INFORMATION FLOW COMPLEXITY

by

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B.A., Ramkhamheang University, Thailand, 1977

A MASTER'S REPORT

submitted in partial fulfillment of

the requirement for the degree

MASTER OF SCIENCE

Department of Computer Science

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1984

APPROVED BY:

MAJOR PROFESSOR

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my major advisor, professor David Gustafson for his guidance, patience and encouragement. He has made this a pleasant and rewarding learning experience. I also would like to extend a personal thank you to my comittee members, Professor William Hankley and Professor Rod Bates for their helpfull suggestions and comments.

I am grateful to my mother for her constant support and encouragement which have been of utmost importance to the success of my education.

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CHAPTER ONE

INTRODUCTION

This report describes the purpose, design and implementation of a software tool that determines the information flow in Pascal programs. Information flow refers to the dependency of a variable on the value of other variables. The software tool is called the information flow complexity (IFC) program. It is implemented on a PDQ-3 computer. The IFC will be used as a research tool to investigate the complexity of software.

Software is becoming more complex because of an increase in the user's needs and because of the rapid advancement in hardware technology. Rapid advancements in hardware cause new system software to become desirable or necessary. Extensions to existing system software are required in order to take full advantage of the new hardware capabilities. With the increasing complexity of new and existing software, there is an increasing need for powerful and adaptive development tools and techniques. Maintenance costs tend to dramatically increase the costs of the software system, often costing more than the rest of the software over its life cycle.

Complexity metrics attempt to quantify the complexity of software. Complex software may be very hard to undestand. Some program modules may be more complex than others and harder to understand. More precisely, the complexity of a program is related to the difficulty people have in understanding the function implemented by the software (Chap 79) (Bak 77). This report is concerned with the use of information flow as a possible complexity metric.

ORGANIZATION OF THE REPORT

Chapter one discusses an overview of the recent work concerning information/control flow. Chapter two introduces a description of the IFC, describing the information flow features associated with the flow structure. Chapter three explains in detail the specification of IFC input programs and the outputof the IFC. Included are the major data structures used in the implementation. Chapter four illustrates the system diagram and describes how to build and use the data structure to analyze the information transfer in the input program. Chapter five discusses the conclusions and extensions which can be done to make the IFC program more powerful. There are appendices provided for users who need to use or modify the IFC program. Appendix A contains the listing of global variables and routines. Appendix B contains the listing of IFC program. Appendix C contains user's guide. Appendix D contains the listing of ten sample programs.

COMPLEXITY MEASURES

Evaluating software quality is becoming a very important activity. Much of the recent work in software engineering has been concentrated in various measures concerning software complexity. Thus the definition of complexity has various meanings depending on the object of interest. The metrics may be used in a software development tool as a mechanism for judging the technical quality of software and the adequacy of the design. Several of these complexity measures concentrate on specific structural characteristics of programs. Halstead's software science counts operators and operands(Hal 77). McCabe's cyclometric complexity counts the number of basic paths through the program (McC 76). The study of Zolonowski and Simons (Zol 77) includes the measurement of programming styles and methods and involves the relationship between program characteristics and program error amounts and types. Berlinger(Ber 80) sees the need to derive a measure of mathematical and intuitive correctness.

Types of Flow

In attempting to evaluate software quality, there are many methods frequently mentioned in the area of information (data) and control flow. The information flow involves the flow relation of program variables that have an influence in transferring the value of information upon the flow structure (Denn 76). Data and control flow have been characterized by Withwort as follows:

> "Regarding software as a mechanism for output production reduces the problem of understanding a software design to the problem of understanding the flow of control and resulting derivation of the system outputs. Control flow analysis involves tracing paths through the design and understanding the logical condition associated with branching and looping in the structure. Dataflow analysis involves tracing some intermediate data and ultimately to system inputs and constants."(With 80)

The various measures cover either the intramodule or intermodule complexity. The intramodule complexity measures deal with the complexity of algorithms (i.e. the inner working of individual system modules). The intermodule complexity measures deal with the interconnection of the system modules. Based on these observations, complexity measures concerning data/control flow can be classified into four types: (1) intermodule control flow; (2) intermodule information flow; (3) intramodule control flow; (4) intramodule information flow.

(1) Intermodule Control Flow.

Intermodule control flow attempts to examine a basic flow graph of a program, the understanding of how program control is passed from module to module, regardless of program loops and program characteristics. An example is McClure's complexity metric (McC 76) which involves an examination of the possible execution paths, the control structures and the variables used to direct path selection. In a well-structured program, the execution hierarchy of a program is determined by the values of control variables in a program loop. She defines three sources for module complexity: (1) the control structures used in module invocation, (2) the control variables referenced in module invocation, (3) the commonality of a module which is a part of the execution hierarchy. She suggests that the complexity can be controlled by the following two rules: The complexity of each module should be minimized, and the complexity among modules in a well-structured program should be distributed.

(2) Intermodule Information Flow.

Intermodule information flow metrics are concerned with the interfaces between procedures, modules, and/or subroutines. This can be viewed as the mapping of the inputs to the outputs from a module to module. Previous

work on flow metrics was done by Chapin (Chapin 78). His complexity measure is described by the difficulty in understanding software's function based on the input/output sets in modularized programs and systems. He defines four roles of data (any one item of data may have more than one role): (1) C_control role, (2) P_processing role, (3) T_pass_through role, (4) M_modify role. Data in the C_control role contribute the most to complexity when considering the source of C_data. The sources of data may come from within the module (or are constants), within the subordinate loop body, or from outside of the loop body. He utilizes the techniques of identifying and parsing functional-oriented design complexity, and sets of dependent variables. For large-scale systems, Henry & Kafura (Hen&kaf 81) proposed that in measuring complexity, an examination of the connection between the system components must be included. The relations generated for each component show the flow of information from input parameters to output parameters, and through the global data structures. The complexity measure is composed of the complexity of the procedure's code which is represented by its length and the complexity of the procedure's connection to its environment.

(3) Intramodule Control Flow.

Intramodule control flow attempts to measure complexity by measuring the control flow structure of the software. An example is McCabe's cyclometric Complexity (McC 76) which describes the decision-making structure of the program. This measure utilizes a graph theoretic technique to assign a complexity measure to a program based on the number of linearly-independent control paths in the program. McCabe sees that the complexity metric must include the measurement of the number of possible execution paths

(4) Intramodule Information Flow.

Intramodule information flow can be viewed as the interconnection of data within program modules which are designed to be as independent and exclusive of each other as possible(Mac 80). The result is that the interconnection of data within modules should be absolutely clear. To understand how the inner working of the module is performed, an information flow graph is used to show the flow of information between the variables which participate in the processing of data for the creation of the desired output.

RELATING INFORMATION FLOW

The intramodule control flow and the intermodule information flow can help analysts or programmers to understand the control of the system by describing input/output and the control variables used to direct the execution path in the program. However,it does not always measure the use of global variables, the value that may be changed during the information flow from input to output. More precisely, a procedure or function which alters the value of non-local variables during the execution is said to have side-effects. For example, the read statement reads a value from an input file and that value is assigned to a global variable instead of using its own variable declared within the procedure or function. This may do no harm to the system execution, but it makes the system harder to understand and to work with.

To enhance the effectiveness of the computer software, it is essential to develop a better understanding of ways to deal with information flow. It turns out that combining the study of these four types, metric and information flow graph may be used to analyze the complexity of the information flow among the program variables. This may lead to an improved understanding of the design. By tracing the connection among the program variables from the initial node

to every other node that exists, program variables can be identified whether they are dependent or independent. A variable is called dependent if it value is affected by the value of other variables. The dependent variable can be shown by flow graph describing the information flow from the source node to the destination node. An independent variable can be defined as a program variable whose value does not change as the result of processing of the program module. Thus the IFC program is presented to accept the input Pascal program. Every program statement contained within the input program module needs to be examined for the information transfer.

CHAPTER TWO

INFORMATION FLOW

Information flow can be defined as the transfer of information from one object to another. The objects are program variables. Each variable may or may not be involved in an information transfer during the program execution. Operations of the program concerned in this report involve assignment, I/O, call statement, with statement and control statement. During program execution, the information transfer usually has a transitive relation. The flow relation (FR) is transitive if, whenever (A,B) is in FR and (B,C) is in FR, (A,C) is in FR also. This can be described by showing that among the program variables A, B, C there is an information transfer from A to B and from B to C, thus, there is an information transfer from A to C (Denn 76).

The features of information flow can be viewed as : (1) explicit information flow; (2) implicit information flow. The following section gives the definitions and explains how the information flow can be represented by a flow graph. Each node represents a variable declared in the program. An arc represents the information flow that transfers from the source node to the destination node.

EXPLICIT INFORMATION FLOW.

