to signal various conditions.

10.2.1 ON and REVERT

The following code sequence illustrates the ON and REVERT statements inside a DO-group.

```
      do while(^EOF);
            on endfile(sysin)
            EOF = '1'b;


            revert endfile(sysin);
            end;
```

Here, both the ON and the REVERT statement execute on each iteration. Processing the ON and REVERT statements involves run time overhead. To avoid this, code the same DO-group as follows:

```
      on endfile(sysin)
      EOF = 'true';
      EOF = 'false';
      do while(^EOF);


      end;'
```

PL/I automatically executes the REVERT statement for any ON conditions that you enable inside a procedure block when control passes outside the block. The program shown in Listing 10-1 illustrates this concept.

```
   1 a
   2 a   /* This program is nonfunctional. Its purpose is to
   3 a   /* illustrate how PL/I executes the ON and REVERT
   4 a   /* statements.
   5 a
   6 a   auto-revert:
   7 b        procedure options(main);
   8 b        declare
   9 b            i fixed,
  10 b            sysin file;
  11 b
  12 c        do i = 1 to 10000;
  13 c            call P(i,exit);
  14 c            exit:
  15 c        end;
  16 b
  17 b   P:
  18 c        procedure (index,lab);
  19 c        declare
  20 c            (t, index) fixed,
  21 c            lab label;
  22 c
  23 c        on endfile(sysin)
  24 c            goto lab;
  25 c
  26 c        put skip list(index,':');
  27 c        get list(t);
  28 c        if t = index then
  29 c            goto lab;
  30 c        end P; /* implicit REVERT supplied here
  31 b
  32 b   end auto-revert;
```

Listing 10–1. The REVERT Program

In the REVERT program, line 13 calls the procedure P and passes to it the actual parameters i, the DO-group index, and the label constant

exit. The ON statement inside P executes every time the procedure is called. Thus, REVERT has three possible ways to exit the procedure P.

If you enter an end-of-file character, CTRL-Z, REVERT executes the enabled ON condition and sends control through the label variable lab to the statement labeled exit. PL/I deactivates the procedure and executes the REVERT statement because the GOTO statement transfers control outside the environment of P.

The second possible exit follows the test on line 28. If you enter a value equal to the index, then the GOTO statement on line 29 executes and again sends control outside the environment of P.

Finally, if control reaches the end of P, PL/I executes the REVERT statement and disables the ON condition set on line 23. No matter how control leaves the environment of the procedure, PL/I always disables the ON condition.

10.2.2 SIGNAL

The SIGNAL statement activates the ON-body, the body of statements corresponding to a particular ON statement. Thus, processing a SIGNAL statement has the same effect as when the run-time system signals the condition.

The following code sequence illustrates the SIGNAL statement.

```
      on endfile(sysin)
            stop;


      do while ('l'b)
            get list(buff);
            if buff = 'END' then
                  signal endfile(sysin);
            put skip list(buff);
```

This code executes the SIGNAL statement whenever the GET LIST statement reads the value END from the file SYSIN. Thus, the ON condition receives control on a real end-of-file, or when the value END is read.

10.3 Examples of Condition Processing

The following two programs, FLTPOLY2 and COPYLPT, incorporate some condition processing, so you can see how these concepts are implemented.

10.3.1 The FLTPOLY2 Program

Listing 10-2 shows the FLTPOLY2 program. This is essentially the same program listed in Section 7-1. The only difference is that it incorporates condition processing to intercept the end-of-file condition for the file SYSIN. If you run this program, you will see how you can stop it with a CTRL-Z character. Unlike FLTPOLY, if you enter all zeros, FLTPOLY2 simply evaluates the polynomial and prompts you for more input.

```
1 a
2 a /* This program evaluates a polynomial expression */
3 a /* using FLOAT BINARY data. It also traps the */
4 a /* end-of-file condition for the file SYSIN. */
```

```
  5 a
  6 a fltpoly2:
  7 b   procedure options(main);
  8 b   %replace
  9 b        false by '01b,
 10 b        true by 111b;
 11 b   declare
 12 b        (x,y,z) float binary(24),
 13 b        eofile bit(l) static initial(false),
 14 b        sysin file;
 15 b
 16 b   on endfile(sysin)
 17 b        eofile = true;
 18 b
 19 c   do while(true);
 20 c        put skip(2) list('Type x,y,z:
 21 c        get list(x,y,z);
 22 c
 23 c        if eofile then
 24 c            stop;
 25 c
 26 c        put skip list('  21);
 27 c        put skip list('  x   + 2y + z =',P(x,y,z));
 28 c   end;
 29 b
 30 b   P:
 31 c        procedure (x,y,z) returns (float binary(24));
 32 c        declare
 33 c            (x,y,z) float binary(24);
 34 c        return (x * x + 2 * y + z);
 35 c   end P;
 36 b
 37 b end fltpoly2;
```

Listing 10–2. The FLTPOLY2 Program

10.3.2 The COPYLPT Program

Listing 10-3 shows an example of I/O processing using ON conditions. The COPYLPT program copies a STREAM file from the disk to a PRINT file, while properly formatting the output line with a page header and line numbers. The program accepts console input to obtain the parameters for the copy operation, and provides error exits and retry operations for each input value. COPYLPT sets up various ON units to intercept errors during the copy operation that takes place in the iterative DO-group between lines 71 and 76. The following sections discuss the individual parts of the program.

```
  1 a
  2 a  /* This program copies a STREAM file on disk to a
  3 a  /* PRINT file, and formats the output with a page
  4 a  /* header, and line numbers.
  5 a
  6 b  copy: procedure options(main);
  7 b
  8 b  declare
  9 b       (sysin, sourcefile, printfile) file,
 10 b       (pagesize, pagewidth, spaces, linenumber) fixed,
 11 b       (line character(14), buff character(254)) varying;
```

```
 12 b
 13 b   put list('^z    File to Print Copy Program');
 14 b
 15 b   on endfile(sysin)
 16 b       go to typeover;
 17 b
 18 b   typeover:
 19 b   put skip(5) list('How Many Lines Per Page?');
 20 b   get list(pagesize);
 21 b
 22 b   put skip list('How Many Column Positions?');
 23 b   get skip list(pagewidth);
 24 b
 25 b   on error(1)
 26 c       begin;
 27 c           put list('Invalid Number, Type Integer');
 28 c           go to getnumber;
 29 c       end;
 30 b   getnumber:
 31 b       put skip list('Line Spacing (1=Single)?   ');
 32 b       get skip list(spaces);
 33 b       revert error(l);
 34 b
 35 b   put skip list('Destination Device/File:   ');
 36 b   get skip list(line);
 37 b
 38 b   open file(printfile) print pagesize(pagesize)
 39 b       linesize(pagewidth) title(line);
 40 b
 41 b   on undefinedfile(sourcefile)
 42 c       begin;
 43 c       put skip list('"',line,'" isn''t a Valid Name');
 44 c       go to retry;
 45 c       end;
 46 b   retry:
 47 b       put skip list('Source File to Print?
 48 b       get list(line);
 49 b       open file(sourcefile) stream environment(b(8000))
 50 b           title(line);
 51 b   on endfile(sourcefile)
 52 c       begin;
 53 c       put file(printfile) page;
 54 c       stop;
 55 c       end;
 56 b
 57 b   on endfile(printfile)
 58 c       begin;
 59 c       put skip list('-g^g^g^g Disk is Full');
 60 c       stop;
 61 c       end;
 62 b
 63 b   on endpage(printfile)
 64 c       begin;
 65 c       put file(printfile) page skip(2)
 66 c           list('PAGE',pageno(printfile));
 67 c       put file(printfile) skip(4);
 68 c       end;
 69 b
```

```
 70 b   signal endpage(printfile);
 71 c        do linenumber = 1 repeat(linenumber + 1);
 72 c        get file (sourcefile) edit(buff)      (a);
 73 c        put file (printfile)
 74 c            edit(linenumber,'|',buff) (f(5),x(l),a(2),a);
 75 c        put file (printfile) skip(spaces);
 76 c   end;
 77 b
 78 b end copy;
```

Listing 10–3. The COPYLPT Program

The COPYLPT program begins by reading five values:

- the number of lines on each page
- the width of the printer line
- the line spacing, normally single- or double-spaced output
- the destination file or device
- the source file or device

While entering these parameters, you can type an end-of-file CTRL-Z character and restart the prompting.

The Put LIST statement on line 13 writes the initial sign-on message. Recall that PL/I allows control characters in string constants. Here, the first character of the message is a CTRL-Z, which clears the screen if you are using an ADM-3A TM CRT device. If you are using some other device, you can substitute the proper character and recompile the program.

The ON statement of line 15 traps the ENDFILE condition for the file SYSIN, so that execution begins at typeover whenever the console reads an end-of-file character.

Lines 19 through 23 read the first two parameters with no error checking other than detecting the end-of-file. Line 25 however, intercepts conversion errors for all operations that follow. If the GET statement on line 32 reads a nonnumeric field, control passes to the on-body between lines 26 and 29 that writes an error message, branches to getnumber, and retries the input operation. Following successful input of the parameter spaces, the REVERT statement on line 33 disables the conversion error handling.

COPYLPT opens the input and output files between lines 38 and 50. The program assumes that the output file can always be opened, but detects an UNDEFINED input file, so you can correct the filename.

The program executes two ON ENDFILE statements between lines 51 and 61. The first statement traps the input end-of-file condition and performs a page eject on the output file. This ensures that the printer output is at the top of a new page after completing the print operation. The STOP statement included in this ON-unit completes the processing with an exit.

The second ON-unit intercepts the end-of-file condition on the print file. This can only occur if the disk file fills, so the unit prints the message,

```
      Disk is Full
```

and ends execution. The CTRL-G character sends a series of beeps to the CRT as an alarm. The run-time system closes all files upon termination, so that the print file is intact to the full capacity of the disk.

Line 63 begins an ON ENDPAGE unit that intercepts the end-of-page condition for the print file. Whenever the run-time system signals this condition, the ON-unit moves to the top of the next page, skips two lines, prints the page number, and skips four more lines before returning to the signal source. The SIGNAL statement on line 70 starts the print file output on a new page by sending control to the ON-unit defined on line 63. All subsequent ENDPAGE signals are generated by the run-time system at the end of each page.

The DO-group beginning on line 71 initializes and increments a line counter on each iteration. The GET EDIT statement on line 72 specifies an A, alphanumeric, format. This fills the buffer with the next input line up to, but not including, the carriage return/line-feed sequence. The PUT EDIT statement on line 73 writes the line to the destination file with a preceding line number, a blank, a vertical bar, and another blank, resulting from the A(2) field. if the run-time system signals the ENDPAGE condition while executing the PUT statement on line 75, the format item SKIP(spaces) might not be processed.

Listing 10-4 shows the user interaction with the COPYLPT program. Here, the source file is the LABELS.PLI program, and $LST, the physical printer, is the destination.

```
A>copylpt
    File to Print Copy Program

How Many Lines Per Page?  20

How Many Column Positions?    80

Line Spacing (1=Single)?  Yes
Invalid Number, Type Integer
Line Spacing (1=Single)?  1
Destination Device/File:  $lst
Source File to Print?     copy.pil

" copy.pil " isn't a Valid Name
Source File to Print?     copy.pli
```

Listing 10–4. Interaction with COPYLPT

Listing 10-5 shows two pages of output produced by the program.

```
PAGE    1



     1 |
     2 |/* This program copies one file to another using
     3 |/* buffered I/O.
     4 |
     5 |copy:
     6 |     procedure options(main);
     7 |     declare
     8 |         (input-file,output_file) file;
     9 |
    10 |     open file (input_file) stream
```

```
    11 |             envirorLment(b(8192))   title('$l.$l');
    12 |
    13 |     open file (output_file) stream output
    14 |             envirorunent(b(8192))   title('$2.$2');
    15 |     declare
    16 |         buff character(254) varying;
    17 |
    18 |     do while('l'b);
    19 |         read file (input_file)      into (buff);
    20 |         write file (output_file) from (buff);


PAGE    2



    21 |     end;
    22 |end copy;
```

Listing 10–5. Output from COPYLPT

This example shows how you can incorporate error handling in your programs to make them easier to use. In fact, you could enhance the COPYLPT program to handle errors in the first two input lines, or errors in the destination filename.

To gain further experience, you could go back over all the previous examples and add ON-units to trap invalid input data and end-of-file conditions. Modifying these small programs gives you a good foundation in condition processing.

References: LRM, Section 9.1 to 9.3, 10.5, 11.3

End of Section 10

11 Character String Processing

PL/I provides powerful character-string handling capabilities essential in a commercial production language. This section presents two sample programs that illustrate the use of some PL/I character-string functions. After you read the text and study the sample programs, you can make changes in the programs to expand your knowledge of PL/I.

11.1 The OPTIMIST Program

Our first example of string processing is a program called the OPTIMIST. The OPTIMIST program turns a negative sentence into a positive sentence. The OPTIMIST performs this task by using the character-string facilities of PL/I.

Listing 11-1 shows the OPTIMIST program. The first segment, between lines 12 and 23, defines the data items used in the program. The remaining portion reads a sentence from the console, ending with a period, and retypes the sentence in its positive form. Listing 11-2 shows a sample console interaction with the OPTIMIST. The OPTIMIST works well if sentences are simple, but complicated sentences confuse the program.

Line 13 gives the OPTIMIST vocabulary of negative words, with the corresponding positive words on line 15. Thus, never becomes always, and none becomes all. OPTIMIST replaces the word not with an empty string. Lines 17 through 20 declare the upper- and lower case alphabets for case translation in the sentence processing section.

OPTIMIST constructs each successive input sentence between lines 28 and 32, where the DO-group reads another word, and concatenates the word on the end of the sentence. The SUBSTR test in the DO WHILE heading checks for a period at the end.

Note: OPTIMIST can only accept a sentence whose maximum length is 254 characters. PL/I discards any additional characters.

After reading the complete sentence, OPTIMIST translates all upper case characters to lower-case to scan the negative words. It performs this case translation on line 33 by using the built-in TRANSLATE function. OPTIMIST uses the built-in VERIFY function on line 34 to ensure that the sentence consists only of letters and a period.

If the sentence consists of characters other than letters or a period, the VERIFY function returns the first nonzero position that does not match, and the OPTIMIST responds with:

```
Actually, that's an interesting idea.
```

If the VERIFY function returns a zero value, then the sentence contains only translated lower-case letters and a period. In this case, control transfers to the DO-group between lines 36 and 42. On each iteration, OPTIMIST uses the built-in INDEX function to search for the next negative word, given by negative (i). If found, it sets j to the position of the negative word, and in the assignment statement on line 39, replaces it with the corresponding positive word. In this assignment, the portion of the sentence that occurs before the negative word is given by,

```
substr(sent,l,j-1)
```

while the replacement value for the negative word is given by,

```
positive(i)
```

and the portion of the sentence that follows the negative word being replaced is given by:

```
substr(sent,j+length(negative(i)))
```

The OPTIMIST concatenates these three segments to produce a new sentence with the negative word replaced by the positive word. It then sends the resulting sentence to the console, and loops back to read another input. Because all negative words have a leading blank, the negative portion is always found at the beginning of a word. Thus, OPTIMIST replaces nevermind with alwaysmind. This can produce interesting results.

You could make at least three improvements to the OPTIMIST. First, if the sentence exceeds 254 characters, the input scan never stops, because the period is not found. You could include a check to ensure that the newly appended word does not exceed the maximum size.

Second, there is no condition processing in the DO-group between lines 25 and 45, so the OPTIMIST never stops talking. It ends only through input of a CTRL-Z, end-of-file, or CTRL-C, system warm start. You could include an ON-unit to detect an end-of-file to end the program in a reasonable fashion.

Finally, you could try to make the OPTIMIST smarter!

```
  1 a
  2 a /* This program demonstrates PL/I character string
  3 a /* processing by turning a negative sentence into a
  4 a /* positive one.
  5 a
  6 a optimist:
  7 b   procedure options(main);
  8 b   %replace
  9 b   true by '1'b,
 10 b   false by '0'b,
 11 b   nwords by 5;
 12 b   declare
 13 b   negative (1:nwords) character(8) varying static initial
 14 b   ('never',' none',' nothing',' not',' no'),
 15 b   positive (1:nwords) character(10) varying static initial
 16 b   ('always',' all',' something','',' some'),
 17 b   upper character(28) static initial
 18 b   ('ABCDEFGHIJKLMNOPQRSTUVWXYZ');
 19 b   lower character(28) static initial
 20 b   ('abcdefghijklmnopqrstuvwxyz');
 21 b   sent character(254) varying,
 22 b   word character(32) varying,
 23 b   (i,j) fixed;
 24 b
 25 c       do while(true);
 26 c       put skip list('What''s up?');
 27 c       sent = ' ';
 28 d            do while
 29 d            (substr(sentrlength(sent))
 30 d            get list (word);
 31 d            sent = sent  word;
```

```
 32 d           end;
 33 c       sent = translate(sent,lower,upper);
 34 c       if verify(sent,lower) ^= 0 then
 35 c       sent = ' that''s an interesting idea.';
 36 d           do i = 1 to nwords;
 37 d           j = index(sent,negative(i));
 38 d           if j ^= 0 then
 39 d           sent = substr(sent,l,j-1)
 40 d           positive(i) !!
 41 d           substr(sent,j+length(negative(i)));
 42 d           end;
 43 c       put list('Actually,'!!sent);
 44 c       put skip;
 45 c       end;
 46 b
 47 b   end optimist;
```

Listing 11–1. The OPTIMIST Program

```
A>optimist

What's up? Nothing is up.
Actually, something is up.

What's up? This is not fun.
Actually, this is fun.

What's up? Programs like this never make sense.
Actually, programs like this always make sense.

What's up? Nothing is easy that is not complicated.
Actually, something is easy that is complicated.

What's up? Nobody cares and its none of your business.
Actually, somebody cares and its all of your business.

What's up? The price of everything.
Actually, the price of everything.

What's up? Boy are you stupid.
Actually, boy are you stupid.

What's up? Dont get smart with me.
Actually, dont get smart with me.

What's up? You started it I didnt.
Actually, you started it i didnt.

What's up? No I did not.
Actually, some i did.

What's up? Thats better.
Actually, thats better.

What's up? You are hard to talk to.
Actually, you are hard to talk to.

What's up? There you go again.
Actually, there you go again.
```

```
What's up? Thats it I quit.
Actually, thats it i quit.

What's up? Stop that.
Actually, stop that.

What's up? If you dont stop I will pull your plug.
Actually, if you dont stop i will pull your plug.

What's up? You can not pull my plug.
Actually, you can pull my plug.

What's up? I know.
Actually, I know.

What's up? ^Z

END OF FILE (1), File: SYSIN=CON
Traceback: 09C5 0970 0157 4100 # 0909 0529 8090 0157
A>
```

Listing 11–2. Interaction with the OPTIMIST

11.2 A Parse Function

This section presents a more practical application of string processing. It is often useful to have a separate subroutine in a program that reads a line of input and separates it into individual numbers and characters. Such a subroutine is called a parser, or a free-field scanner. The FSCAN program, shown in Listing 11-3, gives an example of a parser.

FSCAN demonstrates the embedded subroutine called GNT, Get Next Token, which parses an input line into separate items called tokens. Once you test GNT, you can extract it from this program and put it into a production program where required. Section 13.4 uses GNT to compute values of arithmetic expressions.

Listing 11-4 shows interaction with the FSCAN program. FSCAN reads a line of input, parses the line into separate tokens, and then writes the tokens back to the console, with surrounding apostrophes. The tokens are just numeric values, such as 1234.56, or individual letters and special characters. GNT bypasses all intervening blanks between the tokens in the token scan.