Explicit information flow can be viewed as a straightforward and obvious transfer of information between objects in simple statements(Mac 81). The transfer may occur directly or indirectly. Direct transfer can be described as a transfer of information from source object to destination object which results in a final output. Indirect flow is very much like direct transfer except it involves one or more statements participating in processing a final output.

(a) C := D

(b) A := B + C

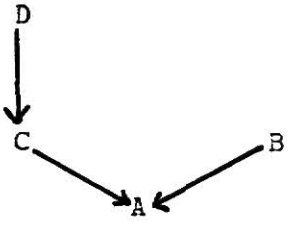


Figure 2.1 Explicit information flow graph.

Figure 2.1 consists of two assignment statements. Statement (b) uses statement (a) to produce a final output A. The flow graph shows a direct information transfer from object D to C in an assignment (a), and also has a transfer from object B to A and from C to A in an assignment (b). However, the result of flow graph shows an indirect information flow,namely, transitive relation , from object D to A in processing these two assignments.

Simple statements used in the explicit information flow in this project are composed of three types: (1) assignment statements, (2) input/output statements, and (3) procedure/function call statements.

(1) ASSIGNMENT statement.

The assignment statement symbol is denoted by ':='. The object which appears on the left hand side(LHS) on an assignment symbol is defined as the destination. The object on the right hand side(RHS) is defined as the source object. It may contain either an expression or a function call statement. LHS := RHS shows the direct explicit flow which tranfers the information from the RHS to LHS.

(2) INPUT/OUTPUT statement.

The input/output statement is used to transfer values to or from the program. Only the I/O statement that performs a value read or write is involved in this analysis. For example, in figure 2.2 the statement READ(A) shows the explicit information flow which is the transfer of an assigned value from the input file to the object A. The statememt: WRITE(B, 'sample') shows the direct explicit flow which is the transfer value from the object B to the output file.

```
READ(A);
WRITE( B, 'sample');
```

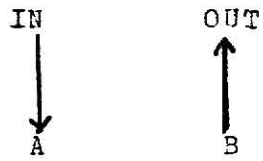


Figure 2.2 Explicit information flow graph of I/O statements.

(3) PROCEDURE_FUNCTION statement.

When a call statement is executed, a mapping is performed depending on the procedure/function declaration. Consider a procedure call with parameter passing. It is obvious that there is at least a direct transfer from the actual parameter to the formal parameter, and a possible direct transfer from the formal parameter back to the actual parameter depending on how the procedure heading is declared. The function call can be only used in an assignment statement while a procedure call can be used by a call statement. These can not be used or contained in any boolean expression of the control statements and in the I/O statement. At the point of call, the exact number of actual parameters and formal parameters are required. Actual parameters must use the variables declared in the prefix declaration, thus they cannot be constants, subprograms or be contained in the expression.

In figure 2.3a, the procedure call statement: ADD(A,B,C) causes the explicit flow from actual

parameters A,B,C to formal parameters x,y,c of the routine heading: PROCEDURE ADD(X,Y,Z:real). In figure 2.3b, the routine heading declared as: PROCEDURE(X,Y:real; VAR Z:real) causes the explicit flow from actual parameters A,B,C to formal parameters X,Y,Z, and also the transfer from formal parameter Z back to actual parameter C in the call statement ADD(A,B,C).

```
PROCEDURE add(X,Y,Z:real);
BEGIN END;
 ....
 ----
add(A,B,C);
```

Figure 2.3a Explicit information flow graph of a call statement.

```
PROCEDURE add(X,Y:real; var Z:real);
 BEGIN END;
  ---
  ...
 add(A,B,C);
```

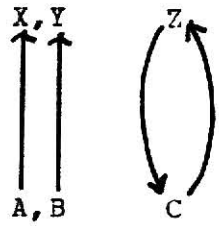


Figure 2.3b Explicit information flow graph of a call statement with a returned value.

IMPLICIT INFORMATION FLOW.

Implicit information flow can be caused by conditional statements(Mac 81). Conditional statements are composed of two parts: the conditional part and the computational body. The conditional part consists of a boolean expression that needs to be evaluated to specify whether to carry on or to terminate the computational phase. During the evaluating of the conditional phase, if there is any variable contained in the boolean expressions, that variable will have an implicit information flow to the appropriate variables contained in the computational body. The computational part consists of executable statements which can be a simple statement, conditional statement, or compound statement composed of a group of statements introduced by BEGIN and terminate by END.

```
WHILE A>B DO BEGIN  READ(X);
                    Y := 1;
                    Z := TRUE;
                    END
```

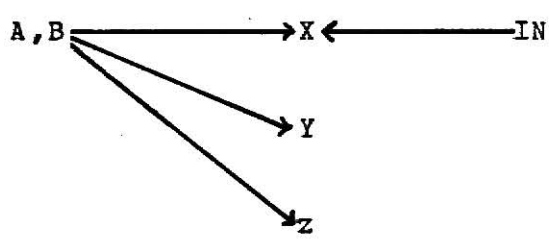


Figure 2.4 Implicit information flow

Figure 2.4 shows the variables used in a WHILE statement. There is an implicit information flow from A and B to its computational body: X,Y and Z , and the explicit information flow from IN to X in an I/O statement.

Statements involved in the implicit information flow measure consist of WHILE DO statements, IF THEN ELSE statements, FOR statements, and REPEAT UNTIL statements. The basic concept and rules of each statement are briefly described in the following section.

(1) WHILE statement.

In a loop statement, WHILE <bool> DO <s1>, the conditional part contains a boolean expression that needs to be evaluated to specify whether to continue or terminate the computational body. If there is any variable participating in the boolean expression, <bool>, that variable will have the implicit information flow to the compuational body, <S1>.

Figure 2.5 shows an implicit information flow from A and B to the appropriate variables contained in the computational body, a procedure call statement. In fact, the evaluation of A>B causes the changing of actual parameter C after the procedure call ADD is invoked. Thus it is important to recognize that there

is an implicit information flow from object A, and B to object C. There also is an explicit information flow which was previously described.

```
PROCEDURE ADD (X,Y:real;VAR Z:real);
BEGIN END;
:
:
WHILE A>B DO ADD (A,B,C);
```

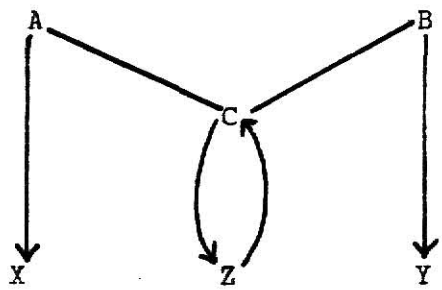


Figure 2.5 WHILE flow graph.

(2) IF THEN ELSE statement.

A conditional statement, IF <bool> THEN <s1> else <s2>, enables the process to select one of the two actions. The selection is made by evaluating the boolean expression, <bool>, in the conditional phase. If there is any variable participating in the evaluation of the boolean expression, there will be an implicit information flow from that control variable to both the THEN and ELSE computational bodies, <S1> and <S2>.

In figure 2.6, the conditional phase, d>0, causes the implicit information transfer from object D to the object C in an I/O statement, and object E which appears on the LHS of the assignment statement. The assignment statement, E := F, causes the explicit information flow transfer from object F to object E. There also has an implicit flow from IN to object C in an I/O statement,READ(C).

```
IF D>0 THEN E := F
       ELSE READ(C)
```

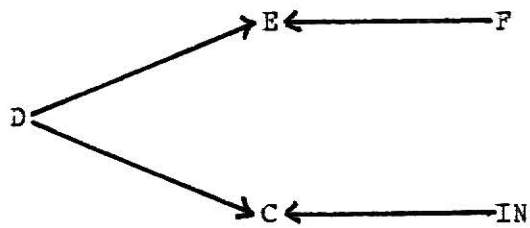


Figure 2.6 IF THEN ELSE flow graph

(3) FOR statement.

The information flow in the statement; FOR <id> := <bool1> (TO|DOWNTO) <bool2> DO <s1>, will work the same way as the WHILE statement except the object "id" will not be involved in an implicit information transfer. When the variable "id" appears in the body, S1, it will be an explicit transfer.

```
FOR I :=  A TO B DO BEGIN
                        C := D+1;
                        writeln(E);
                    END;
```

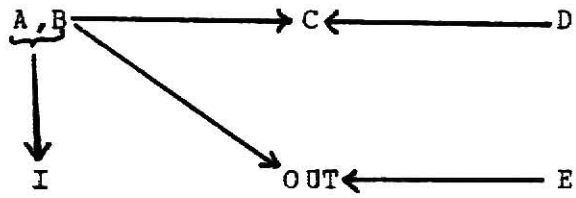


Figure 2.7 FOR statement flow graph.

Figure 2.7 shows the implicit information flow from A and B to object C in an assignment, and to OUT in the I/O statement. There also is an explicit information flow from D to C in the assignment, and from E to out in the I/O statement.

(4) REPEAT statement.

The body of the REPEAT statement looks very much like a compound statement, except that BEGIN and END are missing. UNTIL serves to introduce the boolean expression that needs to be tested to terminate the statement. Any variable used in the evaluation of the boolean expression will cause an implicit information flow to its body.

```
REPEAT
   READ(A);
   C := D+B;
UNTIL E>10;
```

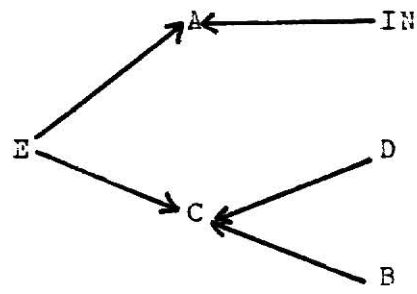


Figure 2.8 REPEAT_until flow graph.

Figure 2.8 shows the implicit information flow from object E to C in the assignment statement, and to A in the I/O statement. The assignment statement, C := D+B, causes the explicit flow from the objects D and B to C. The I/O statement, READ(a),causes an explicit information flow from IN to A.

CHAPTER THREE

DESIGN

The information flow complexity (IFC) program is designed to run under the P-system operating system. The P-system supports UCSD Pascal on many microcomputers. This implementation of IFC is done on the PDQ-3 microcomputer system. This chapter explains in detail the requirement specifications, input source program and output, major data structures used in the implementation, system overview and structure diagram that leads to the pseudo code described in the next chapter.

REQUIREMENT SPECIFICATION.

IFC is concerned only with how the information is transfered, thus it is assumed that the input program is 100% free from syntax errors. The following section assumes that the user already knows the concepts and syntax of the Standard Pascal language definition. Only Standard Pascal language is allowed in the input programs.

IFC Input Program.

There are keywords that the input program may not contain unless they are part of the program statement or comments:

ARRAY	BEGIN	CONST	DO
DOWNTO	ELSE	END	FOR
FUNCTION	IF	OF	PROCEDURE
PROGRAM	READ	READLN	RECORD
REPETE	THEN	TYPE	UNTIL
VAR	WHILE	WITH	WRITE
WRITELN			

Beside the keywords described above, there are additional requirements for input program:

(1). comments must start on a new line.

(2). each input line buffer must be terminated by using semi-colon unless it is the end of the program indicated by '.'

(3). The input line buffer can only contain 80 characters. A line of input is read and accumulated to the input buffer until a semi-colon is reached. The following is an example showing a

program statement that is not greater than 80 characters.

```
IF a >10 THEN
     WHILE  b<> 0 DO
          BEGIN  d := 2* e;
```

The input line buffer would contain:

```
IF a >10 THEN WHILE b<>0 DO BEGIN d := 2* e;
```

Standard Pascal Statements.

Ten operations are acceptable in the IFC input program. They are in the following:

(1). assignment statement

(2). BEGIN_END

(3). FOR_DO

(4). function call

(5). IF THEN ELSE

(6). I/O statement: WRITE, WRITELN, READ, READLN

(7). procedure call

(8). REPEAT_UNTIL

(9). WHILE_DO

(10). WITH statement

IFC outputs

There are three normal outputs: the listing of the input source program, and the arrays KEYTAB and METRIX which are illustrated in the following. The rest of the tables built during the analysis may be printed on the hard copy, if requested (refer to global data structures in this chapter).

KEYTAB

1	IN
2	OUT
3	main...A
4	main...B
5	main...E
6	main...D
:	.....
:	.....

METRIX

TO

FROM	1	2	3	4	5	6 ...
1						
2						
3						1
4						1
5						1
6						
:						
:						

The statement: IF A>10 THEN WHILE B<>0 DO BEGIN D:= 2*E; causes an explicit flow from "E" to "D" and the implicit flow from "A" and "B" to "C". This is shown by the array KEYTAB and METRIX above.

Running IFC

To run IFC, the input source program must be created and kept on the floppy disk. Ten IFC input sample programs are provided in this report. The sample program listings and their results can be found in the appendix D. Appendix C briefly describes how to run and operate the existing input programs. To analyze a user's input program, it is important for the user to read and understand the user's guide to the P-system.

DATA STRUCTURE

IFC is used to report the flow of information between objects. These objects, program variables, must be collected in tables. The IFC program uses six tables. The first three tables: TYPTABLE, INFOTABLE, PROCTAB are built during the scanning of the declarations while the last three tables: INDXTAB, KEYTAB and METRIX are built during the scanning of the body routines. The INDXTAB is used to store the temporary variables during the scanning of program statement execution. The KEYTAB and METRIX are the outputs that are printed after the end of an input file is encountered. The following sections describe the six tables.

(1) TYPTABLE

During the parsing of a type declaration, names of both record types and arrays of record are stored in the TYPTABLE. This table is used for record type checking of program variables declared in the declaration section. The matching of record name and the suspect type of variable in the TYPTABLE will return the location of first record field kept in the INFOTABLE.

TYPTABLE is an array of records. Each record contains two fields of information: TYPENAME and FIRSTFIELD. TYPENAME represents the name of the record and FIRSTFIELD contains a value pointing to the location of the appropriate record field of INFOTABLE.

(2) INFOTABLE.

INFOTABLE is the most important table in the data structure. It keeps all program variable names and function/procedure names that may or may not have an entry in METRIX.

The INFOTABLE is an array of records. Each record is composed of five fields: INFONAME, NEXTINFO, POINTOINDEX, SCOPE and PARAMTYP. INFONAME represents one of these four kinds: (1) a record field , (2) a program variable, (3) a parameter passed in the procedure heading or (4) function name. NEXTINFO contains a value pointing to the next field of the record structure. POINTOINDEX contains a value pointing to the first field of the record structure if it has a value greater than zero. Zero indicates a simple type. SCOPE represents two kinds of variables: global variables and local variables. A SCOPE equal to zero represents a global variable from the main routine, A number greater than zero indicates the location of its procedure name in the procedure table. PARAMTYP indicates two types of parameter passing : PARAMTYP is one when the parameter passed is a returned parameter while PARAMTYP equal to zero indicates a formal parameter passed without a value returned.

(3) PROCTAB.

This table is created when scanning the routine heading and is used for checking the existing procedure name whenever a procedure name is invoked. The procedure call statement performs the information transfer between modules by the use of PROCTAB. The table has a value indicating the location of the first formal parameter kept in the INFOTABLE. PROCTAB is also used for the termination of the procedure block. The table keeps track of the number of actual parameters passed as kept in the INFOTABLE. Thus INFOTABLE can update its index which points to where the last formal parameter passed is located. Local variable names will be deleted from INFOTABLE because they will not be used again in the program.

PROCTAB is an array of records designed for storing procedure and function names and their details. Each record is composed of four fields: PROCNAME, PARAM_CT, TOINFO and PROCTYPE. PROCNAME contains the procedure or function name of the block in which the name is defined. PARAM_CT represents the number of parameters passed. TOINFO contains a number that points to the first parameter in the INFOTABLE. PROCTYPE represents the kind of routine, a "1" is coded for a function routine and a "0" is coded for a procedure routine.

(4) INDXTAB.

This table performs as a stack machine. A stack counter is incremented when a new program statement is encountered and decremented after finishing scanning the program statement. During the scanning, the current stack is used to keep all the possible program variables that may have an information transfer. The variables that are kept in the INDXTAB must be successfully checked through the INFOTABLE and stored as unique key numbers associated with the KEYTAB. How the INDXTAB is used will be discussed in the system overview in this chapter.

INDXTAB is an array of records. Each record contains four fields: MODE, BLOCK, NEXT and INDXARRAY. MODE has a value range of "0" through "6". "0" is coded for simple statements. "1" is coded for an IF THEN ELSE statement and "2" is coded for an IF THEN statement. "3" is coded for FOR and WHILE DO statements. "4" for REPEAT statement "5" for WITH statement and "6" for entering of the routine body. BLOCK = 1 if the statement following the conditional statement is a compound statement, BLOCK = 0 for simple statement. INDXARRAY is an array type with a maximum size of ten. It is used to store program variables in the unique key number that is successfully searched through the INFOTABLE, NEXT keeps track of how many

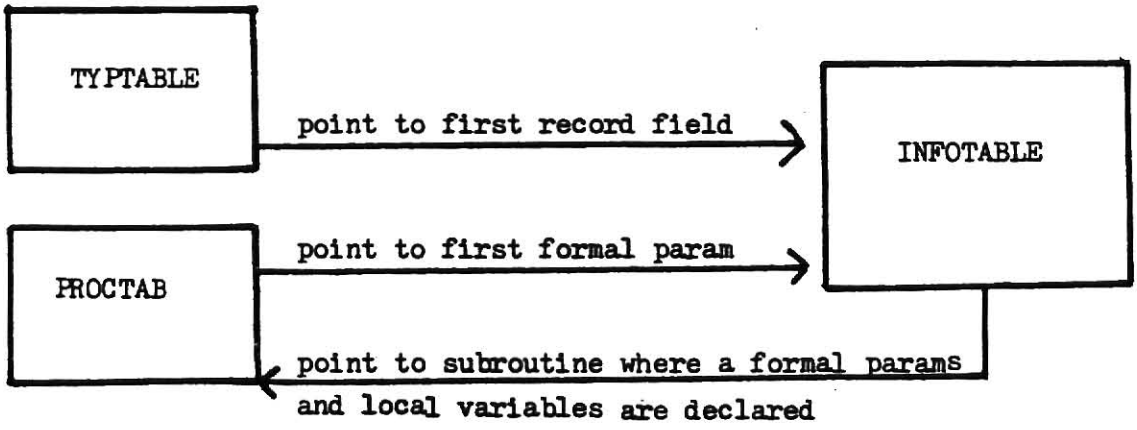
unique keys are kept in the INDXARRAY.