The FSCAN program has three parts. The first part, lines 10 to 12, defines the global data area called token, used by the GNT procedure. The second part, lines 14 to 42, is the GNT procedure itself. The third part is the DO-group between lines 44 and 47 that performs the test of the GNT function procedure.

```
  1 a
  2 a      /* This program tests the procedure called GNT, a */
  3 a      /* free-field scanner, parser, that reads a line  */
  4 a      /* of input and breaks it into individual parts.  */
  5 a
  6 a      fscan:
  7 b          proc options(main);
  8 b          %replace
```

```
  9 b             true by '1'b;
 10 b         dcl
 11 b             token char(80) var
 12 b             static initial('');
 13 b
 14 b         gnt:
 15 c             proc;
 16 c             dcl
 17 c                 i fixed,
 18 c                 line char(80) var
 19 c                 static initial('');
 20 c
 21 c             line = substr(line,length(token)+1);
 22 d                 do while(true);
 23 d                 if line = '' then
 24 d                     get edit(line) (a);
 25 d                 i = verify(line,' ');
 26 d                 if i = 0 then
 27 d                     line = '';
 28 d                 else
 29 e                     do;
 30 e                     line = substr(line,i);
 31 e                     i = verify(line,'0123456789.');
 32 e                     if i = 0 then
 33 e                         token = line;
 34 e                     else
 35 e                     if i = 1 then
 36 e                         token = substr(line,1,1);
 37 e                     else
 38 e                         token = substr(line,1,i-1);
 39 e                     return;
 40 e                     end;
 41 d                 end;
 42 c             end gnt;
 43 b
 44 c             do while(true);
 45 c             call gnt;
 46 c             put edit('''''!!token!!''''') (x(1),a);
 47 c             end;
 48 b         end fscan;
```

Listing 11–3. The FSCAN Program

```
A>fscan
88+9.9
 '88' '+' '9.9'
1234567 89.10
 '1234567' '89.10'
1,2,3,4,5,6,7
 '1' ',' '2' ',' '3' ',' '4' ',' '5' ',' '6' ',' '7'
.... 666 .... 7.7.7.
 '....' '666' '....' '7.7.7.'
^Z

End of File (7), File: SYSIN=CON
Traceback: 08a1 23D1 0143 00FF # 08AB 06B9 0143 01F5
A>
```

Listing 11–4. Interaction with the FSCAN Program

11.2.1 The GNT Procedure

GNT stores the input line in the character variable called line that is initially empty due to the declaration on line 18. On the first call, GNT extracts the first portion of line and places it in token, which becomes the next input item. On each successive call, GNT removes the previous token value from the beginning of a line before scanning the next item.

For example, suppose the input line is,

```
~~~88*9.9
```

where ~ represents a blank character. On the first call to GNT, both token and line are empty strings. The assignment on line 21 removes the previous value of token and leaves line as an empty string. The DO-group between lines 22 and 41 ensures that the line buffer is always filled. If GNT encounters an empty buffer, the GET EDIT statement, line 24, immediately refills it. The call to the built-in VERIFY function on line 25 returns the first position in line that is not blank.

If VERIFY returns a 0, then the entire line is blank and must be cleared. The refill operation takes place on the next iteration. If the line is not entirely blank, then control transfers to the DO group beginning on line 29.

11.2.2 The DO-Group

Processing in the DO-group takes place as follows. On entry, the value of i is the first nonblank position of the line buffer. Thus, the statement on line 30 removes the preceding blanks from line, so the next token starts at the first position. GNT then calls the VERIFY function to determine if the next item in line is a number.

The assignment statement on line 31 sets i to 0 if the entire buffer consists of numbers and decimal points. Line 31 sets i to 1 if the first item is not a number or period. It sets i to a larger value than 1 if the first item is a number that does not extend through the entire line buffer. Thus, this sequence of tests, starting at line 32, either extracts the entire line (i=0) , the first character of the line (i=1), or the first portion of the line (i>1).

In the preceding example input line, on the first iteration GNT sets line to,

```
~     ~     ~     8     8     *     9     .     9
1     2     3     4     5     6     7     8     9
```

where the index 1 through 9, in line, is shown below each character. On line 30, GNT removes the initial blanks, leaving line as:

```
8     8     *     9     .     9
1     2     3     4     5     6
```

Line 31 calls the VERIFY function that locates the first position containing a nondigit or period character. In this case, VERIFY returns the value 3, which corresponds to the * in position 3. As a result of the tests, FSCAN executes line 38 and produces the equivalent of:

```
substr('88*9.9',1,2)
```

This results in a token value of 88, which is the next number in line.

On the next call, GNT removes token from line using the SUBSTR operation on line 21 and leaves line as:

```
      *     9     .     9

      1     2     3     4
```

The VERIFY function on line 31 returns the value 1, because the leading position of line is not a digit or a period. Line 36 extracts and returns the first character of line as the value of token.

The third call to GNT gets the last token in line by first extracting the first character of the line. This leaves line as:

```
      9     .     9

      1     2     3
```

This time, because all characters are either digits or periods, the VERIFY function returns a 0 and GNT executes line 33. This results in a token value of 9.9, which is the remainder of line.

The fourth call to GNT clears the previous value of token from line, so that line is the empty string. This causes GNT to execute the GET EDIT statement, line 24, and refill line from the console. FSCAN proceeds in this manner until you stop it with a CTRL-Z or CTRL-C input.

This simple parser has some obvious flaws. It does not trap the end-of-file condition. You could include an ON-unit to detect this condition, and return a null token value to indicate there is no more input. Furthermore, GNT does not detect multiple period characters. This would cause a subsequent conversion signal (ERROR(l)) if you attempt to convert to a decimal value.'

These enhancements give you an improved version of GNT that you can incorporate into any of your programs.

References: LRM Sections 3.2, 6.4, 6.8, 13.7

End of Section 11

12 List Processing

For some programs it is difficult to determine the exact memory requirements before the program runs. List processing is an example of this kind of program because the number of data elements can vary considerably while the program is running.

PL/I has subroutines in the Run-time Subroutine Library (RSL) that dynamically manage storage allocation. When the operating system loads a PL/I program into the Transient Program Area (TPA) or partition, PL/I first initializes all the remaining free memory as a linked list. The list elements contain information fields and pointers to other list elements. A program dynamically allocates memory by using the ALLOCATE statement and releases memory using the FREE statement. PL/I continuously keeps all memory segments connected to one another by using the linked-list mechanism.

The programs in this section illustrate list processing in two cases where it is not easy to predetermine the amount of storage required.

12.1 Based and Pointer Variables

You can visualize a based variable as a template that fits over a region of memory but has no storage directly allocated to it. A pointer variable is just a two-byte value that holds the address of a variable. When you use a pointer variable, you are programmatically placing this based variable template over a particular piece of memory. The method depends on the form of the based variable declaration.

If the based variable declaration does not include an implied base, then you must qualify any reference to the based variable with a pointer. If the based variable declaration includes an implied base, then you can include a pointer qualifier in any reference to the based variable, or you can simply use the implied pointer given in the declaration as a base.

Consider the following example declaration:

```
declare
      i fixed,
      mat(0:5) fixed,
      (p, q) pointer,
      x fixed based,
      y fixed based(p),
      z fixed based(f());
```

PL/I allocates storage for the two variables i and mat because they are not based variables. PL/I also assigns storage locations for the two pointer variables p and q. However, the three variables x, y, and z are declared as based variables, and they have no storage locations prior to execution. Instead, PL/I determines their actual storage addresses as the program runs. The variable x has no implied base, so every reference to x must have a pointer qualifier such as:

```
      p->x = 5;
```

or,

```
      q->x = 6;
```

The first statement assigns the value 5 to the FIXED BINARY two-byte variable at the memory location given by p. The second statement assigns the value 6 to the location given by q.

The variable y, on the other hand, has an implied base, and you can reference it with or without a pointer qualifier. The reference

```
y = 5;
```

equals

```
p->y = 5;
```

and thus, y = 5; and q->y = 6; have exactly the same effect as the two preceding assignments to x.

The variable z, like the variable y, has an implied base. In this case, the base is an invocation of a pointer-valued function with no arguments. For example, the function f can take the form:

```
f:
      procedure returns(pointer);
      return (addr(mat(i)));
      end f;
```

Using this definition of f, you can reference z as:

```
p->z = 5;
```

or

```
z = 6;
```

The first form is equivalent to those shown above, with the location derived from the pointer variable p. The second form however, is an abbreviation for:

```
f() -> z = 6;
```

In this case, PL/I evaluates the function f to produce the storage address for the based variable z. This form has a twofold advantage. First, the pointer-valued expression can be complex, and not restricted to a simple pointer variable. Second, the code for function f appears only once, rather than being duplicated at each variable reference. This can save a considerable amount of space in a program.

Note: The implied base must be in the scope of the declaration for the based variable.

The following incorrect code sequence illustrates this concept:

```
main:
      procedure options(main);
      declare
            x based(p),
            y based(q),
            p pointer;
      begin;
            declare
                  (p,q) pointer;
            x = 5;
            y = 10;
      end;
      declare
```

```
            q pointer;
        end main;
```

Because the variables x and y are based on p and q, the pointers p and q must be in the same or encompassing scope. Here the pointers p and q are declared in the embedded BEGIN block that is a different environment.

12.2 The REVERSE Program

Our first example of list processing is a program called REVERSE. The OPTIMIST program in Section 11 can accept a sentence with a maximum of 254 characters, the maximum string length. REVERSE, however, accepts sentences of virtually any length by using a list structure instead of a single character string. Instead of performing word substitution, REVERSE simply reverses the input sentence.

Listing 12-1 shows the REVERSE program, which is divided into three parts. The first part, lines 12 through 17, reads a sentence from the console and writes the sentence back to the console in reverse order. Each input sentence consists of a sequence of words up to 35 characters in length. This is sufficient to hold,

```
supercalifragilisticexpialidocious
```

one of the longest words in the English language.

To simplify the input processing, REVERSE requires a space before the period that ends the sentence. REVERSE also ends execution when you type an empty sentence.

The second part of REVERSE is a separate subroutine, called read - it, which starts on line 19. The third part is a subroutine called write it, which begins on line 37. Making these functions separate subroutines in the main program simplifies the overall structure.

Listing 12-2 shows the console interaction with REVERSE.

```
 1 a
 2 a  /* This program reads a sentence and reverses it.
 3 a
 4 a  reverse:
 5 b       procedure options(main);
 6 b       declare
 7 b            sentence pointer,
 8 b            1 wordnode based (sentence),
 9 b                 2 word character(35) varying,
10 b                 2 next pointer;
11 b
12 c       do while('l'b);
13 c            call read it();
14 c            if sentence = null then
15 c                 stop;
16 c            call write-it();
17 c  end;
18 b
19 b       read-it:
20 c            procedure;
21 c            declare
22 c                 newword character(35) varying,
23 c                 newnode pointer;
```

```
 24 c           sentence = null;
 25 c           put skip list('What''s up? ');
 26 d           do while('l'b);
 27 d               get list(newword);
 28 d               if newword then
 29 d                   return;
 30 d               allocate wordnode set (newnode);
 31 d               newnode->next = sentence;
 32 d               sentence = newnode;
 33 d               word = newword;
 34 d           end;
 35 c           end read-it;
 36 b
 37 b       write-it:
 38 c           procedure;
 39 c           declare
 40 c               p pointer;
 41 c           put skip list('Actually, ');
 42 d           do while (sentence ^= null);
 43 d               put list(word);
 44 d               p = sentence;
 45 d               sentence = next;
 46 d               free p->wordnode;
 47 d           end;
 48 c           put list('.');
 49 c           put skip;
 50 c           end write-it;
 51 b
 52 b   end reverse;
```

Listing 12–1. The REVERSE Program

```
A>reverse

What's up? North is up

Actually, up is North

What's up? The rain in Spain falls mainly in the plain

Actually, plain the in mainly falls Spain in rain The

What's up? 3 + 5 = 8

Actually, 8 = 5 + 3

What's up?

A>
```

Listing 12–2. Interaction with the REVERSE Program

The REVERSE program stores each word in a separate area of memory, obtained using the ALLOCATE statement on line 30. On each iteration of the DO-group, the ALLOCATE statement obtains a unique section of the free memory space sufficiently large to hold the wordnode structure defined on line 8. The wordnode elements are linked together through the next field of each allocation, and the beginning of the list is given by the value of the sentence pointer variable.

Each allocation consumes 38 bytes. You can verify this by examining the Symbol Table. The wordnode structure is 38 bytes long because word is declared as CHARACTER(35) VARYING, and requires one byte to hold the current length, 35 bytes to hold the string itself, and is followed by a two-byte pointer value.

For example, given the input sentence,

```
I SHALL RETURN .
```

REVERSE executes the ALLOCATE statement three times, once for each word in the list.

Suppose that these three memory allocations are found at addresses 1000, 2000, and 3000. The REVERSE program begins by reading the sentence in the main DO-group in the read it procedure. It initializes the sentence pointer to the null address (0000). Upon entering the DO-group at line 26, the value of sentence appears as follows:

```
SENTENCE:   0000
```

REVERSE reads the first word with the GET statement on line 27, and because the value is not a period, it allocates the first 38-byte area to hold the word. As it constructs the sentence, REVERSE places the pointer value of the sentence variable into the next field, and the input word into the word field. The most recently read word then becomes the new head of the list. After processing the word I, the list appears as shown:

```
SENTENCE:   1000

1000:
```

REVERSE then proceeds through the loop again. This time, it reads the word SHALL and allocates the second 38-byte area. The newly allocated area becomes the new head of the list, with the resulting pointer structure:

```
SENTENCE:   2000

2000: 1000:

X
```

REVERSE repeats the loop once again and processes the last word, RETURN, and allocates the final 38-byte area, placing it at the head of the list that results in the following sequence of nodes:

```
SENTENCE:   3000

3000: 2000: 1000:
```

The program follows the pointer structure from the sentence variable to the node for RETURN, then to the node for SHALL, and finally to the node for I, where it encounters an end-of-list value 0000.

REVERSE actually builds the list in reverse order. The DO-group in the write_it procedure, lines 42 to 47, simply searches through the list, starting at the sentence pointer, and prints each word it encounters. As soon as the word is written, the FREE statement on line 46 releases the 38-byte area allocated to it. The write it procedure moves the sentence pointer variable to the next item in the list before it executes the FREE statement to free the current element.

Note: Storage does not remain intact after it is released.

The advantage of the list structure is that the sentence can be arbitrarily long, limited only by the size of available memory. The disadvantage, of course, is that there is considerably more storage consumed for sentences that could be represented by a 254-character string.

12.3 A Network Analysis Program

The next example is extensive and illustrates two points. First, it demonstrates the power of PL/I list-handling constructs. Second, it shows how to divide a large, complex program into small, logically distinct units, and thereby simplify the coding task.

The NETWORK program shown in Listing 12-4 performs a network analysis. That is, it finds the shortest path between nodes in a network. The user enters a network of cities and distances between the cities. Then NETWORK constructs a connected set of nodes using list processing structures. Upon demand from the user, NETWORK computes the shortest path from all cities in the network to the assigned destination, and then selectively displays particular optimal paths through the network.

It is easier to understand how the program operates if you first examine the console interaction shown in Listing 12-3. First, you enter a list of cities and distances between the cities, ending the entry with a CTRL-Z. Entering a CTRL-Z triggers a display of the entire network to aid in detection of input errors. NETWORK then prompts you for a destination city, in this case, Tijuana, and a starting city, in this case, Boise.

NETWORK then displays a best route. There can be several of equal length. Next, NETWORK prompts for another starting city. If you enter a CTRL-Z. NETWORK reverts to another destination prompt, leaving the network intact. Interaction continues in this manner until you enter a CTRL-Z in response to the destination prompt. When this occurs, NETWORK clears the network and returns to accept an entirely new network of cities and distances. The entire program ends if you enter an empty network at this point, for example, a CTRL-Z.

```
A>network

Type "Cityl, Dist, City2"
Seattle, 150, Boise
Boise, 300, Modesto
Seattle, 400, Modesto
Modesto, 150, Monterey
Modesto, 50, San-Francisco
San-Francisco, 200, Las-Vegas
Las-Vegas, 350, Monterey
Los-Angeles, 400, Las-Vegas
Bakersfield, 300, Monterey
Bakersfield, 250, Las-Vegas
Los-Angeles, 450, Tijuana
Tijuana, 700, Las-Vegas
Las-Vegas, 920, Boise
Pacific-Grove, 5, Monterey
^Z

Pacific-Grove
    5 miles to Monterey
```

```
Tijuana :
     700 miles to Las-Vegas
     450 miles to LoS-Angeles
Bakersfield :
     250 miles to Las-Vegas
     300 miles to Monterey
Los-Angeles :
     450 miles to Tijuana
     400 miles to Las-Vegas
Las-Vegas :
     920 miles to Boise
     700 miles to Tijuana
     250 miles to Bakersfield
     400 miles to Los-Angeles
     350 miles to Monterey
     200 miles to San-Francisco
San-Francisco :
     200 miles to Las-Vegas
     50 miles to Modesto
Monterey :
     5 miles to Pacific-Grove
     300 miles to Bakersfield
     350 miles to Las-Vegas
     150 miles to Modesto
Modesto :
     50 miles to San-Francisco
     150 miles to Monterey
     400 miles to Seattle
     300 miles to Boise
Boise :
     920 miles to Las-Vegas
     300 miles to Modesto
     150 miles to Seattle
Seattle :
     400 miles to Modesto
     150 miles to Boise

Type Destination Tijuana

Type Start Boise

1250 miles remain,    300miles to Modesto
                 950 miles remain, 50 miles to San-Francisco
                 900 miles remain, 200 miles to Las-Vegas
                 700 miles remain, 700 miles to Tijuana
Type Start ^Z
Type Destination Pacific-Grove
Type Start Seattle
         555 miles remain,400 miles to Modesto
         155 miles remain,150 miles to Monterey
         5 miles remain,  5 miles to Pacific-Grove
Type Start ^Z
Type Destination ^Z
Type "City1, Dist, City2"
^Z
A>
```

Listing 12–3. Interaction with the NETWORK Program

12.3.1 NETWORK List Structures

NETWORK uses two data structures as list elements. The first structure is called a city_node and corresponds to a particular city. It is defined on line 16 of Listing 12-4. The following example shows the city_node structure:

```
CITY_NODE:   city_name
             total-distance
             investigate
             city-list
             route head
```

The city_name field holds the character-string value of the city's name, while the total distance and investigate fields are used by the shortest-distance procedure. The city_list and route – head pointer values link together all the cities in the network.

The second structure is called a route node, and is defined on line 23. A route - node establishes a single connection between a city and one of its neighbors. You allocate several route - nodes for a city, corresponding to the number of connections to its neighboring cities. The route-node structure is shown below:

```
ROUTE-NODE:  next_city
             route-distance
             route-list
```

The list of route - nodes associated with a particular city begins at the pointer value called route head that is a part of the city_node structure. The route is determined by following the route list pointer to additional route - nodes, until you encounter a route node with a null entry in the route list. Each route node also has a pointer value, denoted by next_city, that leads to a neighboring city_node, along with a route-distance field that gives the mileage to the next city.

The following example illustrates this concept. Assume Monterey is 350 miles from Las Vegas. NETWORK must allocate two city_nodes and two route nodes with sample addresses to the left of each allocation as follows. You can temporarily ignore the fields marked x in the diagram.