(5) KEYTAB.

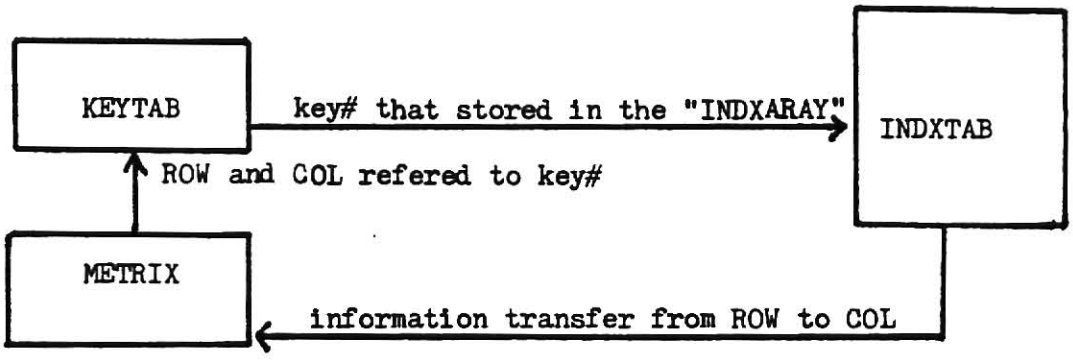
KEYTAB is an array of character strings. KEYTAB(1) represents information read-in, while KEYTAB(2) is the information written-out. Other elements contain program variables according to INFONAME in INFOTABLE. KEYTAB is used to register program variables before making any information transfer to METRIX.

(6) METRIX.

METRIX is a two dimensional array. Each row and column represent the transfer of information from source(row) to destination(col). The source and destination indices are obtained through KEYTAB(see fig 3.14).



Data structure used during the analysis
of the PREFIX declaration.



Data structure used during the analysis of a routine body

Figure 3.1
Relating data structures

TYPTABLE

	TYPNAME	FIRSTFIELD
1	ADD	1

INFOTABLE

	INFONAME	NEXTINFO	POINTOINDEX	SCOPE	PARAMTYP
1	NAME	2	0	0	
2	PHONE	3	0	0	
3	ADDRESS	4	0	0	
4	ACCTNUM	0	0	0	
5	CUSTOMER	0	1	0	
6	DEPT	0	0	0	
7	CACCT	0	0	1	0
8	COST	0	0	1	0
9	BAL	0	0	1	1

PROCTAB

	PROCNAME	TOINFO	PARAMCT	PROC_TYPE
1	SALE	7	3	1

```
PROGRAM sample;
TYPE     add = RECORD  name : string;
                       phone : integer;
                       adderss : string;
                       acctnum : integer;
                       end;
VAR customer : array(1..50) of      add;
    dept : string;
PROCEDURE sale (cacct, cost : integer; VAR bal : integer);
  BEGIN END;
```

Figure 3.2
A sample of relating data structures.

CHAPTER FOUR

IMPLEMENTATION

IFC as implementated on the PDQ-3 microcomputer consists of approximately 1500 lines of code including imbedded comments. The implementation is stored in the disk library with named files of 'IFC.text' and 'IFC.code'. IFC.text can be found in appendix B. The IFC.code which is the result of the successfully compiled translation of IFC.text is kept in P-code and ready for the user to execute.

The following sections help the user to understand the logic of the program. The listing of routines and global variables used during the implementation appears in appendix A. Included are the hierarchical system diagrams, and an IFC sample program.

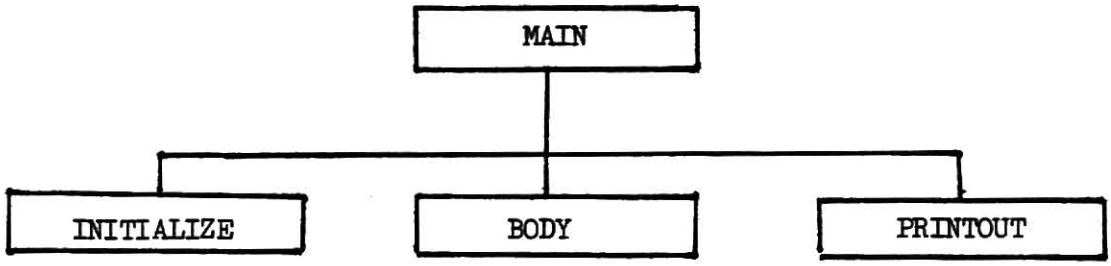


Figure 4.1 SYSTEM design

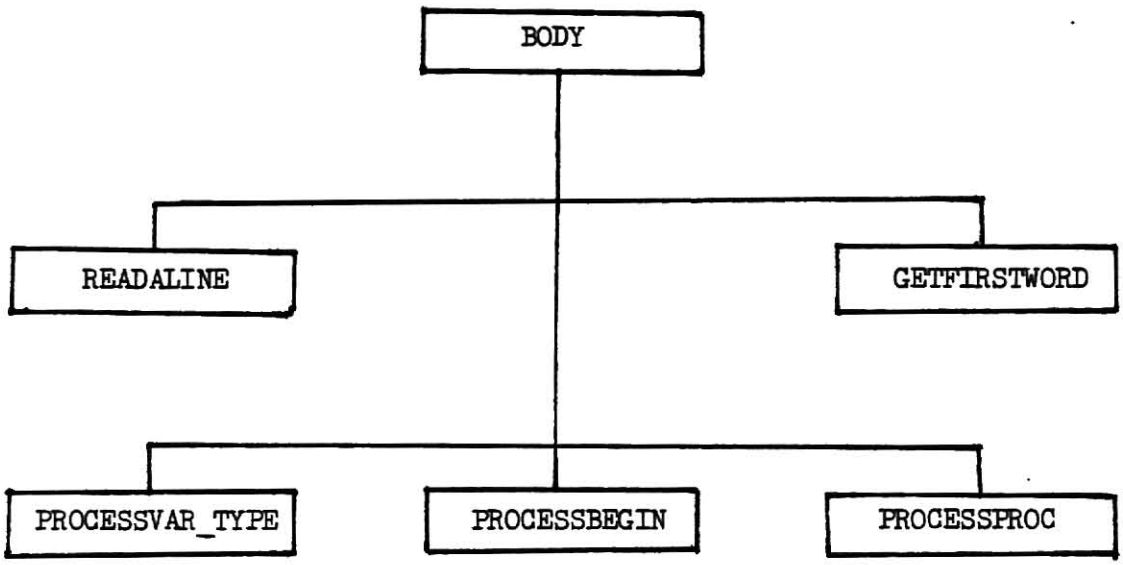


Figure 4.2 Hierarchical diagram of Body routine.

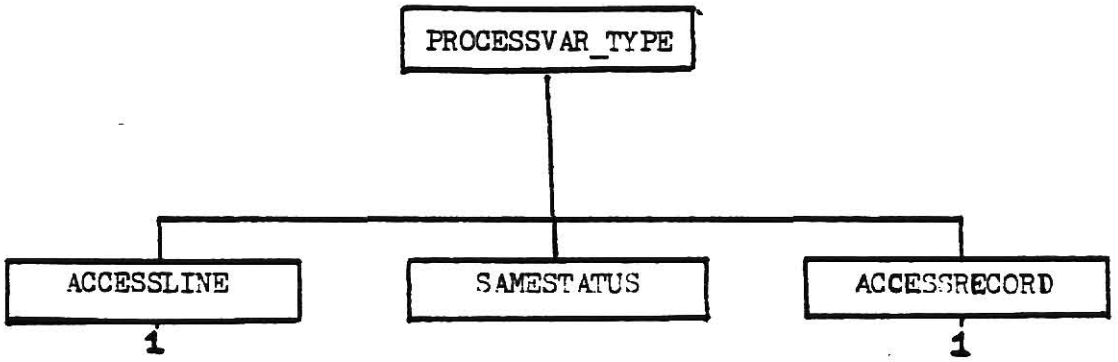


Figure 4.3 Hierarchical diagram of PROCESSVAR_TYPE routine.