```
            CITY-NODE          CITY-NODE


      1000  Monterey     2000  Las Vegas
            xxxxxxx            xxxxxxx
            XXXXXXX            XXXXXXX
            xxxxxxx            xxxxxxx
            3000         4000
            ROUTE-NODE         ROUTE_NODE
      3000  2000   4000  1000
            350          350
```

A linked list, starting at city_head, leads to all cities in the network. Given the preceding two cities, the list of cities appears as follows:

```
CITY-HEAD
F-1 o-o T_~

CITY-NODE    CITY-NODE

1000   Monterey     2000   Las Vegas
       xxxxxxx             xxxxxxx
       xxxxxxx             xxxxxxx
       2000         0000

xxxxxxx
```

12.3.2 Traversing the Linked Lists

Several of the procedures in NETWORK use one particular form of an iterative DO-group to traverse the linked lists. The statement on line 95 is typical:

```
do p = city_head repeat (p->city_list) while (p^=null);
```

The DO-group header successively processes each element of the linked list starting at city_head until it encounters a null link, 0000. On the first iteration, the DO-group sets the pointer variable p to the value of the pointer variable city_head. In the example above, this results in the assignment p = 1000.

On the next iteration, p takes on the value of the city_list field at 1000 that addresses Las Vegas. This results in the value p = 2000. on the last iteration, p takes on the value of the city_list field based at 2000, resulting in p = 0000. The DO-group then stops executing because p is equal to null.

12.3.3 Overall Program Structure

Keeping in mind the preceding discussion, look at the overall program structure. The top-level program calls occur in the DO group between lines 31 and 38. The remainder of the program consists entirely of nested subroutines.

NETWORK is logically divided into four parts:

- The input section constructs and echoes the network of cities, consisting of four procedures beginning on line 45: setup, connect, find, and print_all.
- The analysis of the shortest path between the cities takes place in the shortest-distance procedure starting on line 164.
- The shortest path display operations are split between the two procedures print_paths and print_route, respectively.

- The free all procedure clears the old network before loading a new network.

Beginning on line 32, the main program calls setup to read the network. If the city_list is empty, then NETWORK stops. Otherwise, it calls print_all to display the network, and then calls print-Paths to prompt and display the shortest routes. Upon return, NETWORK calls free - all to release storage. This process continues until you enter an empty network.

12.3.4 The Setup Procedure

The main loop in setup occurs between lines 54 and 58. On each iteration, the GET LIST statement, line 55, reads a pair of cities with a connecting distance. Next, setup calls the connect subroutine twice to establish the connection in both directions between the cities. The ON-unit on line 50 intercepts the CTRL-Z

12.3.5 The Connect Procedure

The connect procedure establishes a single routenode to connect the first city to the second city. The connect procedure does this by calling the find procedure twice, once for the first city and once for the second city. The find procedure locates a city if it exists in the network, or creates the city_node if it does not yet exist. upon return from find, the connect procedure creates and fills in the route-node, lines 79 to 82.

In the previous example, the first call to connect establishes the city_nodes for Monterey and Las Vegas, indirectly through the find procedure, and then produces the route - node under Monterey only. The second call to connect establishes the route-node under Las Vegas.

12.3.6 The Find Procedure

The find procedure, starting at line 89, searches the city_list, beginning at city_head, until it finds the input city or exhausts the city_list. If the input city does not exist, find creates it between lines 100 and 105. In any case, find returns a pointer to the requested city_node.

12.3.7 The Print-All Procedure

The print_all procedure appears between lines 113 and 127. NETWORK calls print_all after creating the network. This procedure starts at city - head and displays all the cities in the city_list. As it visits each city, print all also traverses and displays the route - head. Upon compl~-tion of the print_all procedure, all city-nodes and route-nodes have been visited and displayed.

12.3.8 The Print-Paths Procedure

The print_paths procedure reads a destination city on line 143 and sends it to the shortest distance procedure. Upon return, print_paths sets the total - distance field of each city_node to the total distance from the destination city. You enter the starting city on line 148, and

print_paths sends it to the print_route procedure for the display operation.

12.3.9 The Print-Route Procedure

The print_route procedure at line 214 displays the best route from the input city to the destination. The procedure finds the best route as follows: The total distance from the input city to the destination has already been computed and stored in the total distance field. The procedure obtains the first leg of the best route by finding a neighboring city whose total distance field differs by exactly the distance to the neighbor. I-E then displays the neighbor, moves to the neighboring city, and repeats the same operation. Eventually, it reaches the destination city and completes the display operation.

Line 221 finds the original city_node. Line 231 displays the remaining distance, and the search for the first or next leg occurs between lines 233 and 244. On each iteration, line 236 tests to determine if a neighbor has been found whose total distance plus the leg distance matches the current city. If so, line 238 displays the leg distance and the search terminates by setting q to null.

12.3.10 The Shortest-Distance Procedure

This procedure takes an input city, called the destination, and computes the minimum total distance from every city in the network to the destination. It then records this total at each city_node in the total distance field. In calculating the minimum total distance, Fhe procedure implements the following algorithm:

1. Initially mark all total - distance fields with infinity (32767 in PL/I) to indicate that the node currently has no connection.
2. Set the investigate flag to false for each city. The investigate flag marks a city_node that needs further processing.
3. Set the total distance to the destination at zero; all others are currently set to infinity, but change during processing.
4. Set the investigate flag to true for the destination only.
5. Examine the city_list for the city_node that has the least total-distance, and whose investigate flag is true. At first, only the destination is found. When no city_node has a true investigate flag, all processing is complete and all minimum total-distance fields have been computed.
6. Clear the investigate flag for the city found in 4, and extract the current value of its total distance field. Examine each of its neighbors; if the current Total distance field plus the leg distance is less than the total-distance field marked at the neighbor, then replace the neighbor's total-distance field by this sum. Then mark the neighbor for processing by setting its investigate flag to true. After processing each neighbor, return to step 4.

The algorithm thus proceeds through the network, developing the shortest path to any node, and as a result, visiting each city exactly once. This is because the process is linear, and any additional nodes do not significantly effect the time to analyze the network.

12.3.11 The Free-All Procedure

The final procedure, free all starting at line 251, returns the network storage at the end of processing each network. The procedure visits and then discards each city_node and the entire list of route-node connections.

12.3.12 NETWORK Expansion

You can expand NETWORK in several ways. First, you can open a STREAM file and read the graph from disk, because it is inconvenient to type an entire network each time you run the program. You can also store several networks on disk and retrieve them on command from the console.

```
  1 a
  2 a      /* This program finds the shortest path between nodes   */
  3 a      /* in a network. It has 8 internal procedures:          */
  4 a      /* SETUP, CONNECT, FIND, PRINT_ALL, PRINT_PATHS,        */
  5 a      /* SHORTEST_DISTANCE, PRINT_ROUTE, and FREE_ALL.        */
  6 a
  7 a      network:
  8 b          proc options(main);
  9 b          %replace
 10 b              true     by '1'b,
 11 b              false    by '0'b,
 12 b              citysize by 20,
 13 b              infinite by 32767;
 14 b          dcl
 15 b              sysin file;
 16 b          dcl
 17 b              1 city_node based,
 18 b                2 city_name   char(citysize) var,
 19 b                2 total_dist  fixed,
 20 b                2 investigate bit,
 21 b                2 city_list   ptr,
 22 b                2 route_head  ptr;
 23 b          dcl
 24 b              1 route_node based,
 25 b                2 next_city   ptr,
 26 b                2 route_dist  fixed,
 27 b                2 route_list  ptr;
 28 b          dcl
 29 b              city_head ptr;
 30 b
 31 c              do while(true);
 32 c              call setup();
 33 c              if city_head = null then
 34 c                  stop;
 35 c              call print_all();
 36 c              call print_paths();
 37 c              call free_all();
 38 c              end;
 39 b
 40 b          setup:
 41 c              proc;
 42 c              dcl
 43 c                  dist fixed,
 44 c                  (city1, city2) char(citysize) var;
 45 c              on endfile(sysin) go to eof;
```

```
 46 c             city_head = null;
 47 c             put skip list('Type "City1, Dist, City2"');
 48 c             put skip;
 49 d                 do while(true);
 50 d                 get list(city1, dist, city2);
 51 d                 call connect(city1, dist, city2);
 52 d                 call connect(city2, dist, city1);
 53 d                 end;
 54 c             eof:
 55 c             end setup;
 56 b
 57 b         connect:
 58 c             proc(source_city, dist, dest_city);
 59 c             dcl
 60 c                 source_city char(citysize) var,
 61 c                 dist fixed,
 62 c                 dest_city   char(citysize) var;
 63 c             dcl
 64 c                 (r, s, d) ptr;
 65 c             s = find(source_city);
 66 c             d = find(dest_city);
 67 c             allocate route_node set (r);
 68 c             r->route_dist = dist;
 69 c             r->next_city  = d;
 70 c             r->route_list = s->route_head;
 71 c             s->route_head = r;
 72 c             end connect;
 73 b
 74 b         find:
 75 c             proc(city) returns(ptr);
 76 c             dcl
 77 c                 city char(citysize) var;
 78 c             dcl
 79 c                 (p, q) ptr;
 80 d                 do p = city_head
 81 d                     repeat(p->city_list) while(p^=null);
 82 d                 if city = p->city_name then
 83 d                     return(p);
 84 d                 end;
 85 c             allocate city_node set(p);
 86 c             p->city_name  = city;
 87 c             p->city_list  = city_head;
 88 c             city_head     = p;
 89 c             p->total_dist = infinite;
 90 c             p->route_head = null;
 91 c             return(p);
 92 c             end find;
 93 b
 94 b         print_all:
 95 c             proc;
 96 c             dcl
 97 c                 (p, q) ptr;
 98 d             do p = city_head
 99 d                 repeat(p->city_list) while(p^=null);
100 d             put skip list(p->city_name,':');
101 e                 do q = p->route_head
102 e                     repeat(q->route_list) while(q^=null);
103 e                 put skip list(q->route_dist,'miles to',
```

```
104 e                               q->next_city->city_name);
105 e                 end;
106 d             end;
107 c         end print_all;
108 b
109 b         print_paths:
110 c             proc;
111 c             dcl
112 c                 city char(citysize) var;
113 c             on endfile(sysin) go to eof;
114 d                 do while(true);
115 d                 put skip list('Type Destination ');
116 d                 get list(city);
117 d                 call shortest_dist(city);
118 d                 on endfile(sysin) go to eol;
119 e                     do while(true);
120 e                     put skip list('Type Start ');
121 e                     get list(city);
122 e                     call print_route(city);
123 e                     end;
124 d                 eol: revert endfile(sysin);
125 d                 end;
126 c             eof:
127 c             end print_paths;
128 b
129 b         shortest_dist:
130 c             proc(city);
131 c             dcl
132 c                 city char(citysize) var;
133 c             dcl
134 c                 bestp ptr,
135 c                 (d, bestd) fixed,
136 c                 (p, q, r) ptr;
137 d                 do p = city_head
138 d                     repeat(p->city_list) while(p^=null);
139 d                 p->total_dist  = infinite;
140 d                 p->investigate = false;
141 d                 end;
142 c             p = find(city);
143 c             p->total_dist  = 0;
144 c             p->investigate = true;
145 d                 do while(true);
146 d                 bestp = null;
147 d                 bestd = infinite;
148 e                     do p = city_head
149 e                         repeat(p->city_list) while(p^=null);
150 e                     if p->investigate then
151 f                         do;
152 f                         if p->total_dist < bestd then
153 g                             do;
154 g                             bestd = p->total_dist;
155 g                             bestp = p;
156 g                             end;
157 f                         end;
158 e                     end;
159 d                 if bestp = null then
160 d                     return;
161 d                 bestp->investigate = false;
```

```
162 e                       do q = bestp->route_head
163 e                           repeat(q->route_list) while(q^=null);
164 e                       r = q->next_city;
165 e                       d = bestd + q->route_dist;
166 e                       if d < r->total_dist then
167 f                           do;
168 f                           r->total_dist  = d;
169 f                           r->investigate = true;
170 f                           end;
171 e                       end;
172 d                   end;
173 c               end shortest_dist;
174 b
175 b           print_route:
176 c               proc(city);
177 c               dcl
178 c                   city char(citysize) var;
179 c               dcl
180 c                   (p, q) ptr,
181 c                   (t, d) fixed;
182 c               p = find(city);
183 d                   do while(true);
184 d                   t = p->total_dist;
185 d                   if t = infinite then
186 e                       do;
187 e                       put skip list('(No Connection)');
188 e                       return;
189 e                       end;
190 d                   if t = 0 then
191 d                       return;
192 d                   put skip list(t,'miles remain,');
193 d                   q = p->route_head;
194 e                       do while(q^=null);
195 e                       p = q->next_city;
196 e                       d = q->route_dist;
197 e                       if t = d + p->total_dist then
198 f                           do;
199 f                           put list(d,'miles to',p->city_name);
200 f                           q = null;
201 f                           end; else
202 e                       q = q->route_list;
203 e                       end;
204 d                   end;
205 c               end print_route;
206 b
207 b           free_all:
208 c               proc;
209 c               dcl
210 c                   (p, q) ptr;
211 d                   do p = city_head
212 d                       repeat(p->city_list) while(p^=null);
213 e                       do q = p->route_head
214 e                           repeat(q->route_list) while(q^=null);
215 e                       free q->route_node;
216 e                       end;
217 d                   free p->city_node;
218 d                   end;
219 c               end free_all;
```

```
 220 b
 221 b          end network;
```

Listing 12–4. The NETWORK Program

References: LRM Sections 3.4, 7.1-7.8, 8.2

End of Section 12

13 Recursive Processing

Recursive processing occurs when an active procedure calls itself, or is called by another active procedure. There are many programming problems that lend themselves to this kind of construct. This section has three such problems. The first two illustrate the basic concepts, and the last one uses recursion in a practical problem.

In a recursive procedure, a CALL statement, or function reference contained in the procedure itself, reinvokes the procedure before returning to the first level call. Therefore, you must declare all such procedures with the RECURSIVE attribute so PL/I can properly save and restore the local data areas at each level of recursive call.

Note: To maintain compatibility with full PL/I, you should not use formal parameters on the left of an assignment statement in a PL/I RECURSIVE procedure.

PL/I does not allow BEGIN blocks in RECURSIVE procedures. However , it does allow nested procedures and DO-groups. The examples that follow illustrate the proper formulation of RECURSIVE procedures.

13.1 The Factorial Function

The classic example of recursion is evaluation of the Factorial function. This function, used throughout mathematics, is a good illustration because you can define it by iteration and recursion.

The iterative definition of the Factorial function is

```
n! = (n)(n-l)(n-2) ... (2)(1)
```

where n! is the Factorial function, and n is a nonnegative integer. Therefore:

```
(n-l)! = (n-1)(n-2) ... (2)(1)
```

You can define the Factorial function using the recursive relation:

```
n! = n(n-l)!       (by definition, 0! = 1)
```

Evaluating the Factorial function using either iteration or recursion produces the following values:

```
0! = 1
1!   (1) = 1
2!   (2) (1) = 2
3!   (3) (2) (1) = 6
4!   (4) (3) (2) (1) = 24
5!   (5) (4) (3) (2) (1) = 120
6!   (6) (5) (4) (3) (2) (1) = 720
7!   (7) (6) (5) (4) (3) (2) (1) = 5040
8!   (8) (7) (6) (5) (4) (3) (2) (1) = 40320
9!   (9) (8) (7) (6) (5) (4) (3) (2) (1) = 362880
10! (10) (9) (8) (7) (6) (5) (4) (3) (2) (1) = 3628800
```

Listing 13-1 shows a program called IFACT that computes values of the Factorial function using iteration. The variable F is declared as a FIXED BINARY data item that accumulates the value of the factorial up to a maximum of 32767.

Listing 13-2 shows the output from IFACT. IFACT gives the proper value for the Factorial function up to 71, 5040. At this point, the variable F overflows and produces improper results, but the output continues.

Note: PL/I does not signal FIXEDOVERFLOW for binary computations.

Listing 13-3 shows the program RFACT that performs the equivalent evaluation of the Factorial function using recursion. For comparison, RFACT uses the REPEAT form of the DO-group to control the test. RFACT declares factorial as a RECURSIVE procedure, and calls the procedure at the top level in the PUT statement on line 10. Line 19 contains an embedded recursive call in the RETURN statement. Factorial returns when the input value is zero. All other cases require one or more recursive evaluations of factorial to produce the result. For example, 3! produces the sequence of computations,

```
factorial(3) = 3*factorial(2)
factorial(2) = 2*factorial(l)
factorial(l) = 1*factorial(0)
factorial(0) = 1
1     1
2     1     1
3     2     1     1
```

producing the value 6. Listing 13-4 shows the output for the recursive factorial evaluation produced by RFACT. The values again overflow beyond 5040 due to the precision of the computations.

```
 1 a
 2 a  /* This program evaluates the Factorial
 3 a  /* function (n!) using iteration.
 4 a
 5 a  ifact:
 6 b       procedure options(main);
 7 b       declare
 8 b           (i, n, f) fixed;
 9 b
10 c       do i 0 by 1;
11 c       f = 1;
12 d           do n = i to 1 by -1;
13 d           fact = n * f;
14 d           end;
15 c       put edit('factorial(',i,')=',fact)
16 c           (skip, a,f(2), a, f(7));
17 c       end;
18 b  end ifact;
```

Listing 13–1. The IFACT Program

```
A>ifact

factorial( 0)=   1
factorial( 1)=   1
factorial( 2)=   2
factorial( 3)=   6
factorial( 4)=   24
factorial( 5)=   120
factorial( 6)=   720
factorial( 7)=   5040
factorial( 8)=   -25216       the values are incorrect
factorial( 9)=   -30336       from this point on
```

```
factorial(10)=   24320
factorial(ll)=   5376
factorial(12)=   -1024
factorial(13)=   -13312
factorial(14)=   10240
factorial(15)=   22528
factorial(16)=   -32768
factorial(17)=   -32768
factorial(18)=   0
factorial(19)=   0
```

Listing 13–2. Output from the IFACT Program

```
   1 a
   2 a  /* This program evaluates the Factorial
   3 a  /* function (n!) using recursion.
   4 a
   5 a  rfact:
   6 b       procedure options(main);
   7 b       declare
   8 b            i fixed;
   9 c            do i = 0 repeat(i+l);
  10 c            put skip list('factorial(',i,')=',factorial(i));
  11 c            end;
  12 b       stop;
  13 b
  14 b       factorial:
  15 c            procedure(i) returns(fixed) recursive;
  16 c            declare
  17 c                i fixed;
  18 c            if i = 0 then return (1);
  19 c            return (i * factorial(i-1));
  20 c            end factorial;
  21 b
  22 b       end rfact;
```

Listing 13–3. The RFACT Program

```
A>fact

factorial( 0)=   1
factorial( 1)=   1
factorial( 2)=   2
factorial( 3)=   6
factorial( 4)=   24
factorial( 5)=   120
factorial( 6)=   720
factorial( 7)=   5040
factorial( 8)=   -25216   the values are incorrect
factorial( 9)=   -30336   from this point on
factorial(10)=   24320
factorial(11)=   5376
factorial(12)=   -1024
factorial(13)=   -13312
factorial(14)=   10240
factorial(15)=   22528
factorial(16)=   -32768
factorial(17)=   -32768
factorial(18)=   0
factorial(19)=   0
```

Listing 13–4. Output from the RFACT Program

13.2 FIXED DECINAL and FLOAT BINARY Evaluation

The Factorial evaluation programs here illustrate an important point about arithmetic calculations using different data types. Listing 13-5 shows a program called DFACT. It is the same recursive evaluation of the Factorial function found in RFACT, but it uses FIXED DECIMAL data with the maximum allowable precision. Listing 13-6 shows the output from DFACT. The largest value produced by the program is

```
Factorial(17) = 355,687,428,096,000
```

At this point, the run-time system signals FIXEDOVERFLOW to indicate that the decimal computation has overflowed the maximum 15 digit value.

Listing 13-7 shows the program FFACT that evaluates the Factorial function using FLOAT BINARY data. Listing 13-8 shows the output from FFACT. FFACT can compute the value of the function beyond 17. PL/I truncates the number of significant digits on the right to approximately 7 equivalent decimal digits. Again, FFACT ends when the run-time system signals the OVERFLOW condition because the program produces an exponent value that cannot be maintained in the floating-point representation.