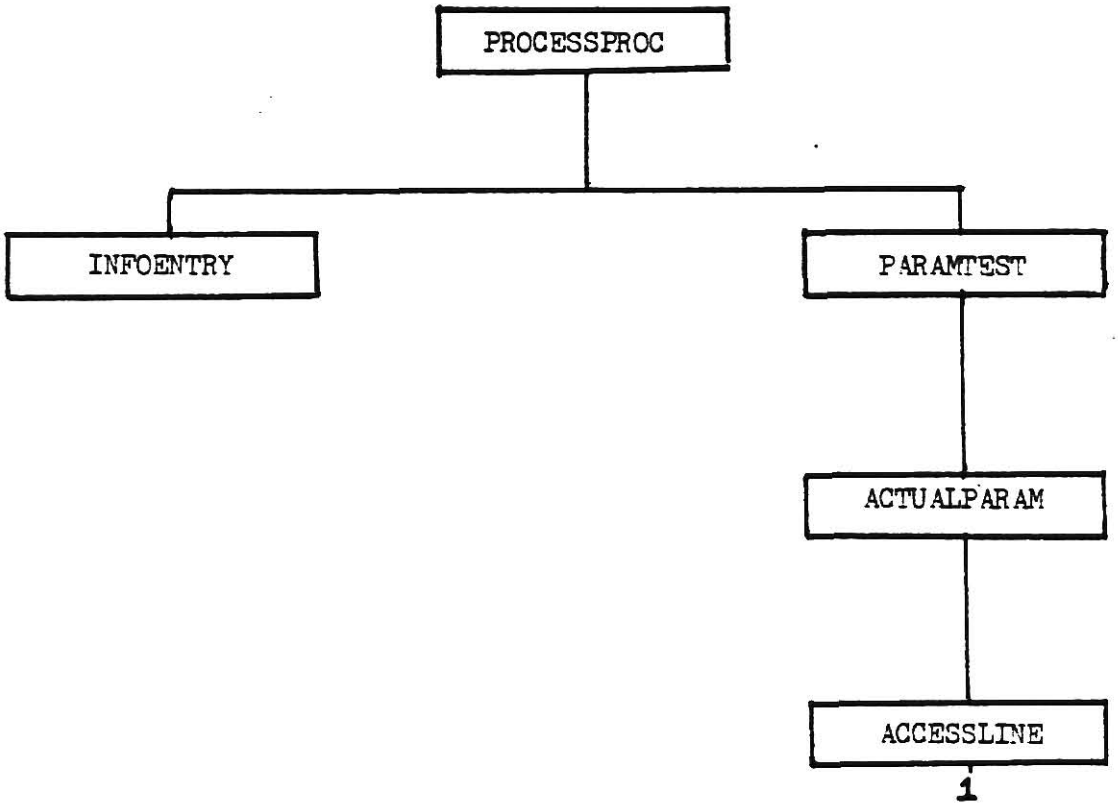


Figure 4.4 Hierarchical diagram of PROCESSPROC routine.

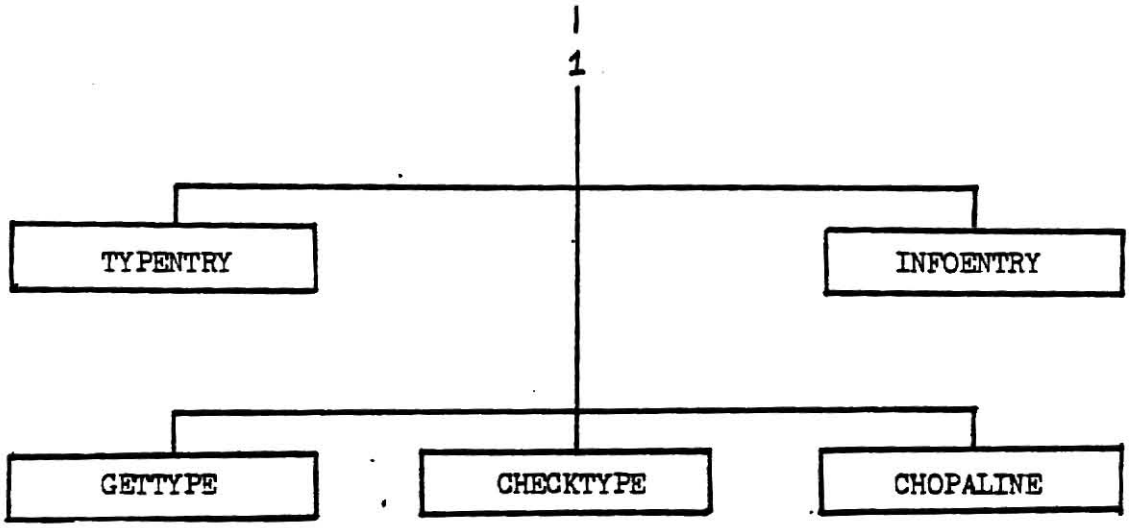


Figure 4.5 Hierarchical subdiagram of
PROCESSVAR_TYPE and PROCESSPROC routines

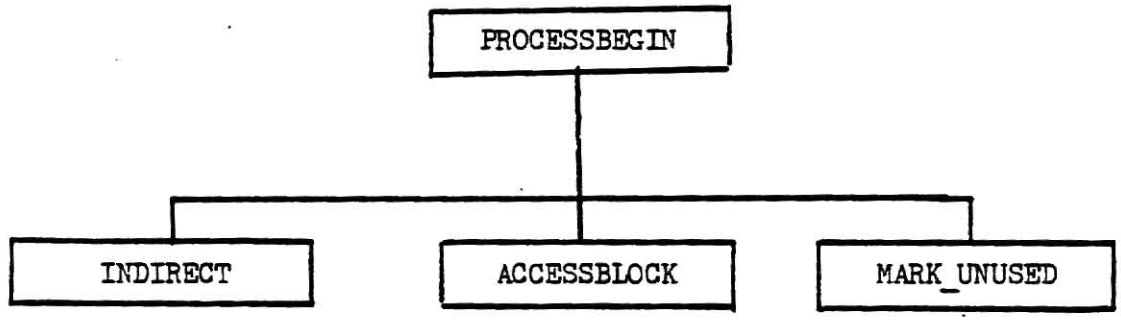


Figure 4.6 Hierarchical diagram
of PROCESSBEGIN.

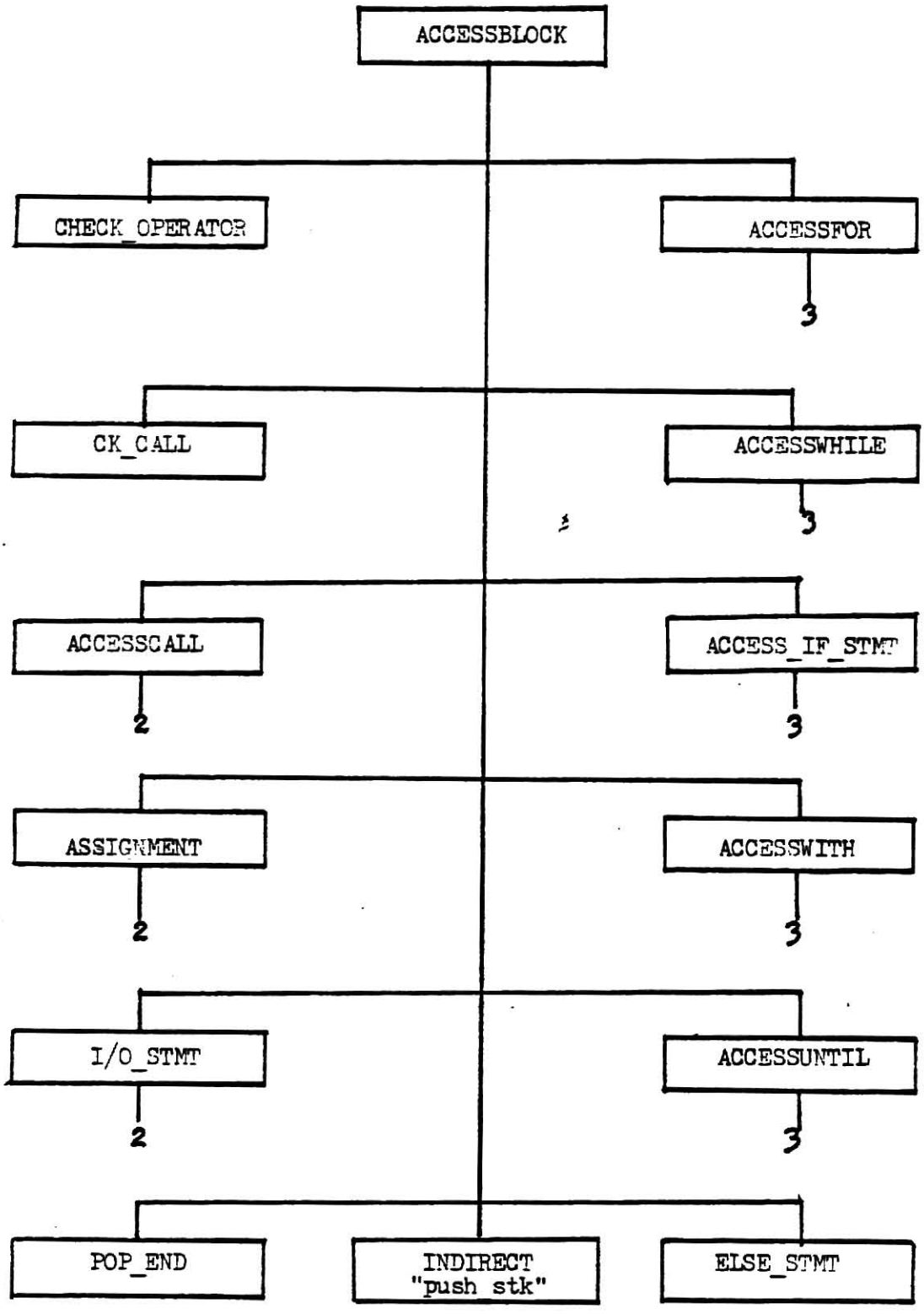


Figure 4.7 Hierarchical diagram of ACCESSBLOCK routine.

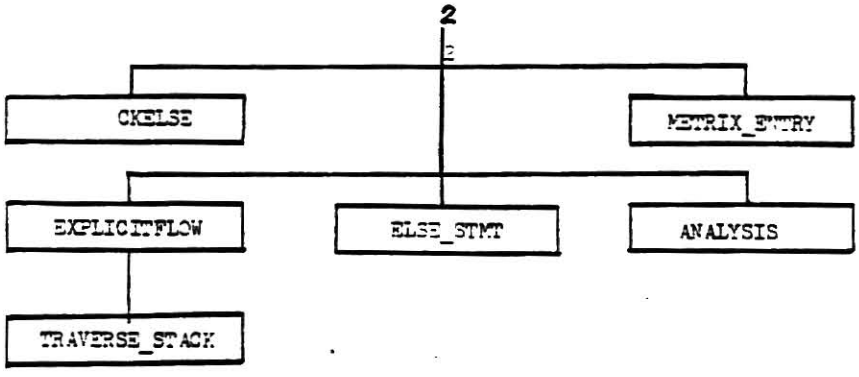


Figure 4.8 Hierarchical diagram for simple statements

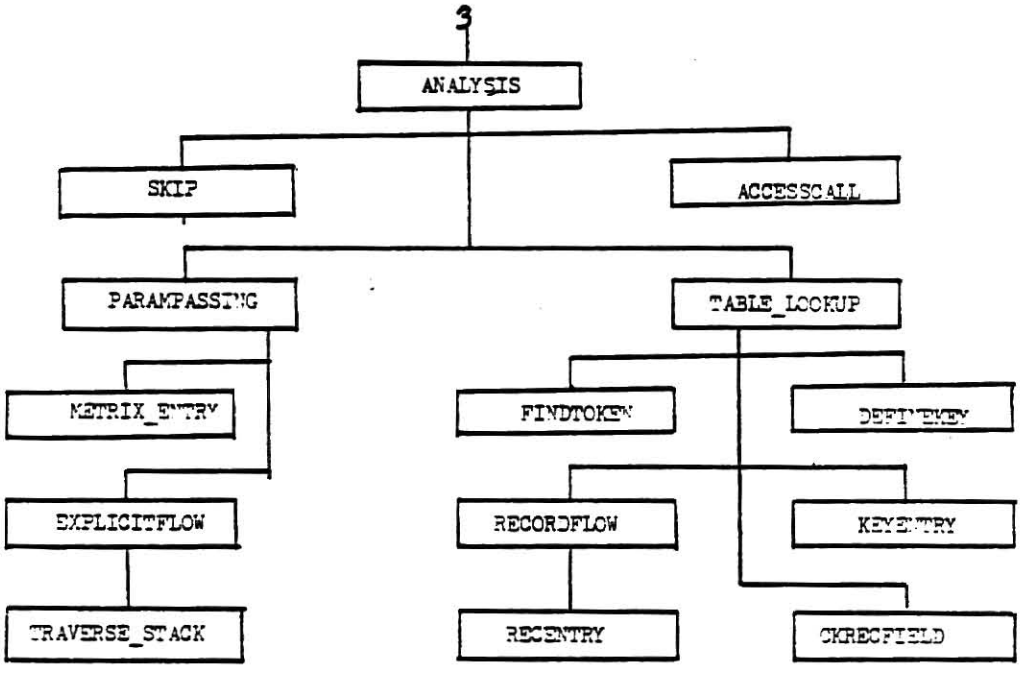


Figure 4.9 Hierarchical diagram
of ANALYSIS routine.

SYSTEM LOGIC.

IFC logically divides the input program into a standard prefix declaration part and a body routine part. The Standard prefix declaration consists of constant, type, variable declarations and routine headings. Since constants remain the same during the program execution, the use of constants may be ignored. Variables and types have to be identified and entered into the appropriate tables. A program variable of type array, will be counted as one object during the scanning of the program statements. For example, statements A(i) := B(j) and A:= B cause the information transfer from object B to object A.

(1) Standard Prefix Declaration.

The IFC scans an input program line by line from top to bottom. The IFC will accumulate an input buffer by making a first call to procedure READALINE and the subsequent call to procedure GETFIRSTWORD, in order to get the first word which is a character string seperated by a blank. The word must be in one of the keywords: TYPE, VAR, PROCEDURE, FUNCTION, and BEGIN in order to enter one of these three subroutines: PROCESSVAR_TYPE, PROCESSPROC, or PROCESSBEGIN. These three routines, and READALINE and GETFIRSTWORD are performed in a while_loop

which is terminated when the end of the input file is encountered. To enter the PROCESSVAR_TYPE, the current word must be either VAR or TYPE while the current word of either PROCEDURE or FUNCTION causes an entry into procedure PROCESSPROC. The routine PROCESSVAR_TYPE will collect record names, program variables and keep them in the INFOTABLE and TYPETAB during scanning of the type and variable declaration sections. The next input buffer is read after scanning the current buffer and the first word is detected in order to check whether to continue or to terminate the routine. The routine is terminated only if the current word is in one of the keywords. Procedure PROCESSPROC is used to scan routine headings. Procedure and function names are kept in the PROCTAB and their parameters are kept in the INFOTAB.

(2) Body Routine Analysis.

After the Standard prefix declaration has been analyzed, the body of the routine, which is a sequence of statement introduced by BEGIN and terminated by END, is examined by procedure PROCESSBEGIN. The procedure uses INDXTAB, a stack, to analyze the effect of the program statements which can be classified as: simple statements, control statements and nesting. An entry is added to the stack with a specific MODE and BLOCK

whenever a new statement is encountered. The entry for a simple non-nested statement is deleted immediately after that program statement is analyzed. Then the next input program statement is read and analyzed. This continues until the end of the routine body. Entering a routine body causes a new INDXTAB entry to be added and this entry is deleted when the end of the routine body is encountered. BLOCK is the key point to determine whether to remain or to delete the current stack entry. The stack entries show the number of the control statement and nesting. Conceptually the operation of a simple statement that may involve the explicit flow will be done on the current stack entry. The subsequent implicit flow will be done by traversing down the remaining stack entries. These stack entries will remain on the stack until the computational bodies are completely analyzed.

```
PROGRAM sample;
VAR a,b,c,d,e:integer;
BEGIN READ (a,b);
      REPEAT
          READ (c);
          IF a>10
          THEN WHILE b<>0
               DO BEGIN d:= 2*e;
                  END;
       UNTIL c=0;
END.
```

Considering only the body of the routine, the input line buffers would be the following:

```
Buff....BEGIN READ (a,b);
    ....REPEAT READ (c);
    ....IF a>10 THEN WHILE b<>0 DO BEGIN d:= 2*e;
    ....END;
    ....UNTIL c=0;
    ....END.
```

Figure 4.10 Example for explaining INDXTAB.