```
 1 a
 2 a  /* This program evaluates the Factorial function
 3 a  /* (n!) using recursion and FIXED DECIMAL data.
 4 a
 5 a  dfact:
 6 b       procedure options(main);
 7 b       declare
 8 b           i fixed;
 9 C       do i = 0 repeat(i+l);
10 c           put skip list('Factorial(',i,')=',factorial(i));
11 c           end;
12 b       stop;
13 b
14 b       factorial:
15 c           procedure(i) returns(fixed decimal(15,0))
16 c               recursive;
17 c           declare
18 c               i fixed;
19 c
20 c           if i = 0 then return (1);
21 c           return (decimal(i,15) * factorial(i-1));
22 c           end factorial;
23 b
24 b       end dfact;
```

Listing 13–5. The DFACT Program

```
A>dfact

Factorial(   0)= 1
Factorial(   1)= 1
Factorial(   2)= 2
Factorial(   3)= 6
Factorial(   4)= 24
Factorial(   5)= 120
```

```
Factorial(   6)= 720
Factorial(   7)= 5040
Factorial(   8)= 40320
Factorial(   9)= 362880
Factorial(   10)=3628800
Factorial(   ll)=39916800
Factorial(   12)=479001600
Factorial(   13)=6227020800
Factorial(   14)=87178291200
Factorial(   15)=1307674368000
Factorial(   16)=20922789888000
Factorial(   17)=355687428096000
Factorial(   18)=
FIXED OVERFLOW (1)
Traceback: 0007 019F 0018 0000 # 2809 6874 0355 0141
A>
```

Listing 13–6. Output from the DFACT Program

```
  1 a
  2 a   /* This program evaluates the Factorial function
  3 a   /* (n!) using recursion and FLOAT BINARY data.
  4 a
  5 a   pfact:
  6 b       procedure options(main);
  7 b       declare
  8 b           i fixed;
  9 c       do i = 0 repeat(i+l);
 10 c           put skip list('Factorial(',i,')=',factorial(i));
 11 c           end;
 12 b       stop;
 13 b
 14 b       factorial:
 15 c           procedure(i) returns(float) recursive;
 16 c           declare
 17 c               i fixed;
 18 c           if i = 0 then return (1);
 19 c           return (i * factorial(i-1));
 20 c           end factorial;
 21 b
 22 b       end pfact;
```

Listing 13–7. The PFACT Program

```
A>pfact

Factorial(   0       1.OOOOOOE+00
Factorial(   I       1.OOOOOOE+00
Factorial(   2       2.OOOOOOE+00
Factorial(   3       0.600000E+01
Factorial(   4       2.400000E+01
Factorial(   5       1.200000E+02
Factorial(   6       0.720000E+03
Factorial(   7       0.504000E+04
Factorial(   8       4.032000E+04
Factorial(   9       3.628799E+05
Factorial(   10      3.628799E+06
Factorial(   11      3.991679E+07
Factorial(   12      4.790015E+08
Factorial(   13      0.622702E+10
```

```
Factorial(   14      0.871782E+ll
Factorial(   15      1.307674E+12
Factorial(   16      2.092278E+13
Factorial(   17      3.556874E+14
Factorial(   18      0.640237E+16
Factorial(   19      1.216450E+17
Factorial(   20      2.432901E+18
Factorial(   21      0.510909E+20
Factorial(   22      1.124000E+21
Factorial(   23      2.585201E+22
Factorial(   24      0.620448E+24
Factorial(   25      1.551121E+25
Factorial(   26      4.032914E+26
Factorial(   27      1.088887E+28
Factorial(   28      3.048883E+29
Factorial(   29      0.884176E+31
Factorial(   30      2.652528E+32
Factorial(   31      0.822283E+34
Factorial(   32      2.631308E+35
Factorial(   33      0.868331E+37
Factorial(   34
OVERFLOW (1)
Traceback: 006C 13CB 019B 0000 # 8608 OB15 FB51 0141
A>
```

Listing 13–8. Output from the FFACT Program

13.3 The Ackermann Function

The PL/I run-time system maintains a 512-byte stack area to hold subroutine return addresses and some temporary results. Under normal circumstances, this stack area is sufficiently large for nonrecursive and most simple recursive procedure processing. The program in this section, however, illustrates multiple recursion using a stack depth that can exceed the 512-byte default value.

The Ackermann function, denoted by A(m,n) , comes from Number Theory and has the following recursive definition:

```
A(m,n+l)           if m=0, otherwise
A(m,n)=A(m-1,1)    if n=0, otherwise
A((m-1),A(m,n-1))
```

Listing 13-9 shows the ACK program that reads two values for the maximum m and, n on line 11, and then evaluates the function for these values. Listing 13-10 shows the program interaction. Although the Ackermann function returns a FIXED BINARY value, the program uses the built-in DECIMAL function to control the size of the converted field in the PUT statements on lines 12, 15, and 17.

In this example, ACK uses the STACK option on line 7 to increase the size of the run-time stack from its default value, 512 bytes, to 2000 bytes.

Note: The STACK option is only valid with the MAIN option. You must determine the value of the STACK option empirically, because the compiler cannot compute the depth of recursion. If the allocated stack size is too small and the stack overflows during recursion, the run-time system outputs the message

```
FREE SPACE OVERWRITE
```

and then ends the program.

This kind of multiple recursion processing is CPU intensive. You should experiment with some different values for max, and see if you can determine how much stack is being used.

```
  1 a
  2 a  /* This program evaluates the Ackermann function
  3 a  /* A(m,n), and increases the size of the stack
  4 a  /* because of the large number of recursive calls.
  5 a
  6 a  ack:
  7 b       procedure options(main,stack(2000));
  8 b       declare
  9 b           (m,maxm,n,maxn) fixed;
 10 b       put skip list('Type max m,n: ');
 11 b       get list(maxm,maxn);
 12 b       put skip
 13 b       list('   ',(decimal(n,4) do n=0 to maxn));
 14 c       do m = 0 to maxm;
 15 c           put skip list(decimal(m,4),':');
 16 d           do n = 0 to maxn;
 17 d               put list(decimal(ackermann(m,n),4));
 18 d           end;
 19 c       end;
 20 b       stop;
 21 b
 22 b       ackermann:
 23 c           procedure(m,n) returns(fixed) recursive;
 24 c           declare (m,n) fixed;
 25 c           if m = 0 then
 26 c               return(n+l);
 27 c           if n = 0 then
 28 c               return(ackermann(m-1,1));
 29 c           return(ackermann(m-l,ackermann(m,n-1)));
 30 c           end ackermann;
 31 b
 32 b       end ack;
```

Listing 13–9. The ACK Program

```
A>ack

Type max m,n: 3,5

    0   1   2   3   4   5
0:  1   2   3   4   5   6
1:  2   3   4   5   6   7
2:  3   5   7   9   11  13
3:  5   13  29  61  125 253
A>
```

Listing 13–10. Interaction with the ACK Program

13.4 An Arithmetic Expression Evaluator

One of the practical uses of recursion is the translation of statements in a high-level programming language. This is because most languages are defined recursively. In block-structured languages like PL/I for example, DO-groups and BEGIN and PROCEDURE blocks can all be nested,

and the resulting structure lends itself easily to recursive processing.

The next example illustrates how you can use recursion to evaluate arithmetic expressions. Here is a simple, recursive definition of an arithmetic expression: An expression is a simple number, or a pair of expressions separated by a +, -, *, or /, and enclosed in parentheses.

Using this definition, the number 3.6 is an expression because it is a simple number. Clearly,

```
(3.6 + 6.4)
```

is an expression because it consists of a pair of expressions that are both simple numbers, separated by a +, and enclosed in parentheses. Also,

```
(1.2 * (3.6 + 6.4))
```

is a valid expression because it contains the two valid expressions 1.2 and (3.6 + 6.4), separated by a * and enclosed in parentheses Using the definition given above, the sequences,

```
3.6 + 6.4
```

```
(1.2 + 3.6 + 6.4)
```

are not valid expressions because the first is not enclosed in parentheses, while the second is not a pair of expressions in parentheses.

The preceding definition of an expression is somewhat restricted. Once a definition is established, it is easy to expand it to include more complex expressions.

Listing 13-11 shows an expression evaluation program called EXPR1. The main processing takes place between lines 27 and 31 where EXPR1 reads an expression from the console and types the evaluated result back to you. Listing 13-12 shows the console interaction with EXPR1 where the user enters several properly and improperly formed expressions.

```
 1 a
 2 a      /* This program evaluates an arithmetic expression      */
 3 a      /* using recursion. It contains two procedures. GNT     */
 4 a      /* obtains the input expression consisting of separate  */
 5 a      /* tokens, and EXP that performs the recursive          */
 6 a      /* evaluation of the tokens in the input line.          */
 7 a
 8 a      expression:
 9 b          proc options(main);
10 b          dcl
11 b              sysin file,
12 b              value float,
13 b              token char(10) var;
14 b
15 b          on endfile(sysin)
16 b              stop;
17 b
18 b          on error(1)
19 b              /* conversion or signal */
20 c              begin;
21 c              put skip list('Invalid Input at ',token);
22 c              get skip;
```

```
 23 c             go to restart;
 24 c             end;
 25 b
 26 b         restart:
 27 c             do while('1'b);
 28 c             put skip(3) list('Type expression: ');
 29 c             value = exp();
 30 c             put skip list('Value is:',value);
 31 c             end;
 32 b
 33 b         gnt:
 34 c             proc;
 35 c             get list(token);
 36 c             end gnt;
 37 b
 38 b         exp:
 39 c             proc returns(float binary) recursive;
 40 c             dcl x float binary;
 41 c             call gnt();
 42 c             if token = '(' then
 43 d                 do;
 44 d                 x  = exp();
 45 d                 call gnt();
 46 d                 if token = '+' then
 47 d                     x = x + exp();
 48 d                 else
 49 d                 if token = '-' then
 50 d                     x = x - exp();
 51 d                 else
 52 d                 if token = '*' then
 53 d                     x = x * exp();
 54 d                 else
 55 d                 if token = '/' then
 56 d                     x = x / exp();
 57 d                 else
 58 d                 signal error(1);
 59 d                 call gnt();
 60 d                 if token ^= ')' then
 61 d                     signal error(1);
 62 d                 end;
 63 c             else
 64 c                 x = token;
 65 c             return(x);
 66 c             end exp;
 67 b
 68 b         end expression;
```

Listing 13–11. The EXPRESSION Program using Evaluator EXPR1

13.4.1 The Exp Procedure

The heart of the expression analyzer is the RECURSIVE procedure exp. This procedure implements the recursive definition given above and decomposes the input expressions piece by piece. The GNT, Get Next Token, procedure reads the next element or token, a left or right parenthesis, a number, or one of the arithmetic operators, in the input line. GNT uses a GET LIST statement, so you must separate each token with a blank or end-of-line character.

On line 41, exp calls GNT. GNT places the next input token into the CHARACTER(10) variable called token. If the first item is a number, then the series of tests in exp sends control to line 64. The assignment to x automatically converts the value of token to a floating-point value. Then exp returns this converted value to line 29, where EXPR1 stores it into value, and subsequently writes it out as the result of the expression.

If the expression is nontrivial, then exp scans the leading left parenthesis on line 42, and enters the DO-group on line 43. EXPR1 immediately evaluates the first subexpression no matter how complicated, and stores it into the variable x on line 44. EXPR1 then checks token for an occurrence of +, -, *, or /. Suppose, for example, token contains the * operator. The statement on line 53 recursively invokes the exp procedure to evaluate the right side of the expression. Upon return, it multiplies this result by the value of the left side that was previously computed. EXPR1 then checks the balancing, right parenthesis starting on line 60, and returns the resulting product as the value of exp on line 64.

13.4.2 Condition Processing

EXPR1 performs condition processing in three places. The first ON unit, line 15, intercepts an end-of-file, CTRL-Z, condition on the input file, and executes a STOP statement. The second ON-unit, line 18, receives control if an error occurs during conversion from character to floating-point representation at the assignment on line 64. The ON-unit displays the token in error, and then executes a GET SKIP statement to clear the data to the end of the line. It then transfers control to the restart label, which prompts for another input expression.

EXPR1 signals a condition when it encounters an invalid operator or an unbalanced expression. If the operator is not a +, -, *, or /, then EXPR1 executes line 58 and signals the ON-unit, line 18. Again, the ON-unit displays the error and transfers control to the restart label. Similarly, a missing right parenthesis on line 60 signals the ERROR(l) ON-unit to report the error and restart the program. When the program restarts, PL/I discards the information on the current level of recursion.

```
A>exprl

Type expression: ( 4 + 5.2 )

Value is: 0.920000E+01

Type expression: 4.5e-1

Value is: 4.499999E-01

Type expression: ( 4 & 5 )

Invalid input at &

Type expression: ( ( 3 + 4 ) * ( 10 / 8 ) )

Value is: 0.875000E+01

Type expression: ( 3 * 4 )
```

```
Value is: 1.200000E+01

Type Expression: ^Z

A>
```

Listing 13–12. Interaction with EXPR1

13.4.3 Improvements

The expression analyzer requires spaces between tokens in the input line. Recall that Section 11.2 contains a more advanced version of GNT.

We incorporate this expanded version of GNT into the expression analyzer, and also change the error recovery mechanism so that now line 27 discards the remainder of the current input when restarting the program. Listing 13-13 shows the improved version called EXPR2, and Listing 13-14 shows the console interaction with this improved expression evaluator.

Even in EXPR2 there is room for expansion. First, you can add more operators to expand upon the basic arithmetic functions. Also, you can add operator precedence and eliminate the requirement for explicit parentheses. Beyond that, you can add variable names and assignment statements to turn the program into a BASIC interpreter!

```
  1 a     /*
  2 a     /* This program evaluates an arithmetic expression
  3 a     /* using recursion. It contains an expanded version
  4 a     /* of the GNT procedure that obtains an expression
  5 a     /* containing separate tokens. EXP then recursively
  6 a     /* evaluates the tokens in the input line.
  7 a     */
  8 a
  9 a     expression:
 10 b         proc options(main);
 11 b
 12 b         %replace
 13 b             true by '1'b;
 14 b
 15 b         dcl
 16 b             sysin file,
 17 b             value float,
 18 b             (token char(10), line char(80)) varying
 19 b                 static initial('');
 20 b
 21 b         on endfile(sysin)
 22 b             stop;
 23 b
 24 b         on error(1) /* conversion or signal */
 25 c             begin;
 26 c             put skip list('Invalid Input at ',token);
 27 c             token = ''; line = '';
 28 c             go to restart;
 29 c             end;
 30 b
 31 b         restart:
 32 b
 33 c             do while('1'b);
```

```
 34 c              put skip(3) list('Type expression: ');
 35 c              value = exp();
 36 c              put edit('Value is: ',value) (skip,a,f(10,4));
 37 c              end;
 38 b
 39 b          gnt:
 40 c              proc;
 41 c              dcl
 42 c                  i fixed;
 43 c
 44 c              line = substr(line,length(token)+1);
 45 d                  do while(true);
 46 d                  if line = '' then
 47 d                      get edit(line) (a);
 48 d                  i = verify(line,' ');
 49 d                  if i = 0 then
 50 d                      line = '';
 51 d                  else
 52 e                      do;
 53 e                      line = substr(line,i);
 54 e                      i = verify(line,'0123456789.');
 55 e                      if i = 0 then
 56 e                          token = line;
 57 e                      else
 58 e                      if i = 1 then
 59 e                          token = substr(line,1,1);
 60 e                      else
 61 e                          token = substr(line,1,i-1);
 62 e                      return;
 63 e                      end;
 64 d                  end;
 65 c              end gnt;
 66 b
 67 b          exp:
 68 c              proc returns(float binary) recursive;
 69 c              dcl x float binary;
 70 c              call gnt();
 71 c              if token = '(' then
 72 d                  do;
 73 d                  x  = exp();
 74 d                  call gnt();
 75 d                  if token = '+' then
 76 d                      x = x + exp();
 77 d                  else
 78 d                  if token = '-' then
 79 d                      x = x - exp();
 80 d                  else
 81 d                  if token = '*' then
 82 d                      x = x * exp();
 83 d                  else
 84 d                  if token = '/' then
 85 d                      x = x / exp();
 86 d                  else
 87 d                  signal error(1);
 88 d                  call gnt();
 89 d                  if token ^= ')' then
 90 d                      signal error(1);
 91 d                  end;
```

```
 92 c              else
 93 c                  x = token;
 94 c              return(x);
 95 c              end exp;
 96 b
 97 b          end expression;
```

Listing 13–13. Expression Evaluator EXPR2

```
A>expr2

Type expression: (2 * 14.5)

Value is:    29.0000

Type expression: ((2*3)/(4.3-1.5))
Value is:    2.1429

Type expression: zot
Invalid Input at z

Type expression: ((2*3)-5)
Value is:    1.0000

Type expression: (2 n5)
Invalid Input at n

Type expression: ^Z
A>
```

Listing 13–14. Interaction with EXPR2

References: LRM Sections 2.8 to 2.9, 3.1 to 3.2, 4.2, 9.1 to 9.4

End of Section 13

14 Separate Compilation

All of the programs presented so far are single, complete units, although many contain one or more internal procedures. It is often useful to break larger programs into distinct modules to be subsequently linked with one another and with the PL/I Run-time Subroutine Library (RSL).

There are two reasons for separately compiling and linking programs in this manner. First, large programs take longer to compile. Smaller segments can be independently developed, tested, and integrated, requiring less overall compilation time for the entire project. A large program can also overrun the memory space available for the Symbol Table.

Second, particular subroutines are useful for your own application programming. You can build your own library of subroutines and selectively link them to your programs. Having such a library of common subroutines greatly reduces the overall development time for any particular program.

This section presents basic information required to link program segments. It also presents an example of a program that is compiled as two separate modules and then linked together.

14.1 Data and Program Declarations

You can direct separate modules to share data areas by including the EXTERNAL attribute in the declaration of the data item. For example, the statement,

```
declare x(10) fixed binary external;
```

defines a variable named x occupying 10 FIXED BINARY locations, 20 contiguous bytes, that is accessible by any other module that uses the same declaration.

Similarly, the statement,

```
declare
      1 s external,
            2 y(10) bit(8),
            2 z character(9) varying;
```

defines a structure named s, occupying a 20-byte area that is accessible by any other modules that use the same declaration.

The following list summarizes basic rules that apply to the declaration of external data:

- EXTERNAL data items are accessible in any block in which you declare them. The EXTERNAL attribute overrides the scope rules for internal data.
- Initialize an EXTERNAL data item in only one module. Other modules can then reference the item.

Declare all EXTERNAL data areas with the same length in all modules in which they appear.

In 8-bit implementations, EXTERNAL data items must be unique in the first six characters because the linkage editing format truncates from

the seventh character on. In 16-bit implementations, there are no restrictions.

Avoid using ? symbols in variable names, because this character is used as a prefix for names in the RSL.

Remember that PL/I automatically assigns the STATIC attribute to any EXTERNAL data item.

14.2 ENTRY Data

ENTRY constants and ENTRY variables are data items that identify procedure names and describe their parameter values. ENTRY constants correspond to external procedures, or procedures defined in the main procedure.

ENTRY variables take on ENTRY constant values when the program runs through a direct assignment statement, or an argument- to-par ameter assignment implicit in a subroutine call.

You invoke a procedure directly through a call to an ENTRY constant, or indirectly by calling a procedure constant value held by an ENTRY variable. As with label variables, you can also subscript ENTRY variables.

The program shown in Listing 14-1 illustrates ENTRY data. The ENTRY variable f declared on line 8 is an array containing three ENTRY constants. Starting on line 12, the program initializes the subscripted elements to the constants a, b, and c respectively. Note that the constant a corresponds to an externally compiled procedure (see Listing 3-1a).

On line 16, the DO-group prompts for input of a value to send to each function, and then on line 19 calls each function once with the invocation,

```
f(i)(x)
```

where the first parenthesis pair defines the subscript, and the second encloses the list of actual arguments.

The declaration of ENTRY constants and ENTRY variables is similar to FILE constants and FILE variables. PL/I assumes all formal parameters declared as type ENTRY to be entry variables. In all other cases, an entry is constant unless you declare it with the VARIABLE keyword.

The following rules apply to external procedure declarations:

- You can access data items with the EXTERNAL attribute in any procedure where they are declared EXTERNAL.
- In 8-bit implementations, you must make external procedure names unique in the first six characters (see Section 14.1). In 16-bit implementations, there are no restrictions.
- Avoid using the ? symbol in procedure names.

Note: In addition, you must ensure that each parameter exactly matches the procedure declaration, and that the RETURNS attribute exactly matches the form returned for function procedures.

```
1 a     /*
2 a     /* This program illustrates ENTRY variables and
```

```
  3 a      /* constants.
  4 a      */
  5 a      call:
  6 b          proc options(main);
  7 b          dcl
  8 b              f (3) entry (float) returns (float) variable,
  9 b              g entry (float) returns (float);
 10 b          dcl
 11 b              i fixed, x float;
 12 b
 13 b          f(1) = sin;
 14 b          f(2) = g;
 15 b          f(3) = h;
 16 b
 17 c              do i = 1 to 3;
 18 c              put skip list('Type x ');
 19 c              get list(x);
 20 c              put list('f(',i,')=',f(i)(x));
 21 c              end;
 22 b          stop;
 23 b
 24 b          h:
 25 c              proc(x) returns (float);
 26 c              dcl x float;
 27 c              return (2*x + 1);
 28 c              end h;
 29 b          end call;
```

Listing 14–1. An Illustration of ENTRY Constants and variables

14.3 An Example of Separate Compilation

This section presents an example program consisting of two modules that are compiled separately and then linked together. The two modules are called MAININVT and INVERT, and are shown in Listings 14-2 and 14-3, respectively. Compiling each of these modules and then linking them together produces a program that interacts with the console to produce the solution set for a system of simultaneous equations.

To understand how the programs work, first consider the following system of equations in three unknowns:

```
a - b + c = 2      a - b + c = 3.5

a + b – c = 0      a + b – c = 1

2a – b = 0   2a – b = -1
```

The values,

```
a = 1        a = 2.25

b = 2        b = 5.50

c = 3        c = 6.75
```

constitute valid solutions to this system of equations, because:

```
1 - 2 + 3 = 2      2.25 - 5.50 + 6.75 = 3.50

1 + 2 - 3 = 0      2.25 + 5.50 - 6.75 = 1

2*1 – 2 = 0  2*2.25 - 5.50 = -1
```

The values 2,0,0 and 3.5,1,-1 are called solution vectors for the matrix. The coefficients of the matrix are

```
1   -1      1
1    1      -1
2   -1      0
```

The MAININVT module interacts with the console to read the coefficients and the solution vectors for a system of equations. The INVERT module performs the actual matrix inversion that solves the system of equations.

The essential difference between these two modules is found in the procedure heading. The MAININVT procedure is the main program because it is defined with the MAIN option. The invert procedure is a subroutine called by the main program. In Listing 14-2, the declaration starting on line 15 defines invert as an EXTERNAL entry constant that is then called on line 49.

On line 21, MAININVT declares the parameters for the invert procedure as a matrix of floating-point numbers denoted by maxrow and maxcol. Invert is defined with two additional FIXED(6) parameters, but does not return a value.

The invert procedure, shown in Listing 14-3 has three formal parameters called a, r, and c. They are defined on line 2 and declared in lines 7 and 8. INVERT takes the actual values of maxrow and maxcol, corresponding to the largest possible row and column value, from a %INCLUDE file, as indicated by the + symbols following the line number at the left of both listings.

After you compile both of the modules, link them together with the command:

```
A>link invmat=maininvt,invert
```

The linkage editor combines the two modules, selects the necessary subroutines from the RSL, and creates the command file, named INVMAT.

Listing 14-4 shows the interaction with INVMAT. In this sample interaction, the user first enters the identity matrix to test the basic operations. The inverse matrix produced for this input value is also the identity matrix.

The user then enters the preceding system of equations, together with two solution vectors. The output values for this system are shown under Solutions: and match the previously shown values. The second set of solutions corresponds to the second solution vector input.

Finally, the user tests INVMAT with an invalid input matrix size, and then ends the program by entering a zero row size.

```
 1 a     /*
 2 a         This program is the main module in a program that
 3 a         performs matrix inversion. It calls the entry
 4 a         constant INVERT which does the actual inversion.
 5 a     */
 6 a     maininvt:
 7 b         procedure options(main);
 8 b         %replace
 9 b             true   by '1'b,
10 b             false  by '0'b;
```

```
 11+b          %replace
 12+b              maxrow by 26,
 13+b              maxcol by 40;
 14 b          dcl
 15 b              mat(maxrow,maxcol) float (24);
 16 b          dcl
 17 b              (i,j,n,m) fixed(6);
 18 b          dcl
 19 b              var char(26) static initial
 20 b              ('abcdefghijklmnopqrstuvwxyz');
 21 b          dcl
 22 b              invert entry
 23 b                  ((maxrow,maxcol) float(24), fixed(6), fixed(6));
 24 b
 25 b          put list('Solution of Simultaneous Equations');
 26 c              do while(true);
 27 c              put skip(2) list('Type rows, columns: ');
 28 c              get list(n);
 29 c              if n = 0 then
 30 c                  stop;
 31 c
 32 c              get list(m);
 33 c              if n > maxrow ! m > maxcol then
 34 c                  put skip list('Matrix is Too Large');
 35 c              else
 36 d                  do;
 37 d                  put skip list('Type Matrix of Coefficients');
 38 d                  put skip;
 39 e                      do i = 1 to n;
 40 e                      put list('Row',i,':');
 41 e                      get list((mat(i,j) do j = 1 to n));
 42 e                      end;
 43 d
 44 d                  put skip list('Type Solution Vectors');
 45 d                  put skip;
 46 e                      do j = n + 1 to m;
 47 e                      put list('Variable',substr(var,j-n,1),':');
 48 e                      get list((mat(i,j) do i = 1 to n));
 49 e                      end;
 50 d
 51 d                  call invert(mat,n,m);
 52 d                  put skip(2) list('Solutions:');
 53 e                      do i = 1 to n;
 54 e                      put skip list(substr(var,i,1),'=');
 55 e                      put edit((mat(i,j) do j = 1 to m-n))
 56 e                          (f(8,2));
 57 e                      end;
 58 d
 59 d                  put skip(2) list('Inverse Matrix is');
 60 e                      do i = 1 to n;
 61 e                      put skip edit
 62 e                          ((mat(i,j) do j = m-n+1 to m))
 63 e                          (x(3),6f(8,2),skip);
 64 e                      end;
 65 d                  end;
 66 c              end;
 67 b      end maininvt;
```

Listing 14–2. MAININVT - Matrix Inversion Main Program Nodule

```
  1 a      invert:
  2 b          proc (a,r,c);
  3+b          %replace
  4+b              maxrow by 26,
  5+b              maxcol by 40;
  6 b          dcl
  7 b              (d, a(maxrow,maxcol)) float (24),
  8 b              (i,j,k,l,r,c) fixed (6);
  9 c          do i = 1 to r;
 10 c          d = a(i,1);
 11 d              do j = 1 to c - 1;
 12 d              a(i,j) = a(i,j+1)/d;
 13 d              end;
 14 c          a(i,c) = 1/d;
 15 d              do k = 1 to r;
 16 d              if k ^= i then
 17 e                  do;
 18 e                  d = a(k,1);
 19 f                      do l = 1 to c - 1;
 20 f                      a(k,l) = a(k,l+1) - a(i,l) * d;
 21 f                      end;
 22 e                  a(k,c) = - a(i,c) * d;
 23 e                  end;
 24 d              end;
 25 c          end;
 26 b      end invert;
```

Listing 14–3. INVERT Matrix Inversion Subroutine

```
A>invmat
Solution of Simultaneous Equations

Type rows, columnst 3,3

Type Matrix of Coefficients
Row 1        :1  0   0
Row 2        :0      1   0
Row 3        :0  0   1

Type Solution Vectors

Solutions:
a=
b=
C=

Inverse Matrix is
1.00    0.00    0.00
0.00    1.00    0.00
0.00    0.00    1.00

Type rows, columns: 3,5

Type Matrix of Coefficients
Row             1 :1 -1 1
Row             2 :11 -1
Row             3 :2 -1 0
Type Solution Vectors
Variable a :2 0 0
```

```
Variable b :3.5 1 -1
Solutions:
a =          1.00 2.25
b =          2.00 5.50
C =          3.00 6.75
Inverse Matrix       is
    0.50     0.50 0.00
    1.00     1.00 -1.00
    1.50     0.50 -1.00

Type rows, columns: 41,0

Matrix is Too Large

Type rows, columns: 0

A>
```

Listing 14–4. Interaction with the INVMAT Program

References: LRM Sections 3.3.2, 5.1 to 5.4, 8.2

End of Section 14

15 Decimal Computations

This section explains how PL/I handles decimal computations, stores decimal data, and converts data types. Study this material thoroughly because it is vital to understanding commercial processing.

15.1 A Comparison of Decimal and Binary Operations

The arithmetic with which we are most familiar uses the decimal number system. All operations, such as addition and multiplication, are based on the number ten, and involve the digits zero through nine. Computers, however, perform arithmetic operations using binary, or base 2, numbers. Computers use binary numbers because the ls and Os can be directly processed by the on-off electronic switches found in arithmetic processors.

Most programming languages allow you to write programs that process base 10 constants and data items in simple and readable forms. Because the programs process decimal values, it is necessary to convert values into a binary form on input and back to a decimal form on output. This conversion from one type to another can introduce truncation errors that are unacceptable in commercial processing. Thus, decimal arithmetic is often required to avoid propagating errors throughout computations.

In most programming languages, you have no control over the internal format used for numeric processing. Specifically, two of the most popular BASIC interpreters for microprocessors differ primarily in the internal number formats. One uses floating-point binary, while the other performs calculations using decimal arithmetic.

PASCAL compilers generally use floating- and fixed-point binary formats with implementation-defined precision, while FORTRAN compilers always use floating- or fixed-point binary.

However, COBOL was designed for use in commercial applications where exact dollars and cents must be maintained throughout computations. Therefore, COBOL processes data items using decimal arithmetic.

PL/I gives you a choice between representations, so that you can tailor the data in each program to the exact needs of the particular application. PL/I uses FIXED DECIMAL data items to perform commercial functions, and FLOAT BINARY items for scientific processing where computation speed is the most important factor, and truncation errors are insignificant or ignored altogether.

The following two programs illustrate the essential difference between the two data types:

Table 15–1. Difference of Decimal and Binary Data

```
decimal_comp:
    procedure options(main);
    declare
      i fixed,
      t fixed decimal(7,2);
    t = 0;
    do i = 1 to 10000;
      t = t + 3.10;
```

```
binary_comp:
    procedure options(main);
    declare
      i fixed,
      t float binary(24);
    t = 0;
    do i = 1 to 10000;
      t = t + 3.10;
```

```
    end;
    put edit(t) (f(10,2));
end decimal_comp;
```

```
    end;
    put edit(t) (f(10,2));
end binary_comp;
```

Both of these programs sum the value 3.10 a total of 10,000 times. The only difference between these programs is that DECIMAL_COMP computes the result using a FIXED DECIMAL variable, While BINARY_COMP performs the computation using FLOAT BINARY.

DECIMAL_COMP produces the correct result 31000.00, while BINARY_COMP produces the approximation 30997.30. The 2.70 difference is due to the inherent truncation errors that occur when PL/I converts certain decimal constants, such as 3.10, to their binary approximations. DECIMAL_COMP produces the exact result because no conversion occurs when using FIXED DECIMAL variables.

These two programs illustrate a more general problem. Suppose that during a particular day, Chase Manhattan Bank processes 10,000 deposits of $3.10. Using a program with FLOAT BINARY data, $3.10 cannot be represented as a finite binary fractional expansion. Therefore it is approximated in FLOAT BINARY form as 3.099999E+00. Each addition propagates a small error into the sum, resulting in an extra $2.70 unaccounted for at the end of the day.

There are also situations where decimal arithmetic produces truncation errors that can propagate throughout computations. For example, the fraction 1/3 cannot be represented as a finite decimal fraction, and thus is approximated as

```
0.3333333 ...
```

to the maximum possible precision. Such errors only occur when explicit division operations take place.

The difficulty with FLOAT BINARY representations is that some decimal constants expressed as finite fractional expansions in FIXED DECIMAL cannot be written as finite binary fractions. PL/I necessarily truncates these during conversion to FLOAT BINARY form.

There are both advantages and disadvantages in selecting FIXED DECIMAL arithmetic instead of FLOAT BINARY. One advantage of FIXED DECIMAL arithmetic is that it guarantees there is no loss of significant digits. All digits are considered significant in a computation, so that multiplication, for example, does not truncate digits in the least significant positions. Another advantage is that FIXED DECIMAL arithmetic precludes the necessity for exponent manipulation, and the operations are relatively fast when compared to alternative decimal arithmetic formats.

The disadvantage is that you must keep track of the range of values that arithmetic operands can assume because all digits are considered significant.

15.2 Decimal Representation

Decimal variables and constants have both a precision and scale factor. The precision is the number of digits in the variable or constant, while the scale factor is the number of digits in the fractional part. For FIXED DECIMAL variables and constants, the precision cannot exceed 15, and the scale factor cannot exceed the precision.

You can define the precision and scale factor of a variable in the variable declaration. For example,

```
declare x fixed decimal(10,3);
```

declares the variable x to have precision 10 and scale factor 3. The compiler automatically derives the precision and scale factor of a constant by counting the number of digits in the constant, and the number of digits following the decimal point. For example, the constant

```
-324.76
```

has precision 5 and scale factor 2.

Internally, PL/I stores FIXED DECIMAL variables and constants as Packed Binary Coded Decimal (BCD) pairs, where each BCD digit occupies either the high or low-order four bits of each byte. The most significant BCD digit defines the sign of the number. A zero denotes a positive number, and a nine denotes a negative number in the 10's-complement form, as described below. Because PL/I always stores numbers into 8-bit byte locations, there can be an extra pad digit at the end of the number to align it to an even byte boundary. For example, PL/I stores the number 83.62 as

```
0 8 3  6 2
```

where each digit represents a 4-bit half-byte position in the 8-bit value. PL/I stores the leading BCD pair lowest in memory.

PL/I stores negative numbers in 10's-complement form to simplify arithmetic operations. A 10's-complement number is similar to a 2's-complement binary representation, except the complement value of each digit x is 9-x.

To derive the 10's-complement value of a number, form the complement of each digit by subtracting the digit from 9, and add 1 to the final result. Thus, the 10's complement of -2 is formed as follows:

```
(9 - 2) + 1 = 7 + 1 = 8
```

PL/I adds the sign digit to the number that then appears as the single-byte value:

```
98
```

Look at an example. Suppose you want to add -2 and +3. PL/I represents these numbers as follows:

```
+ FO 3]
```

PL/I ignores the integers beyond the preceding sign digit, and produces the correct result 01. In the following discussion, we show negative numbers with a leading - sign, with the assumption that the internal representation is in 9's-complement form. Thus, we write the number -2 as

```
F- _2~
```

There is no need to explicitly store the decimal position in memory, because the compiler knows the precision and scale factor for each variable and constant. Before each arithmetic operation, the compiled code causes the necessary alignment of the operands. In later examples, we show a decimal point position to emphasize the effect of alignment.

For example, the number -324.76 appears as

```
3 1 2 47:F~
```

When PL/I prepares this value for arithmetic processing, it first loads it into an 8-byte stack frame, consisting of 15 BCD digits with a high-order sign. In this case, the -324.76 is shown as

```
0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 3 1 2 4 1 7 6
```

In ordinary arithmetic, when beginning each operation you must properly align the operands for that operation and, upon completion, you must decide where the resulting decimal point appears.

In PL/I, the compiler performs the alignment and accounts for the decimal point position, but it is useful for you to imagine what is taking place, so you can avoid overflow or underflow conditions. In some cases, you might want to force a precision or scale factor change during the computation using the DECIMAL or DIVIDE built-in functions. The sample programs discussed in the following sections give examples of these functions.

15.3 Addition and Subtraction

In PL/I, addition and subtraction are functionally equivalent. In subtraction, PL/I first forms the 10's complement of the subtrahend and then performs the addition. Given two numbers x and y, with precision and scale factor (p,q) and (p2,q2), respectively, the addition operation proceeds as follows.

First, PL/I loads the two operands onto the stack and then aligns them by shifting the operand with the smaller scale factor to the left until the decimal positions are the same. Given that the scale factor of x is greater than the scale factor of y, y is shifted q, - q2 positions to the left, with zero values introduced in the least significant positions.

After alignment, y has precision p,+(q,-q2) and scale factor q,. PL/I signals a FIXEDOVERFLOW condition if significant digits are shifted into the sign position during the alignment process.

Here is a specific example. Suppose x = 31465.2437 and y = 9343.412 so that x has precision p, = 9 and scale q, = 4, while y has precision p, = 7 and scale factor q2 = 3. Before alignment, the numbers appear as

```
9 ---------- 4W
x           +     0 0 0 0 0 0 3 1 4 6 5 A 2 4 3 7
            -4-4 --- 4~
            7.
y           +     0 0 0 0 0 0 0 0 9 3 4 3A4 1 2
            --&-3-w-
```

PL/I aligns y with x by shifting ql-q2 = 4-3 1 positions to the left, producing

```
          x = + 0 0 0 0 0 0 3 1 4 6 5 A 2 4 3 7
                4


y = + 0 0 0 0 0 0 0 9 3 4 3 4 1 2 0
```

The number of digits in the whole part of x is p,-q,, while the whole part of y contains P2-q2 digits,

-*-pl - q 1 ~ 5 --1.,

3 1 4 6 5

-0-P 2 - q2 ~ 4-p

9 3 4 3

so the sum must contain p,-ql = 5 digits in the whole part:

3 1 4 6 5
+ 9 3 4 3

4 0 8 0 8

-*- 5

There is a possibility that some values could produce an overflow, requiring one extra digit in the whole part:

9 9 9 9 9
+ 9 9 9 9 9

F119 9 9 9 8

(p, - qj) + = 6-p-

The total number of digits in the sum of x and y is the number of digits in the whole part, (pl-q,)+1=6, plus the number of digits in the fraction, given by qj, resulting in a precision of

(pi-q,) + 1 + q, = p, + 1

Given two values x and y, of arbitrary precision and scale factor, you can use the specific case shown above to derive the form of the resulting precision and scale factor. First, the scale must be the greater of q, and q21 given by,

max (ql,q2)

and the resulting precision must have max(q, q2) fractional digits.

Second, the whole part of x contains pj-qj digits, while the whole part of y contains P2-q2 digits. The result contains the larger of pi-q, and P2-q2 digitsr plus the fractional digits, along with one overflow digit, for a total of

max (pl-q,fP2-q2) + max (ql,q2) + 1

digit positions.

Because the precision cannot exceed 15 digits, the resulting precision must be the following:

min(15,max(p,-q,,p,-q,)+max(ql,q2)+')

digits.

The precision and scale factor of the resulting addition or subtraction written as a pair (p',ql) is the following:

```
      P I
      IN
      min(15,max(pl-q,,p~-q2)+max(q,,q2)+l), max(q,,q,)
```

Using the preceding example:

```
      9 -------------- W
            ..*.- 4
      x           +     0 0 0 0 0 0 3 1 4 6 5 A 2 4 3 7
      y           +     0 0 0 0 0 0 0 9 3 4 3 A 4 1 4 2 0
      p, + (qz - q 1           8
      x + y       + 0 0 0 0 0 0 4 0 8 0 8A6 5 5 7
                  --*- 4
```

The precision (10,4) shown in the diagram is derived using the Expression

```
      pf    qI
      min(15,max(9-4,7-3)+max(4,3)+l), max(4,3)
```

or

```
      min(15,max(5,4)+4+1), 4         (min(15,10),4)     (10,4)
```

15.4 Multiplication

Evaluating the precision and scale factor for multiplication is simpler than addition and subtraction because PL/I does not have to align the decimal point before the multiplication. Given two operands x and y with precision and scale factor (pl,q,) and (p,, q2) respectively, PL/I multiplies the two operands digit by digit to produce the result.

Just as in ordinary hand calculations, the number of decimal places in the result is the sum of the scale factors q, and P2. The total number of digits in the result is the sum of the precisions of the two operands. To conform to the PL/I Subset G standard, PL/I includes one additional digit position in the final precision. The precision and scale factor of the result (pl,q') is given by the following:

```
            p I q1
            (min(15rp,+P2+1)tql+q2)
```

Suppose that x = 924.5 and y = 862.33, with the precision and scale factor values (4,1) and (5,2):

```
      x + 0 0 0 0 0 0 0 0 0 0 0 9 2 4 A 5
      y + 0 0 0 0 0 0 0 0 0 0 8 6 2 A 3 3
```

The product of the digits of x and y is shown with the resulting precision and scale factor:

```
      '0
      x * y = + 0 0 0 0 0 0 7 9 7 2 2 4 A 0 8 5
            *- 3 --,W
```

where PL/I computes the precision and scale factor as

```
(min(15,4+5+1),1+2) = (min(15,10),3) = (10,3)
```

PL/I signals the FIXEDOVERFLOW condition if the product contains more than 15 significant digits. In the previous section, where x = 31465.2437 and y = 9343.412, the product x*y has precision 17, causing FIXEDOVERFLOW.

In this particular case, you must apply the DECIMAL function to reduce the number of significant digits in either x or y. The computation is carried out as

```
DECIMAL(x,9,3) * y
```

which loads the stack with the two following values before the multiplication takes place:

```
DECIMAL(x,9,3)     + 0 0 0 0 0 0 0 3 1 4 6 5 A 2 4 3

y     + 0 0 0 0 0 0 0 0 9 3 4 3 A 4 1 2
```

The precision and scale factor of the product is the following:

```
x * y = + 2 9 3 9 9 2 7 2 9 A 0 2 9 1 1 6

      6
```

PL/I first computes the precision as p,+p,+l = 16, and then reduces this to the maximum 15 digit precision by the following:

```
min(15,pl+p2+1) = min(15,16) = 15
```

When performing multiplication, it is your responsibility to ensure that the precisions of the operands involved do not produce overflow. You can explicitly declare the precision and scale factor of the variables involved in the computation, or apply the DECIMAL function to reduce the precision of a temporary result.

15.5 Division

Division is the only one of the four basic arithmetic operations that can produce truncation errors. Therefore each division operation produces a maximum precision value consisting of 15 decimal digits, and a resulting scale factor that depends upon the scale factors of the two operands.

Assuming that x and y have precision and scale factor (pllql) and (P2 q,) respectively, and that x is to be divided by y, the division operation takes place as follows.

First, PL/I shifts x to the extreme left by introducing 15-p, zero values on the right, leaving the dividend on the stack as

```
-           P I   *--l 5 - P 1       -

x x . . . x x            0 0 . . . 0 0

      A .*-q, ---s.
```

PL/I then shifts the decimal point of x right by an amount q2 to properly align the decimal point in the result, producing the following operands:

```
-*-PI        -     -.*- 15 - p,

x x . . . x x      0 0 . . . 0 0

'J'q, - q2~
```

```
0          0 0 0 y y y  y y
                 A
                 ,oq2"-
```

The significant digits of y then continuously divide the significant digits of x until the operation generates 15 decimal digits.

In the preceding diagram, the number of fractional digits produced by the division is determined by the placement of the adjusted decimal point in x. The field following the decimal point contains (q1-q.) plus (15-p,) positions, yielding the following precision and scale factor for the result of the division:

```
(15, (q1-q2)+(l5-p1))                or    (15,15-p1+q1-q2)
```

Suppose x = 31465.243, and y = 9343.41, have precision and scale factor values of (8,3) and (6,2), respectively. The value x when loaded on the stack appears as the following:

```
8
x = + 0 0 0 0 0 0 0 3 1 4 6 5A 2 4 3
```

PL/I then shifts the value of x to the extreme left and loads the value of y, producing the values:

```
              -W- 8
                    .q- 3  15 - 8 = 7
x     +               3 1 4 6 5 A 2 4 3 00 0 0 0 0 0
y + 0 0 0 0 0 0 0 0 0 9 3       4 3A4 1
              A*- 2 -0
        -W- 6
```

The imaginary decimal points are shifted to the right by two positions to properly align the decimal point in the result, producing

```
8 ------     7
x + 3 1 4 6 5            2 4 3 0 0 0 0 0 0 0
      ~-f)
y + 0 0 0 0 0            0 0 0 0 9 3 4 3 4 1 A
-*- 6
```

The six significant digits of y divide the significant digits of x with the following result:

```
15 --
x/y = + 0 0 0 0 0 0 3A3 6 7 6 4 0 1 8
      -..*- 8
```

In this case, the precision and scale factor of the result is given by

```
(15,(15-pl+ql-q,) = (15,15-8+3-2) = (15,8)
```

The most important consideration in decimal division is generating enough digits in the fractional part for the computation being performed. This is done in two ways.

First, when aligning the dividend, PL/I pads with zeros and provides 15-p, fractional digits. Thus, dividend values with small precision generate more fractional digits.

Second, if q, is greater than q2, then PL/I generates (ql,-q2) additional fractional digits as shown above. If on the other hand, the dividend contains fewer fractional digits than the divisor, then q, is less than q2 and (q2-ql) fractional digits are consumed.

The case of q, = q2 occurs quite often. In this particular situation, the number of fractional digits depends entirely upon the precision of the divisor, and results in 15-p, fractional digits.

You might also want to truncate or extend the result with zeros using the DIVIDE built-in function during a particular computation (see the PL/I Language Reference Manual, Section 4.2.5) The function has the form:

```
DIVIDE (x,y,p,q)
```

where p and q are literal constants. They can appear as an expression or subexpression in an arithmetic computation, and have the same effect as the statement:

```
DECIMAL (x/y,p,q)
```

As before, y divides x, but the precision and scale factor values are forced to (p,q) . PL/I carries out the computation as described, and then shifts the resulting value by the appropriate number of digits to obtain the desired precision and scale factor.

References: LRM Sections 3.1.2, 4.2

End of Section 15

16 Commercial Processing

Commercial applications of PL/I use decimal calculations. The four programs in this section illustrate PL/I built-in functions, EDIT formats including picture, and the method of breaking down a complex program into small, logically distinct procedures.

16.1 A Simple Loan Program

Listing 16-1 shows the LOAN1 program that computes a loan payment schedule using three input values corresponding to the loan principal (P) , the yearly interest rate (i) , and monthly payment (PMT) . LOAN1 continuously applies the following algorithm until the remaining principal reaches zero, and the loan is paid off.

The algorithm is

1. Each month, increase the starting principal P by an amount fixed by the interest rate.
   P = P + (i * P)

2. Each month, reduce the remaining principal by the payment amount.
   P = (P + (i * P)) - PMT

LOAN1 assumes that the principal does not exceed $999,999,999.99. Thus, the declaration on line 12 defines P as a FIXED DECIMAL variable with precision 11 and scale factor 2. The payment does not exceed $9,999-99, so PMT is declared as FIXED DECIMAL with precision 6 and scale factor 2. Finally, LOAN1 defines the interest rate i as FIXED DECIMAL(4,2), allowing numbers as large as 99.99%. The two variables m and y correspond to the month and year, beginning at the first month of the first year.

LOAN1 reads the initial values between lines 17 and 22. In this example, LOAN1 does not perform any range checking. Thus it can accept negative values, and can process payment values that cannot pay off the loan. These checks would have to be made in a real application environment.

On each iteration, LOAN1 increases the month until it reaches the 12th month, at which point the built-in MOD function, line 26, increments the year. LOAN1 then displays the current principal P on line 32, and adds the monthly interest on the following line.

LOAN1 performs the computation on line 33. The variable i has precision and scale factor (4,2) , while the variable P has precision and scale factor (11,2). Therefore, the multiplication i * P yields a temporary result with precision and scale factor (15,4).

Next, the division by the literal constant 1200 is required because the interest rate is expressed as a percentage (division by 100) over a one-year period (division by 12). The result of the division (i * P)/1200 has precision 15, because the constant 1200 has precision and scale factor (4,0). PL/I computes precision and scale factor in division as (15,15-15+4-0). Finally, LOAN1 uses the built-in function ROUND to round the second decimal place, the cents position.

In the last month, if the remaining principal is less than the payment, LOAN1 performs the test on line 34. if the test is true, line 35 changes the payment to equal the principal. Line 36 prints the payment,

and finally, line 37 reduces the principal by the payment using the assignment statement:

```
P = P - PMT;
```

Listing 16-2 shows the output from LOANI using an initial loan of $500, interest rate of 14%, and payment of $22.10 per month.

```
 1 a
 2 a  /* This program produces a schedule of loan payments
 3 a  /* using the following algorithm: if P = loan payment,
 4 a  /* I = interest, and PMT is the monthly payment then
 5 a  /* P = (P + (I * P) - PMT).
 6 a
 7 a  loan1:
 8 b      procedure options(main);
 9 b      declare
10 b          M fixed binary,
11 b          Y fixed binary,
12 b          P fixed decimal(11,2),
13 b          PMT fixed decimal(6,2),
14 b          I fixed decimal(4,2);
15 b
16 c      do while('1'b);
17 c          put skip list('Principal 1);
18 c          get list(P);
19 c          put list('Interest
20 c          get list(I);
21 c          put list('Payment
22 c          get list(PMT);
23 c          M = 0;
24 c          Y = 0;
25 d          do while (P > 0);
26 d              if mod(m,12) = 0 then
27 e                  do;
28 e                      Y = Y + 1;
29 e                      put skip list('Year',y);
30 e                  end;
31 d              M = M + 1;
32 d              put skip list(M,P);
33 d              P = P + round(I * P / 1200, 2);
34 d              if P < PMT
35 d                  then PMT = P;
36 d              put list(PMT);
37 d              P = P - PMT;
38 d          end;
39 c      end;
40 b
41 b  end loan1;
```

Listing 16–1. The LOAN1 Program

```
A>loan1

Principal 500
Interest 14
Payment 22.10

Year 1
    1       500.00   22.10
```

```
    2       483.73   22.10
    3       467.27   22.10
    4       450.62   22.10
    5       433.78   22.10
    6       416.74   22.10
    7       399.50   22.10
    8       382.06   22.10
    9       364.42   22.10
    10      346.57   22.10
    11      328.51   22.10
    12      310.24   22.10
Year    2
    13      291.76   22.10
    14      273.06   22.10
    15      254.15   22.10
    16      235.02   22.10
    17      215.66   22.10
    18      196.08   22.10
    19      176.27   22.10
    20      156.23   22.10
    21      135.95   22.10
    22      115.44   22.10
    23      94.69    22.10
    24      73.69    22.10
Year    3
    25      52.45    22.10
    26      30.96    22.10
    27      9.22 22.10
Principal ^C
A>
```

Listing 16–2. Output from the LOAN1 Program

16.2 Ordinary Annuity

Listing 16-3 shows the ANNUITY program. Given the interest rate (i) and two of three values, ANNUITY computes either the present value (PV), the payment (PMT), or the number of pay periods (n) for an ordinary annuity.

ANNUITY contains one main loop between lines 35 and 80 which reads the present value, payment, and yearly interest from the console. On each iteration, you enter two nonzero values and one zero value, then ANNUITY computes the value of the variable that you enter as zero. ANNUITY retains the values on each loop so that you can enter a comma if you do not want to change the value. In this example, ANNUITY does not check that the input values are in the proper range.

```
  1a
  2a   /* This program computes either the present value(PV),
  3a   /* the payment(PMT), or the number of periods in an
  4a   /* ordinary annuity.
  5a
  6a   annuity:
  7b   procedure options(main);
  8b   %replace
  9b       clear by AZ,,
 10b       true by 111b;
 11b   declare
```

```
12 b       PMT fixed decimal(7,2),
13 b       PV  fixed decimal(9,2),
14 b       IP  fixed decimal(6,6),
15 b       x   float binary,
16 b       yi  float binary,
17 b       i   float binary,
18 b       n   fixed;
19 b
20 b   declare
21 b       ftc entry(float binary(24))
22 b           returns(character(17) varying);
23 b
24 b   put list (clear, A i^iO R D I N A R Y     A N N U I T Y1)
25 b   put skip(2) list
26 b   ('^iEnter Known Values, or 0, on Each Iteration');
27 b
28 b   on error
29 c       begin;
30 c           put skip list('^iInvalid Data, Re-enter');
31 c           goto retry;
32 c       end;
33 b
34 b   retry:
35 c   do while (true);
36 c       put skip(3) list('^iPresent Value');
37 c       get list(PV);
38 c       put list('^iPayment');
39 c       get list(PMT);
40 c       put list('^iInterest Rate');
41 c       get list(yi);
42 c       i = yi / 1200;
43 c       put list('^iPay Periods');
44 c       get list(n);
45 c
46 c       if PV 0 PMT = 0 then
47 c           x = 1 – 1 / (1 + i) ** n;
48 c
49 c
50 c       /* compute the present value
51 c
52 c       if PV = 0 then
53 c           do;
54 d               PV = PMT * dec(ftc(x/i),15,6);
55 d               put edit('^iPresent Value is ',PV)
56 d                   (a,p'$$$,$$$,$$$V.99');
57 d           end;
58 c
59 c
60 c       /* compute the payment
61 c
62 c       if PMT = 0 then
63 d           do;
64 d               PMT = PV * dec(ftc(i/x),15,8);
65 d               put  edit(I^iPayment is ',PMT)
66 d                   (a,p'$$,$$$,$$$V.99');
67 d           end;
68 c
69 c
```

```
 70 c       /* compute number of periods
 71 c
 72 c       if n = 0 then
 73 d           do;
 74 d               IP ftc(i);
 75 d               x = char(PV * IP / PMT);
 76 d               n   = ceil ( - log(l-x)/log(l+i)
 77 d               put edit('-i',n,' Pay Periods')
 78 d               (a,p'ZZZ9',a);
 79 d           end;
 80 c   end;
 81 b
 82 b end annuity;
```

Listing 16–3. The ANNUITY Program

Listing 16-4 shows an interaction with the ANNUITY program in which several different values are used as input.

```
A>annuity
    O R D I N A R Y   A N N U I T Y

Enter Known Values, or 0, on Each Iteration

Present Value        32000
Payment  0
Interest Rate        8.75
Pay Periods          360
Payment is           $251.74
Present Value ,
Payment  0
Interest Rate ,
Pay Periods          240
Payment is               $282.78
Present Value 0
Payment
Interest Rate
Pay Periods
Present Value is                 $31,998.87

Present Value 32000
Payment
Interest Rate
Pay Periods      0
    240 Pay Periods

Present Value ^C
A>
```

Listing 16–4. Interaction with the ANNUITY Program

16.2.1 Mixed Data Types

ANNUITY uses both FLOAT BINARY and FIXED DECIMAL data because it must perform a mixture of decimal arithmetic calculations and analytic function evaluations. The variables used throughout the program are defined between lines 12 and 18 as follows:

- PMT holds the payment value, is declared as FIXED DECIMAL (7,2) , and can be as large as $99,999.99.

- PV holds the present value, is declared as FIXED DECIMAL (9,2) and can be as large as $99,999,999.99.
- The variable IP holds the interest rate for a one month period, and is declared as FIXED DECIMAL with six decimal places.
- The variable n holds the number of payment periods, is declared as FIXED BINARY, and can range from 1 to 32767.
- The variables x, yi, and i are FLOAT BINARY numbers used during the computations to approximate decimal numbers with 7 decimal places.

ANNUITY computes the unknown value using the equations shown below, rather than the iteration. ANNUITY assumes the interest rate is greater than zero.

First, the present value is given by:

$$PV = PMT \cdot \frac{1 - \frac{1}{(1 + i)^{n}}}{i} \qquad (1)$$

Transposing equation (1) gives:

$$PMT = PV \cdot \frac{i}{1 - \frac{1}{(1 + i)^{n}}} \qquad (2)$$

Finally, solving for n gives:

$$n = \frac{\log\left(1 - \frac{PV}{PMT} \cdot i\right)}{\log(1 + i)} \qquad (3)$$

The following expression appears in both equations (1) and (2):

```
1 - 1/(l + i) ** n
```

Therefore, ANNUITY stores this value in the variable x, line 47, and uses it when evaluating PV and PMT. x is only an approximation of the decimal value given by this expression.

16.2.2 Evaluating the Present Value PV

If you enter a zero value for PV, then ANNUITY executes the DO-group between lines 53 and 57, and computes PV as:

```
PV = PMT * dec(ftc(x/i),15,6);
```

Line 20 declares ftc as an external subroutine. It is part of the PL/I Run-time Subroutine Library (RSL), so ANNUITY only needs to declare it as an entry constant to use it.

The division x/i produces a FLOAT BINARY temporary result that ftc then converts from FLOAT to CHARACTER form. For example, suppose that x/i produces the value 3.042455E+01. Then ftc(x/i) returns 30.42455 which is acceptable for conversion to decimal. If PL/I cannot convert the floating-point argument to a 15-digit decimal number, ftc signals the ERROR(l) condition indicating a conversion error.

Finally, the built-in DECIMAL function is applied to the character string to convert it to a specific precision and scale factor (15,6). When this is done, the multiplication and subsequent assignment to PMT takes place.

How is this particular value for precision and scale factor decided? To answer the question, first consider a restricted form of the same program:

```
declare
      PMT          fixed decimal(7,2),
      PV           fixed decimal(9,2),
      Q            fixed decimal (u, v)
PV = PMT * Q;
```

where you must decide on the appropriate constant values for u and V.

PV has precision and scale factor (9,2) , and thus there must be seven digits in the whole part and two digits in the fraction. PL/I generates the full seven digits in the whole part if the product PMT Q results in any of the precision and scale factor values:

```
(9,2) (10,3) (11,4) (12,5) (13,6) (14,7) (15,8)
```

The assignment to PV truncates any fractional digits beyond the second decimal place. Because PMT has precision and scale factor (7,2) , you can choose Q with a precision and scale factor of (15,6). Then the multiplication produces a result with precision and scale factor,