The following relates how INDXTAB stack is used when the routine of Figure 4.10 is input. The entries are shown in Figure 4.11a and 4.11b. The first line buffer; BEGIN READ (a,b); is read. 'BEGIN' of the main body causes the first entry to be added to the stack with MODE=6. The second entry is added with MODE=0 for the I/O statement READ (a,b); and is deleted after the statement is analyzed. The next input buffer: REPEAT READ (c); is read. A stack entry is added with MODE=5 for REPEAT statement. The second entry is added to the stack for the I/O statement and it is deleted after the statement has been analyzed. The statement READ (c); will first make an explicit flow from IN to "c" then traverse down the remainning stack for an implicit flow. In this case, the previous stack is the REPEAT statement of MODE=5; the variable "c" will be kept on this entry until the UNTIL statement is analyzed. Figure 4.11a shows the remaining stack entries after the statement READ (c); is analyzed.

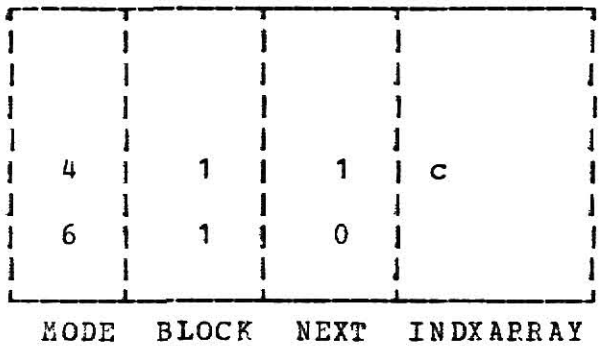


Figure 4.11a

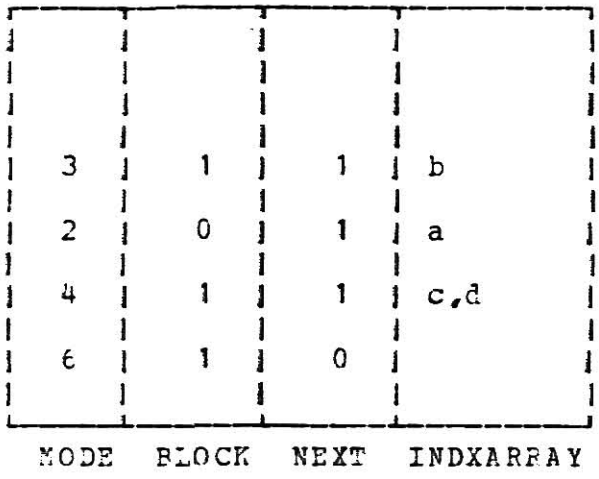


Figure 4.11b

The next line buffer; IF a>10 THEN WHILE b <> 0 DO BEGIN d:=2*e; is read. Their entries are put on the stack. First, an entry is put on for an IF statement with MODE=2. Second for the WHILE statement with MODE=3 and BLOCK=1 and third for the assignment statement. The current entry is deleted after the assignment is analyzed and traversed down the remaining stack entries. Figure 4.11b shows the remaining stack entries after the

assignment is completely analyzed. The next line buffer END; causes two entries to be deleted from the stack: first, for the WHILE statement because of the matching pair BEGIN_END and second, the entry for the IF statement with nesting. If BLOCK contains a value equal to one, this entry will remain on the stack until the matching pair is encountered. If there is an ELSE statement, this entry will remain on the stack and the MODE is changed from 2 to 1 before the ELSE statement will be analyzed. The next line buffer, UNTIL c=0, is read. An entry is added on the stack. There is an implicit flow from the variable names stored in the current stack entry to the variable names stored in the previous entry (REPEAT). Then these two entries are deleted from the stack and the next line buffer is read.

The line buffer, END., which is the end of the input program causes the last entry to be deleted from the stack. If it is the END of the subroutine, INFOTABLE needs to clean up all the local variables, if any, because they will not be used again in the program. This is done by procedure MARK_UNUSED.

IFC Sample Program.