```
(min(15,7+15+1),2+6) = (15,8)
```

according to the rules stated previously.

Given an expression with precision and scale factor values as shown below,

```
a     b     c
(p1,q1)     (p2, q2)     (p3, q3)
```

where p1, q1, p2, and q2 are constants, you can set the precision and scale factor of c to:

```
p3 = 15     q3    = 15 - (p + q - s)
```

Thus, using the values shown in the original program, the precision and scale factor of Q becomes

```
q3 = 15 - (9 + 2 - 2) = 8, or (p3,q3) = (15,6)
```

16.2.3 Evaluating the Payment PHT

If you enter a nonzero present value for PV and a zero value for the payment PMT, then ANNUITY enters the DO-group beginning at line 63 and computes the value of PMT as:

```
PMT = PV * dec (ftc(i/x),15,8);
```

The computation uses essentially the same technique as shown in the previous example. You must decide the precision and scale factor of the second operand in the multiplication. You are really concerned only with the value of the scale factor because the precision can be taken as 15. Using the preceding analysis, evaluate the form:

```
a     b     c

      (7,2) (9,2) (15,q3)
```

and determine the value for q3:

```
q3 = 15 - (pl + ql - q2) = 15 -(7 + 2 - 2) = 8
```

16.2.4 Evaluating the Number of Periods n

When you enter nonzero values for PV and PMT, but set the number of periods to zero, ANNUITY executes the DO-group beginning on line 73 to compute n. The assignment on line 74 first changes the interest for a monthly period from FLOAT BINARY to FIXED DECIMAL. Next, the assignment on line 75:

```
x = char(PV * IP / PMT);
```

first computes the partial decimal result PV * IP / PMT, then converts the result to CHARACTER, and then to FLOAT BINARY through the assignment to x.

The multiplication PV * IP produces a temporary result with the precision and scale factor:

```
PV    IP

(9,2) (7,2)

1     1 1

(15,4)
```

The temporary result is now divided by PMT and results in another temporary result with the following precision and scale factor:

```
PV * IP      PMT

(15,4)       (7,2)

1            1 1

(15,2)
```

because, according to the rules for division:

```
(15,15-pl+ql-q2) = (15,15-15+4-2) = (15,2)
```

thus providing two decimal places in the computation.

The intermediate conversion to CHARACTER form is necessary because otherwise PL/I would first convert the intermediate result to FIXED BINARY, and then to FLOAT BINARY, resulting in truncation of the fraction. This sequence of conversions is necessary to maintain compatibility with the full language.

If required, you could generate additional fractional digits by applying the DECIMAL built-in function following the multiplication:

```
x = char( dec( PV*P, 11,4 ) / PMT);
```

and produce a quotient with precision and scale factor:

```
(15,15-11+4-2) = (15,6)
```

ANNUITY uses the value x in the expression on line 76 to compute the number of payment periods, and applies the CEIL function to the result so that any partial month is treated as a full month in the payment period analysis.

Finally, ANNUITY uses the picture edit format to write out the values of PV, PMT, and n.

16.3 Loan Payment Schedule Format

The LOAN2 program shown in Listing 16-5 is essentially the same as that presented in Section 16.1, but it has a more elaborate analysis and display format. LOAN2 uses an algorithm similar to that described in Section 16.1. The main processing occurs between lines 101 and 136, where the program increases the initial principal by the monthly interest, and reduces it by the monthly payment until the principal becomes zero.

The four listings that follow the discussion of the program show several examples of interaction with LOAN2.

Listing 16-6 shows a minimal display corresponding to a loan of $3000 at a 14% interest rate with a payment of $144.03. Assume an inflation rate of 0% with a starting payment on 11/80, and end-of year taxes due in December.

The display shows the principal, interest in December, monthly payment, amount paid toward principal in December, and amount of interest paid in the last month of the fiscal year.

Listing 16-7 shows another execution using the same values as the first time, but using a display level of 1. The output also contains the yearly interest paid on the loan for each fiscal year that would be deducted from the taxable income.

Listing 16-8 uses the same initial values of the previous examples, but provides a full display of the monthly principal, interest, monthly payment, payment applied to the principal, and interest payment.

Listing 16-9 also shows the same loan and interest rate with an adjustment in dollar value due to inflation. This example assumes the inflation rate of 10%, so that all amounts are scaled to the value of the dollar at the time the loan is issued.

For tax reporting purposes, the display showing the total interest paid at the end of each year is not scaled, and thus does not match the sum of the interest paid during the year. If we assume a 0% inflation rate, the total loan payment is 3,456.97, taken from the previous output.

But if we assume an inflation rate of 10%, the total cost of the loan in dollars today is

```
2,457.00
+     374.25


2,831.25
```

resulting in a net gain of 68.75 over a two year period!

```
   1 a
   2 a   /* This program computes a schedule of loan payments
   3 a   /* using an elaborate analysis and display format.
   4 a   /* It contains five internal procedures: DISPLAY,
   5 a   /* SUMMARY, CURRENT YEAR, HEADER, and LINE.
   6 a
   7 a   loan2:
   8 b   procedure options(main);
   9 b   %replace
  10 b       true by '1'b,
  11 b       false  by '0'b,
  12 b       clear  by '^z';
  13 b
  14 b   declare
  15 b       end bit(l),
  16 b       m   fixed binary,
  17 b       sm  fixed binary,
  18 b       y   fixed binary,
  19 b       sy  fixed binary,
  20 b       fm  fixed binary,
  21 b       dl  fixed binary,
  22 b       P   fixed decimal(10,2),
  23 b       PV  fixed decimal(10,2),
  24 b       PP  fixed decimal(10,2),
  25 b       PL  fixed decimal(10,2),
  26 b       PMT fixed decimal(10,2),
  27 b       PMV fixed decimal(10,2),
  28 b       INT fixed decimal(10,2),
  29 b       YIN fixed decimal(10,2),
  30 b       IP  fixed decimal(10,2),
  31 b       yi  fixed decimal(4,2),
  32 b       i   fixed decimal(4,2),
  33 b       INF fixed decimal(4,3),
  34 b       ci  fixed decimal(15,14),
  35 b       fi  fixed decimal(7,5),
  36 b       ir  fixed decimal(4,2);
  37 b
  38 b   declare
  39 b       name character(14) varying static initial('$con'),
  40 b       output file;
  41 b
42   b   put list(clear,'^i^iS U M M A R Y   0 F   P A Y M E N T S');
  43 b
  44 b   on undefinedfile(output)
  45 c       begin;
  46 c           put skip list('^i^icannot write to',name);
  47 c           goto open_output;
  48 c       end;
  49 b
  50 b   open_output:
  51 b   put skip(2) list('^i^iOutput File Name
  52 b   get list(name);
  53 b   if name = '$con' then
  54 b       open file(output) title('$con') print pagesize(0);
  55 b   else
  56 b       open file(output) title(name) print;
  57 b
```

```
 58 b   on error
 59 c   F begin;
 60 c            put skip list('^i^iBad Input Data, Retry');
 61 c            goto retry;
 62 c        end;
 63 b
 64 b   retry:
 65 c   do while(true);
 66 c        put skip(2) list('^i^iPrincipal
 67 c        get list(PV);
 68 c        P = PV;
 69 c        put list('^i^iInterest
 70 c        get list(yi);
 71 c        i = yi;
 72 c        put list('^i^iPayment
 73 c        get list(PMV);
 74 c        PMT = PMV;
 75 c        put list('^i^i%Inflation
 76 c        get list(ir);
 77 c        fi = I + ir/1200;
 78 c        ci = 1.00;
 79 c        put list('^i^iStarting Month
 80 c        get list(sm);
 81 c        put list('^i^iStarting Year
 82 c        get list(sy);
 83 c        put list('^i^iFiscal Month
 84 c        get list(fm);
 85 c        put edit('^i^iDisplay Level
 86 c                 '^i^iYr Results : 0
 87 c                 '^i^iYr Interest: 1
 88 c                 '^i^iAll Values : 2
 89 c                 (skip,a);
 90 c        get list(dl);
 91 c        if dl < 0 | dl > 2 then
 92 c            signal error;
 93 c        m = sm;
 94 c        y = sy;
 95 c        IP = 0;
 96 c        PP = 0;
 97 c        YIN = 0;
 98 c   if name then
 99 c   put file(output) page;
100 c   call header();
101 d   do while (P > 0);
102 d        end = false;
103 d        INT = round ( i * P / 1200, 2
104 d        IP = IP + INT;
105 d        PL = P;
106 d        P = P + INT;
107 d        if P < PMT then
108 d            PMT  P;
109 d        P = P    PMT;
110 d   PP = PP + (PL - P);
111 d   INF = ci;
112 d   ci = ci  fi;
113 d   if P = 0 | dl > 1 | m fm then
114 e        do;
115 e   put file(output) skip
```

```
116 e   edit('11,100*m+y) (a,p'99/99');
117 e   call display(PL * INF, INT * INF,
118 e            PMT * INF, PP * INF, IP     INF);
119 e                end;
120 d            if m = fm & dl > 0 then
121 d                call summary()
122 d            m            m + 1;
123 d            if m > 12 then
124 e                do;
125 e                    m = 1;
126 e                    y = y + 1;
127 e                    if y > 99 then
128 e                    y = 0;
129 e                end;
130 d        end;
131 c        if dl = 0 then
132 c            call line();
133 c        else
134 c        if ^end then
135 c            call summary();
136 c   end retry;
137 b
138 b   /* This procedure performs the output of the actual
139 b   /* parameters passed to it by the main part of the
140 b   /* program.
141 b
142 b   display:
143 c   procedure(a,b,c,d,e);
144 c   declare
145 c        (a,b,c,d,e) fixed decimal(10,2);
146 c
147 c   put file (output) edit
148 c        ('11 , a,'j',b,'j',c,'j',d,'1'1e,'j1)
149 c        (a,2(2(p1$zz,zzz,zz9v.99',a),
150 c        pl$zzz,zz9.v991,a));
151 c   end display;
152 b
153 b
154 b   /* This procedure computes the summary of yearly
155 b   /* interest.
156 b
157 b   summary:
158 c   procedure;
159 c   end = true;
160 c   call current_year(IP-YIN);
161 c   YIN = IP;
162 c   end summary;
163 b
164 b
165 b   /* This procedure computes the interest paid during
166 b   /* current year.
167 b
168 b   current_year:
169 c   procedure(I);
170 c   declare
171 c        yp fixed binary,
172 c        I fixed decimal(10,2);
173 c   yp ~ y;
```

```
174 c   if fm < 12 then
175 c       yp = yp - 1;
176 c   call line();
177 c   put skip file(output) edit
178 c            ('I','Interest Paid During -',yp,'-111,y,1 is
179 c            (a,x(15),2(a,p'99'),a,p'$$$,$$$,$$9v.991,x(16),a);
180 c   call line();
181 c   end current-year;
182 b
183 b
184 b   /* This procedure defines and prints out an elaborate
185 b   /* header format.
186 b
187 b   header:
188 c   procedure;
189 c   put file(output) list(clear);
190 c   call line();
191 c   put file(output) skip edit
192 c       (111,1L 0 A N    P A Y M E N T  S U M M A R Y','J')
193 c       (a,x(19));
194 c   call line();
195 c   put file(output) skip edit
196 c       ('I','Interest Rate',yi,'%','Inflation RateI,ir,'%','I')
197 c       (a,x(15),2(a,p'b99v.99',a,x(6)),x(9),a);
198 c   call line();
199 c   put file(output) skip edit
200 c   ('IDate 1','Principal 1','Plus Interest1',' Payment     1',
201 c       'Principal Paidy','Interest Paid I') (a);
202 c   call line();
203 c   end header;
204 b
205 b
206 b   /* This procedure prints out a series of dashed lines.
207 b
208 b   line:
209 c   procedure;
210 c   declare
211 c       i fixed bin;
212 c   put file(output) skip edit
213 c            ------- I', -----------
214 c            ---------------- do i 1 to 4)) (a);
215 c   end line;
216 b
217 b
218 b   end loan2;
```

Listing 16–5. The LOAN2 Program

16.3.1 Variable Declarations

Starting on line 14, LOAN2 declares several data items:

- PV present value, initial principal
- yi yearly interest rate
- PMV monthly payment
- ir yearly inflation rate

- sm starting month of payment (1-12)
- sy starting year of payment (0-99)
- fm fiscal month, end of fiscal year (1-12)
- dl display level (0-2)

16.3.2 Program Execution

Missing pages 16-19 through 16-20

16.3.3 Display Formats

Missing pages 16-20 through 16-26

Listing 16–6. First Interaction with LOAN2

Listing 16–7. Second Interaction with LOAN2

Listing 16–8. Third Interaction with LOAN2

Listing 16–9. Fourth Interaction with LOAN2

16.4 Computation of Depreciation Schedules

Missing pages 16-26 through 16-26

16.4.1 General Algorithms

Missing pages 16-26 through 16-34

16.4.2 Selecting the Schedule

Missing pages 16-34 through 16-34

Listing 16–10. The DEPREC Program

is equivalent to:

```
call schedule (index(syd,select-sched));
```

and for the valid inputs s, y, or d, produces 1, 2, or 3 respectively.

Thus, if select-sched is s, the call statement evaluates to:

```
call schedule(1);
```

which calls the subroutine straight_line. Similarly, an input of y or d evaluates to:

```
call schedule(2); or call schedule(3);
```

producing a call to sum_of_years or double-declining respectively

If the value of select sched is not s, y, or d, then the INDEX function returns a zero value. All invalid character input values produce the following:

```
call schedule(0);
```

which calls the error subroutine and prints the error message.

16.4.3 Displaying the Output

Another construct of DEPREC is the output file variable, defined on line 39. During the parameter input phase, DEPREC prompts you with:

```
List? (yes/no)
```

A yes response sends the output from the program to both the console and the list device.

Line 40 declares two file constants, sysprint and list, to address the console and the list device. DEPREC first opens the console file, line 51, using an infinite page length to avoid form feed characters.

On any iteration of the main DO-group, if you give an affirmative response on line 77, DEPREC subsequently opens the list device, line 78. This statement can be executed several times during a particular execution of the program, but only the first OPEN statement has any effect; PL/I ignores the OPEN statement if the file is already open.

Line 91 calls the display subroutine to compute and display the output report for a specific set of input values. Display has a single actual parameter consisting of the file constant sysprint that is defined as the formal parameter f on line 104. Line 107 assigns the formal parameter to the global variable output. Subsequent PUT statements write data to the console, producing the first report.

on line 92, if the variable copy_to_list has the character value yes, then DEPREC calls display once again. This time, the actual parameter is list, corresponding to the system list device. Thus, the output file variable is indirectly assigned the value list, and all PUT statements that reference file output send data to the printer. This results in both a soft and hard copy of the report.

DEPREC uses several different forms of decimal arithmetic. Examine the various declarations while cross-checking the output formats with the displayed results.

```
A>deprec
```

```
Depreciation Schedule

Selling Price?       200000
Residual Value?      40000
Sales Tax       (%)? 6
Tax Bracket(%)?      50
ProRate Months?      10
How Many Years?      7
New? (yes/no)        no
Schedule:
Straight     (s)
Sum-of-Yrs       (y)
Double Dec       (d)? d
List? (yes/no)       no

    D 0 U B L E      D E C L I N I N G
-------------------------------------------------
    $212,000.00 Used     $40,000.00 Residual Value
    10 Months Left       06% Tax  50% Tax Bracketl
-------------------------------------------------
Y I Depreciation ~ Depreciation                    Book Value
r        For Year Remaining    I    I
-------------------------------------------------
1       $   35,357.14    $   122,642.86     $     162,642.86
2       $   34,852.04    $   87,790.82      $     127,790.82
3       $   27,383.75    $   60,407.07      $     100,407.07
4       $   21,515.79    $   38,891.28      $     78,891.28
5       $   16,905.27    $   21,986.01      $     61,986.01
6       $   13,282.71    $   8,703.30 $     48,703.30
7       $   8,703.30 $   0.00$   40,000.00
-------------------------------------------------
    First Year Reduction in Taxable Income         I
-------------------------------------------------
Depreciation $       35,357.14
Sales Tax    $       12,000.00
ITC (Adjusted)   $   20,000.00
Bonus Depreciation   $   2,000.00
    ------------
Total for First Year  $   69,357.14
Direct Reduction in Tax       $   34,678.57
-------------------------------------------------
```

Listing 16–11. First Interaction with DEPREC

```
Depreciation Schedule

Selling Price?
Residual Value?
Sales Tax (%)?
Tax Bracket(%)?
ProRate Months?
How Many Years?
New? (yes/no)    ~es
Schedule:
Straight (s)
Sum-of-Yrs       (y)
Double Dec       (d)? y
List? (yes/no)   no
```

```
    S U M   0 F  T H E   Y E A R S
-------------------------------------------------
$212,000.00 New  $40,000.00 Residual Value I
    8 Months Left    06% Tax  50% Tax Bracketl
-------------------------------------------------
Y I Depreciation I Depreciation   Book Value
r   For Year Remaining    I   I
-----------------------------------------
1       $   26,333.33    $   131,666.67     $     171,666.67
2       $   28,214.29    $   103,452.38     $     143,452.38
3       $   18,473.64    $   84,978.74      $     124,978.74
4       $   12,139.82    $   72,838.92      $     112,838.92
5       $   7,804.17 $   65,034.75    $     105,034.75
6       $   4,645.34 $   60,389.41    $     100,389.41
1 7 J$  2,156.76     $   58,232.65    $     98,232.65
-------------------------------------------------
    First Year Reduction in Taxable Income   I
-------------------------------------------------
Depreciation $   26,333.33
Sales Tax    $   12,000.00
ITC (Adjusted)   $   40,000.00
Bonus Depreciation   $   2,000.00
    ------------
Total for First Year  $   80,333.33
Direct Reduction in Tax   $   40,166.66
-------------------------------------------------
```

Listing 16–12. Second Interaction with DEPREC

```
Depreciation Schedule

Selling Price?           310000
Residual Value?          30000
Sales Tax (%)?
Tax Bracket(%)?
ProRate Months?      12
How Many Years?      5
New? (yes/no)            yes
Schedule:
Straight     (s)
Sum-of-Yrs       (y)
Double Dec       (d)?d
List? (yes/no)           no

D 0 U B L E      D E C L I N I N G
-------------------------------------------------
$328,600.00 New        $30,000.00 Residual Value |
12 Months Left      06% Tax      50% Tax Bracket |
-------------------------------------------------
Y I Depreciation I Depreciation        Book Value
r       For Year Remaining    I   I
-----------------------------------------
1       $   123,200.00   $   154,800.00     $     184,800.00
2       $   73,920.00    $   80,880.00      $     110,880.00
3       $   44,352.00    $   36,528.00      $     66,528.00
4       $   26,611.20    $   9,916.80 $     39,916.80
5       $   9,916.80 $   0.00$   30rOOO.OO
-------------------------------------------------          -
    First Year Reduction in Taxable Income         I
```

```
-----------------------------------------------
Depreciation $   123,200.00
Sales Tax    $   18,600.00
ITC (Adjusted)   $   62,000.00
Bonus Depreciation   $   2,000.00
    ------------
Total for First Year     $   205,800.00
Direct Reduction in Tax      $   102,900.00
-------------------------------------------------
```

Listing 16–13. Third Interaction with DEPREC

```
Depreciation Schedule

Selling Price?
Residual Value?
Sales Tax    (%)?
Tax Bracket(%)?
ProRate Months?
How Many Years?
New? (yes/no)
Schedule:
Straight (s)
Sum-of-Yrs       (y)
Double Dec       (d)?s
List? (yes/no)               r
        S T R A I G H T  L I N E
-------------------------------------------------
$328,600.00 New  $30,000.00 Residual Value
1   12 Months Left   06% Tax  50% Tax Bracketi

Y I Depreciation I Depreciation   Book Value
r   For Year Remaining    I   I
--- ------------ --------------------------
1       $   55,600.00    $   222,400.00     $     252,400.00
2       $   44,480.00    $   177,920.00     $     207,920.00
3       $   35,584.00    $   142,336.00     $     172,336.00
4       $   28,467.20    $   113,868.80     $     143,868.80
5       $   22,773.76    $   91,095.04      $     121,095.04
--- ------------- ------------------------------
First Year Reduction in Taxable Income I
-------------------------------------------------
Depreciation $   55,600.00
Sales Tax    $   18,600.00
ITC (Adjusted)   $   62,000.00
Bonus Depreciation   $       2,000.00
    ------------
Total for First Year  $   138,200.00
Direct Reduction in Tax   $   69,100.00
-------------------------------------------------
```

Listing 16–14. Fourth Interaction with DEPREC

References: Sections 3.1, 3.5, 4.2, 11.3 LRM

End of Section 16

17 Dynamic Storage and Stack Routines

This section describes some functions in the PL/I Run-time Subroutine Library (RSL) that perform dynamic memory management and manipulate the stack size.

17.1 Dynamic Storage Subroutines

The RSL includes a number of functions that provide access to the dynamic storage routines. These routines maintain a linked list of all unallocated storage. Upon request, these routines search for the first available segment in the free list that satisfies the request size, remove the requested segment, and return the remaining portion to the free list. If the storage is not available, the run time system signals ERROR(7), Free Space Exhausted.

PL/I dynamically allocates storage upon entry to RECURSIVE procedures, when processing explicit or implicit OPEN statements for files performing disk I/O, or when processing an ALLOCATE statement. PL/I always allocates an even number of bytes or whole words, no matter what the request size.

17.1.1 The TOTWDS and MAXWDS Functions

It is often useful to find the amount of storage available at any given point while the program is running. The TOTWDS (Total Words) and MAXWDS (Max Words) functions provide this information.

You must declare the functions in the calling program as:

```
declare totwds entry returns(fixed(15));

declare maxwds entry returns(fixed(15));
```

When you invoke the TOTWDS subroutine, it scans the free storage list and returns the total number of words (double bytes) available. The MAXWDS subroutine returns the size (in words) of the largest contiguous segment in the free list. A subsequent ALLOCATE statement that specifies a segment size less than or equal to MAXWDS does not signal ERROR(7) , because at least that much storage is available.

Both TOTWDS and MAXWDS count in word units, so the returned values can be held by FIXED BINARY(15) counters. Both TOTWDS and MAXWDS return the value -1 if they encounter invalid link words while scanning the free space list. This return is usually due to an out of-bounds subscript or pointer store operation. Otherwise, these functions return a nonnegative integer value.

17.1.2 The ALLWDS Subroutine

The PL/I Run-time Subroutine Library contains a subroutine, called ALLWDS, that you use to control the dynamic allocation size. You must declare the subroutine in the calling program as:

```
declare allwds entry(fixed(15)) returns(pointer);
```

The ALLWDS subroutine allocates a memory segment in words equal to the size given by the input parameter, and returns a pointer to the allocated segment. If no segment is available, ALLWDS signals the ERROR(7) condition. The input value must be a nonnegative integer.

Listing 17-1 shows the ALLTST program which is an example of how to use the TOTWDS, MAXWDS, and ALLWDS functions. Listing 17-2 shows a sample interaction with the ALLTST program.

```
   1a
   2a   /* This program tests the TOTWDS, MAXWDS, and ALLWDS
   3a   /* functions from the Run-time Subroutine Library.
   4a
   5a   alltst:
   6b   procedure options(main);
   7b   declare
   8b        totwds entry returns(fixed(15)),
   9b        maxwds entry returns(fixed(15)),
  10b        allwds entry(fixed(15)) returns(pointer);
  11b
  12b   declare
  13b        allreq fixed(15),
  14b        memptr ptr,
  15b        meminx fixed(15),
  16b        memory (0:0) bit(16) based(memptr);
  17b
  18c   do while('1'b);
  19c        put edit (totwds(),' Total Words Available',
  20c            maxwds(),' Maximum Segment Size',
  21c            'Allocation Size? ') (2(skip,f(6),a),skip,a);
  22c        get list(allreq);
  23c        memptr = allwds(allreq);
  24c        put edit('Allocated',allreq,' Words at ',unspec(memptr))
  25c            (skip,a,f(6),a,b4);
  26c
  27c        /* clear memory as example
  28d        do meminx = 0 to allreq-1;
  29d            memory(meminx) = '0000'b4;
  30d        end;
  31c   end;
  32b
  33b   end alltst;
```

Listing 17–1. The ALLTST Program

```
A>alltst

    24470 Total Words Available
    24470 Maximum Segment Size
Allocation Size? 0

Allocated        0 Words at 28D6
    24468 Total Words Available
    24468 Maximum Segment Size
Allocation Size? 100

Allocated        100 Words at 28DA
    24366 Total Words Available
    24366 Maximum Segment Size
Allocation Size? 500

Allocated        500 Words at 29A6
    23864 Total Words Available
    23864 Maximum Segment Size
```

```
Allocation Size? 23865

ERROR (7), Free Space Exhausted
Traceback; 016D
A>
```

Listing 17–2. Interaction with the ALLTST Program

17.2 The STKSIZ Function

In PL/I, the program stack is placed above the code and data area, and below the dynamic storage area (TPA). The default size of the program stack is 512 bytes, but can be changed using the STACK(n) option in the main procedure heading.

The STKSIZ (Stack Size) function returns the current stack size in bytes. This function is particularly useful for checking possible stack overflow conditions, or in determining the maximum stack depth during program testing.

You must declare the STKSIZ function in the calling program as:

```
declare stksiz returns(fixed(15));
```

Listing 17-3 shows an example of the STKSIZ function in the program called ACKTST, where it checks the maximum stack depth during RECURSIVE procedure processing. Listing 17-4 shows an interaction with this program.

```
 1 a
 2 a /* This program tests the STKSIZ function while
 3 a /* evaluating a RECURSIVE procedure.
 4 a
 5 a   ack:
 6 b       procedure options(main,stack(2000));
 7 b       declare
 8 b           (m,n) fixed,
 9 b           (maxm,maxn) fixed,
10 b           ncalls decimal(6),
11 b           (curstack, stacksize) fixed,
12 b           stksiz entry returns(fixed);
13 b
14 b       put skip list('Type max m,n:
15 b       get list(maxm,maxn);
16 c       do m = 0 to maxm;
17 d           do  n = 0 to maxn;
18 d               ncalls  = 0;
19 d               curstack = 0;
20 d               stacksize = 0;
21 d               put edit('Ack(l,m,',',n,')=',ackermann(m,n),
22 d                   ncalls,' Calls,',stacksize,' Stack Bytes')
23 d                       (skip,a,2(f(2),a),f(6),f(7),a,f(4),a);
24 d           end;
25 c       end;
26 b       stop;
27 b
28 b       ackermann:
29 c           procedure(m,n) returns(fixed) recursive;
30 c
31 c           declare
```

```
 32 c                (m,n)    fixed;
 33 c                ncalls = ncalls + 1;
 34 c                curstack = stksizo;
 35 c            if curstack > stacksize then
 36 c                stacksize = curstack;
 37 c            if m = 0 then
 38 c                return(n+l);
 39 c            if n = 0 then
 40 c                return(ackermann(m-1,1));
 41 c            return(ackermann(m-l,ackermann(m,n-1)));
 42 c        end ackermann;
 43 b
 44 b    end ack;
```

Listing 17–3. The ACKTST Progran

```
A>acktst

Type max m,n: 6,6

Ack( 0, 0) = 1   1   Calls,   4   Stack Bytes
Ack( 0, 1) = 2   1   Calls,   4   Stack Bytes
Ack( 0, 2) = 3   1   Calls,   4   Stack Bytes
Ack( 0, 3) = 4   1   Calls,   4   Stack Bytes
Ack( 0, 4) = 5   1   Calls,   4   Stack Bytes
Ack( 0, 5) = 6   1   Calls,   4   Stack Bytes
Ack( 0, 6) = 7   1   Calls,   4   Stack Bytes
Ack( 1, 0) = 2   2   Calls,   6   Stack Bytes
Ack( 1, 1) = 3   4   Calls,   8   Stack Bytes
Ack( 1, 2) = 4   6   Calls,   10  Stack Bytes
Ack( 1, 3) = 5   8   Calls,   12  Stack Bytes
Ack( 1, 4) = 6   10  Calls,   14  Stack Bytes
Ack( 1, 5) = 7   12  Calls,   16  Stack Bytes
Ack( 1, 6) = 8   14  Calls,   18  Stack Bytes
Ack( 2, 0) = 3   5   Calls,   10  Stack Bytes
Ack( 2, 1) = 5   14  Calls,   14  Stack Bytes
Ack( 2, 2) = 7   27  Calls,   18  Stack Bytes
Ack( 2, 3) = 9   44  Calls,   22  Stack Bytes
Ack( 2, 4) = 11  65  Calls,   26  Stack Bytes
Ack( 2, 5) = 13  90  Calls,   30  Stack Bytes
Ack( 2, 6) = 15  119 Calls,   34  Stack Bytes
Ack( 3, 0) = 5   15  Calls,   16  Stack Bytes
Ack( 3, 1) = 13  106 Calls,   32  Stack Bytes
Ack( 3, 2) = 29  541 Calls,   64  Stack Bytes
Ack( 3, 3) = 61  2432 Calls,  128 Stack Bytes
Ack( 3, 4) = 125 10307 Calls, 256 Stack Bytes
Ack( 3, 5) =
```

Listing 17–4. Output From the ACKTST Program

End of Section 17

18 Overlays

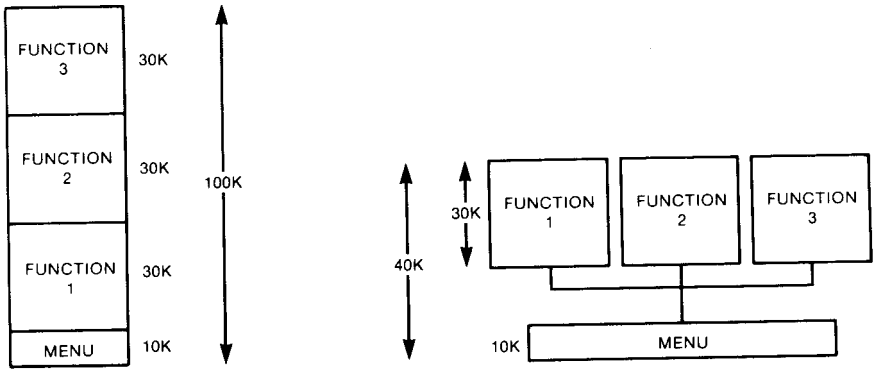
This section describes how to use the linkage editor to create PL/I overlays. Overlays are programs comprised of separate files. The advantage of overlays is that they share the same memory locations, so you can write large programs that run in a limited memory environment.

18.1 Using Overlays in PL/I

In both the 8-bit and 16-bit implementations, the size of the Transient Program Area (TPA) determines the upper limit on the size of a program. However, there is another constraint in the 16-bit implementations. Although there can be enough memory space available on the system, the compiler generates code that assumes the small memory model. The small model means that when you link one or more OBJ files with the Run-time Subroutine Library (RSL), the size of the code and data sections in the CMD or EXE are each limited to 64K. Thus, the compiler determines the upper limit on the size of any program, but the size limit is not encountered until link time.

With modular design, you can write a large program that does not need to reside in memory all at once. For example, many application programs are menu-driven, in which the user selects one of a number of functions to perform. Because the functions are separate and invoked sequentially, they do not need to reside in memory simultaneously. When one of the functions is complete, control returns to the menu portion of the program, from which the user selects the next function. Using overlays, you can divide such a program into separate subprograms that can be stored on disk and loaded only when required.

The following figure illustrates the concept of overlays. Suppose a menu-driven application program consists of three separate user selected functions. If each function requires 30K of memory, and the menu portion requires 10K, then the total memory required for the program is 100K, as shown in Figure 18-1a. However, if the three functions are designed as overlays, as shown in Figure 18-lb, the program requires only 40K, because all three functions share the same memory locations.



18-la. Without Overlays

18-lb. Separate Overlays

Figure 18-1. Using Overlays in a Large Program

You can also create nested overlays in the form of a tree structure, where each overlay can call other overlays up to a maximum nesting level that the overlay manager determines. Section 18.3 describes the command line syntax for creating nested overlays.

Figure 18-2 illustrates the tree structure of overlays. The top of the highest overlay determines the total amount of memory required. In Figure 18-2, the highest overlay is SUB4. This is substantially less memory than would be required if all the functions and subfunctions had to reside in memory simultaneously.

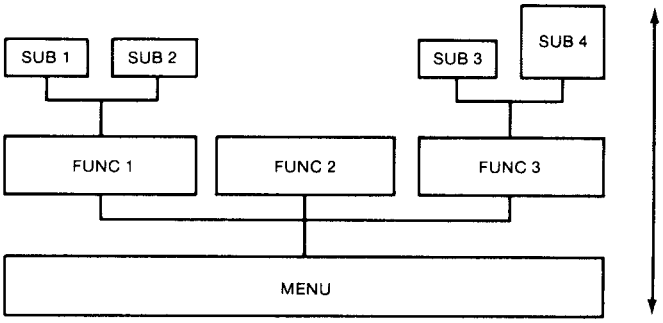


Figure 18–2. Tree Structure of Overlays

18.2 Writing Overlays in PL/I

There are two ways to write PL/I programs that use overlays. The first method involves no special coding, but has two restrictions. The first restriction is all that overlays must be on the default drive; the second is that the overlay names must be determined at translation time and cannot be changed at run-time.

The second method requires a more involved calling sequence, but does not have either of the restrictions of the first method.

18.2.1 Overlay Method One

To use the first method, you declare an overlay as an entry constant in the module where it is referenced. As an entry constant, the overlay can have parameters declared in a parameter list. The overlay itself is simply a PL/I procedure or group of procedures.

For example, the following program is a root module with one overlay:

```
root:
      procedure options(main);
      declare
            ovlay1 entry(character(15));
      put skip list('root');
      call ovlay1('overlay 1');
end root;
```

The overlay OVLAY1.PLI is defined as follows:

```
ovlay1:
      procedure(c);
      declare
            c character(15);
```

```
        put skip list(c);
    end ovlay1;
```

Note: When passing parameters to an overlay, you must ensure that the number and type of the parameters are the same in both the calling program and the overlay.

When the program runs, ROOT first displays the message 'root' at the console. The CALL statement then transfers control to the overlay manager . The overlay manager loads the file OVLAY1 from the default drive and transfers control to it.

When the overlay receives control, it displays the message 'overlay 1' at the console. OVLAY1 then returns control directly to the statement following the CALL statement in ROOT. The program then continues from that point.

If the requested overlay is already in memory, the overlay manager does not reload it before transferring control.

The following constraints apply to overlay method one:

- The label in the call statement is the actual name of the overlay file loaded by the overlay manager; consequently, the two names must agree.
- The name of the entry point to an overlay need not agree with the name used in the calling sequence, but using the same name avoids confusion.
- The overlay manager only loads overlays from the drive that was the default when the root module began execution. The overlay manager disregards any changes in the default drive that occur after the root module begins execution.
- The names of the overlays are fixed. To change the names of the overlays, you must edit, recompile, and relink the program.
- No nonstandard PL/I statements are needed. Thus, you can postpone the decision on whether or not to create overlays until link time.

18.2.2 Overlay Method Two

In some applications, you might want to have greater flexibility with overlays, such as loading overlays from different drives, or determining the name of an overlay from the console or a disk file at run-time.

To do this, a PL/I program must declare an explicit entry point into the overlay manager, as follows:

```
declare ?ovlay entry(character(10),fixed(l));
```

This entry point requires two parameters. The first is a 10 character string that specifies the name of the overlay to load, and an optional drive code in the standard format (d:filename).

The second parameter is the load flag. If the load flag is 1, the overlay manager loads the specified overlay whether or not it is already in memory. If the load flag is 0, the overlay manager loads the overlay only if it is not already in memory.

Using this method, the example illustrating method one appears as follows:

```
root:
      procedure options(main);
      declare
            ?ovlay entry(character(10),fixed(l)),
            dummy entry(character(15)),
            name character(10);

      put skip list('root');
      name = 'OV1';
      call ?ovlay(name,0);
      call dummy('overlay 1');
end root;
```

The file OV1.PLI is the same as the previous example.

At run-time, the statement:

```
call ?ovlay(name,0);
```

directs the overlay manager to load OV1 from the default drive (1 is the current value of the variable name); control then transfers to OV1. When OV1 finishes processing, control returns to the statement following the invocation.

In this example, the variable name is assigned the value 'OV1'. However, you could also supply the overlay name as a character string from some other source, such as the console keyboard.

The following constraints apply to overlay method two:

- You can specify a drive code so the overlay manager can load overlays from drives other than the default drive. If you do not specify a drive code, the overlay manager uses the default drive as described in method one.
- If you pass any parameters to the overlay, they must agree in number and type with the parameters that the overlay expects

18.2.3 General Overlay Constraints

The following general constraints apply when creating overlays in a PL/I program:

- Each overlay has only one entry point. The overlay manager in the PL/I Run-time Subroutine Library assumes that this entry point is at the load address of the overlay.
- You cannot make an upward reference from a module to entry points in overlays higher on-the tree. The only exception is a reference to the main entry point of the overlay. You can make downward references to entry points in overlays lower on the tree or in the root module.
- Common segments (EXTERNALS in PL/I) that are declared in one module cannot be initialized by a module higher in the tree. The linkage editor ignores any attempt to do so.
- You can nest overlays to a depth of 5 levels.

- The overlay manager uses the default buffer located at 80H, so user programs should not depend on data stored in this buffer. Note that in the 8086 implementations, the default buffer is at 80H relative to the base of the data segment.

18.3 Command Line Syntax

To specify overlays in the command line of the linkage editor, enclose each overlay specification in parentheses. You can create overlays with LINK-80™ in one of the following forms:

```
link root(ovl)

link root(ovl,part2,part3)

link root(ovl=partl,part2,part3)
```

The first form produces the file OV1. OVL from the file OV1. REL. The second form produces the file OVl.OVL from OV1.REL, PART2.REL, and PART3. REL. The third form produces the file OV1. OVL from PART1. REL, PART2.REL, and PART3.REL.

Create overlays with LINK-86™ using the same forms:

```
link86 root(ovl)

link86 root(ovl,part2,part3)

link86 root(ovl=partl,part2,part3)
```

The first form produces the file OVl.OVR from the file OV1.OBJ. The second form produces the file OVl.OVR from OV1.OBJ, PART2.OBJ, and PART3.OBJ. The third form produces the file OVl.OVR from PART1.OBJ, PART2.OBJ, and PART3.OBJ.

In the command line, a left parenthesis indicates the start of a new overlay specification, and also indicates the end of the group preceding it. All files to be included at any point on the tree must appear together, without any intervening overlay specifications. You can use spaces to improve readability, but do not use commas to set off the overlay specifications from the root module or from each other.

For example, the following command line is invalid:

```
A>1ink root(ovl),moreroot
```

The correct command is as follows:

```
A>1ink root,moreroot(ovl)
```

To nest overlays, you must specify them in the command line with nested parentheses. For example, the following command line creates the overlay system shown in Figure 18-2:

```
A>1ink menu(funcl (subl)(sub 2)) (func2) (func3 (sub3)(sub4))
```

End of Section 18

Index

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