This section shows a sample program and output in which users are assumed to be testing one of the provided input programs. Ten input programs have been created and kept in the list directory under prefix name of "IP##", where "##" represents the number 1..10. More than that to update, modify, create and run the input programs, the user needs to read and understand the short manual of instructions and commands. (refer to USER's GUIDE in appendix C.) .

```
PROGRAM SAMPLE;
(* IP1 *);
VAR A, B, C, D, E : INTEGER;

BEGIN
     READ (A, B);
     REPEAT
         READ(C);
         IF A>10 THEN WHILE B <>0
                      DO BEGIN D:= 2*E;
                         END;
     UNTIL (C=0);
END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	A. .	0	0	0
2	B. .	0	0	0
3	C. .	0	0	0
4	D. .	0	0	0
5	E. .	0	0	0

KEY TABLE

1	IN
2	OUT
3	MAIN. . A
4	MAIN. . B
5	MAIN. . C
6	MAIN. . E
7	MAIN. . D

MATRIX

	1	2	3	4	5	6	7
1	0	0	1	1	1	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	1
4	0	0	0	0	0	0	1
5	0	0	0	0	1	0	1
6	0	0	0	0	0	0	1
7	0	0	0	0	0	0	0

CHAPTER FIVE

CONCLUSION and EXTENSIONS

In summary, the task of the IFC program is to report overall information transfer between objects in the input program. The resulting output, the matrix table, can be used in various ways in the area of software development and software testing techniques. The information flow graph can be derived from the matrix table. The flow graph may be used to analyze the complexity in tracing the connections among the program variables from the initial node to every other node that exists. Path testing of the information flow graph may be used to identify whether the program variable is dependent or independent. Combining both the graph flow and the matrix table can help designers and programmers to understand the logic of the system design that may lead to reduce the number of test cases in path testing.

Path testing may be defined as the process of finding a set of program variables that force the path predicates to the truth value that corresponds to the desired path. Since the information transfer is based on the program variables associated with the function performed, it can be used as an adaptive development tool

for the management of the path-testing. Subsequently, the matrix table can be summarized as the selected set of the dependent program variables needed to develop, execute and evaluate the test case. Thus the independent program variables whose values do not change as the result of processing need not be included in the test case.

FUTURE EXTENSIONS

The IFC program covers only the simple data structures and program statements which were described in previous chapters. In attempting to make the IFC program more powerful, there are some future extensions that may be included in this IFC program.

1. Input specification.

   Increase of the input line buffer to greater than 80 characters per line of program statement. This would allow the user to construct more complicated statement or nested statements especially in the repetition statements and conditional statements.

2. Standard Prefix declaration.

The following could be added in the analysis of label declaration (for GOTO statements), enumeration types, dynamic allocation with the use of pointer variables associated with record structures. In the routine heading, the analysis of FORWARD routine may be included in the declaration.

3. More executable program statements.

IFC should involve the use of the case statement and the UCSD Pascal statements such as CONCAT, COPY, INSERT as well as the use of multiple exit routine and goto statements. Included are implicit subroutine and function calls as contained in I/O statements and boolean expressions of the control statements.

4. OUTPUT Specifications.

The IFC output could provide statistics based on the information transfer of either intramodule or intermodule. The examples are the total number of routines used in the input program, total number of the program variables and number of the occurences of the transfer of information.

If the items discussed above can be included in the IFC program, IFC should apply to most UCSD Pascal programs.

REFERENCES.

(Ber 80) Berlinger, E.,"An Information Theory Based Complexity Measure", National Computer Conference, 1980.

(Cha 78) Chapin, N.,"INPUT/OUTPUT Tables in Structure Design", Structure analysis and Design (Vol 2), Infotech, 1978.

(Chap79) Chapin, N.,"A Measure Complexity", National Computer Conference, 1979.

(Che 78) Chen, E.T.,"Program Complexity and Program Productivity", IEEE Transactions on Software Engineering, vol. SE-4, No.3, May 1978, pp.187-19

(Cha 79) Chapin,N.,"Function Parsing in Structure Design", Infotech International, 1979

(Den 76) Denning, D. E.,"A Lattice Model of Secure Information Flow", CACM, #5, May 76, pp 236-243

(Hal 75) Halstead, M. H.,"Software Physic: Basic Principles", Watson Research Center, 1975

(Kaf 81) Kafura, D. G., and Henry, S. M.,"A Viewpoint on Software Quality Metrics : Criteria, Use and Integration". Paper sumitted to Siq Soft Symposium on Tool and Methodology Evaluation, Pingree Park, Co, June 9-11,1981

(kaf 81) Kafura, D. G., and Henry, S. M.,"Software Structure Metrics Based on Information Flow", IEEE

Transaction on Software Engineering, Vol. SE-7, No.5, Sep 1981, pp 510-518

(Mac 81) Allen L. Mennie, and Glenn H. MacEWAN, "Information Flow Certification Using an Intermediate Code Program Code Program Representation", IEEE Transaction on Software Engineering, vol.SE-7, No.6, Nov 1981.

(McC 76) McCabe, T.J.,"A Complexity Measurement", IEEE Trans on Software Enginerring vol SE-2 (1976).

(MCl 76) McClure, C. L.,"Formalization and Application of Structure Program and Program Complexity", Ph.D. Thesis, Illinois Institute of Technology , Chicago, 1976.

(McT 80) McTap, J. L.,"The Complexity of Individual Program", National Computer Conference, 1980

(May 77) Mayer, G. J.,"An Extension to The Cyclometric Measure of Program Complexity", ACM SIGPLAN Notices, Oct 1977, pp 61-64

(Zol 77) Zolnowski, J., and Simons, D. B.,"Measuring Program Complexity in a COBOL Environment", National Computer Conference, 1977

(Whi 80) Whitwort, M. H., and Szulewski, P. H.,"The Measurement of Control and Data Flow Complexity in Software Design", IEEE COMPSAC , 1980,pp 733-735

APPENDIX A

VARIABLE NAMES AND ROUTINES LISTING

Global variables listing

VARIABLES NAME	DESCRIPTION
ACTION	scope of the current program status
BUFF	contains first word of repetition statements to determine kind of current operation.
CALL	a boolean flag is set to 'true' while accessing the procedure call
FLAG	a boolean flag used to indicate end of input source program
INDX	index to INDXTAB
INDXTAB	table used for holding program variables that successfully checked through INFOTABLE and may have the information

	transfer between objects.
INFOINDEX	index to INFOTABLE
INFOTABLE	table used for keeping program variables that may have the information transfer during scanning of program statements.
IPFILE	temporary file for an input program
KEYINDX	index to KEYTAB and METRIX
KEYTAB	output table used for storing program variables names that have an access to information metrix
LETTER	a..z lowercase only
LN	the current input line buffer
METRIX	table used for information transfer from row to column. The number of row and column are refered by KEYINDX
NAME	name of input source program
NAMEREC	hold record name which currently in accessed.
NAMESPACE	contains temporary values that have the same type during the scanning of the variable declaration section and routine

	heading.
NUMBERS	0..9
OP, OPERATOR	represent the current operation of program statement only use for repetition statements and WITH statement.
OUTFILE	temporary file for output
PARAM_ENTRY	contains location of INFOTABLE where the first parameter is kept
PROCINDX	index to PROCTAB
PROCTAB	table used for keeping the procedure names and their information
STATUS	scope of the current program status
TYPEINDEX	index to TYPETABLE
TYPETABLE	table used for keeping type names of record type and links to first record field
WITH_STMT	a boolean flag used to indicate whether WITH statement is being used or not
WORD	first word of the line buffer

MAIN Routines listing

ROUTINE	FUNCTION
BODY	to generate all possible information transfer of the input program.
GETFIRSTWORD	to isolate a first word from current input line buffer.
INITIALIZE	to define the initial value of static program variables
PRINTOUT	output tables printouts upon user requested.
READALINE	to read an input line of code one at a time and accumulate into an input buffer. The routine return to caller when end of statement,';'. or end of input file is encountered.

Routiones used to analyze the Prefix Declarations.

ROUTINE	FUNCTION
ACCESSLINE	to isolate program variables or actual parameters contained in the current line buffer and save them in the INFOTABLE.
ACCESSRECORD	to collect record name and record fields of record data structure that may be used both in type declaration and variable declaration. The record name declared in the type declaration is kept in the TYPETAB, otherwise it is kept in the INFOTABLE. The routine scans line per line until the current line is 'end' of record structure.
ACTUALPARAM	to store each actual parameter in to the INFOTABLE and keep the total number of actual parameters declared in the PROCTAB.
CHECKTYPE	to searsh a given type through the TYPETAB. If the search is failed, value return is zero. IF not, It is the type of record structure , the

routine returns the value contained the location of the first record field kept in the INFOTABLE.

CHOPALINE — to seperate program variables contained in the current line and temporary kept in the NAMESPACE, data of an array type.

GETTYPE — to isolate a type string that is associated with program variables or record structure declared in the prefix declaration If it is an array type, it will get the string of type of that array. For example, routine will return the value <string> of the following declaration '...array (1..10) of <STRING>;'

INFOENTRY — to increment a counter of INFOTABLE and deposit variable names, parameters and record fields into the INFOTABLE.

PARAMTEST — to isolate the actual parameter string declared in the procedure heading and keep then in the PROCTAB.

PROCESSPROC — to parse a procedure heading and correct the information needed to

keep in the PROCTAB.

PROCESSVAR_TYPE to parse variable and type declaration and collect necessary information. in to TYPETABLE and INFOTABLE

SAMESTATUS to determine whether to terminate or to continue the current operation. The status is changed when the current word contained in the keyword 'type', 'var', 'procedure', 'function' and 'begin'.

TYPENTRY to add a record name and its details to the TYPETAB.

Routines used to analyze the Routine Body.

ROUTINE	FUNCTION
ACCESS BLOCK	use to generate program statements and is done in a series of operations in side of a big case statement. Each operation perform its function by pushing the program variables that may be contained in the statement onto the stack in order to get ready for information transfer. A new input buffer is read when finished scanning each simple statement and UNTIL statement. For the repetition statement, the current line buffer is updated, the statement body becomes the current line, excluding 'BEGIN' in a compound statement. The routine then returns to the caller.
ACCESSCALL	to make the implicit information transfer from formal parameters to actual parameters, if any. The passing parameter string must contain program variable names that

have been predeclared in the prefix declaration. Explicit information transfers of the repetition statement are done by searching down the stack.

ACCESSFOR — add a program variable to INDXTAB with mode = 3 and block = 1 if the body statement is a compound statement. TO save control variables on the current stack by calling procedure analysis.

ACCESSIF_STMT — simialarly to ACCESSFOR routine except enter MODE = 2.

ACCESSUNTIL — keeps a control variable contained in an expression on the stack by calling the ANALYSIS routine. Makes the implicit information transfer from the current top(until) to the previous stack, with MODE=5 for a REPEAT statement, its first word seperated and returns to caller.

ACCESSWHILE — similarly to ACCESSFOR routine except enter MODE=3.

ACCESSWITH — add a stack with mode = 4 and block = 1. If the computational statement body is a compound statement, sets a

flag WITH_STME and calls the ANALYSIS routine with string of record name.

ANALYSIS — to isolate a program variable from a given string, searches for the isolated string in INFOTAB. If a match is found, assigned a key number and kept in KEYTAB. The key number will be kept on the current stack in INDXARRAY and will make the information transfer for that program statement, if any.

ASSIGNMENT — to make an information transfer from the variables contained on the RHS of the assignment to the variable on the LHS. The RHS and LHS string are examined by the ANALYSIS routine.

CHECKCALL — to search for a given string through PROCTAB. If the search is successful, the returned value points to the first parameter.

CKELSE — to seperate a current line from an IF THEN ELSE statement to be the line which follows the ELSE statement. The previous statement will be returned to caller.

CK_OPERATOR	to determine the type of the program statement currently being scanned.
CKRECFIELD	to search a given string which may be a record field or program variable while a WITH statement is in effect. According to the global data NAMEREC, it will link to all validated fields. If the search is successful, the routine will call DEFINEKEY routine to get the unique number.
DEFINEKEY	to search for the program variables in the KEYTAB and return is a unique key to the caller.
ELSE_STMT	to change the status in the INDXTAB if it is the IF THEN ELSE statement from MODE equals to 2 to 1.
EXPLICITFLOW	to examine an explicit information flow after each statement being scanned.
FINDTOKEN	to search for a given token proceeds from bottom to top of the INFOTABLE. The routine returns the location where the match is found.
FUNCT_CALL	to determine a function call

INDIRECT	to increment the stack counter of an INDXTAB.
IO-STMT	to compute an information transfer, and check for explicit information flow
KEY_ENTRY	to add a new key number and keep the given string in the KEYTAB if it has not been stored in the table. Return the key number to caller.
MARK_UNUSED	dispose all local variables from INFOTABLE
PARAMPASSING	to generate the information transfer from formal parameters to actual parameters.
POP_END	decrement index counter of INDXTAB
PROCESSBEGIN	to mark an entry into the body routine by adding a stack entry in INDXTAB with MODE=6, BLOCK=1 and NEXT contains the location where the current body routine is being accessed. Program statements contained in the body routine are handled by procedure ACCESSBLOCK. After the body routine is terminated, INFOTABLE needs to clean up all local variables.

RECORDFLOW — to scan the WITH statement. The variables contained in a given string may be or may not be a record field. If it is found in the record field, it must be concatenate to the record name before assign the key number in the KEYTAB.

RECENTRY — to find the last record name in the given string and return its first field where its kept in INFOTABLE. For example: agiven string < rec1.rec2.rec3.field31 >, the routine will return a value that indicates the location in INFOTABLE of the first field of <rec3>.

SKIP — to delete array subscription and string contained in the quotation mark,'' from the current input line.

TABLE_LOOKUP — to determine whether a given token is a program variable or not. If it is, KEYTAB is checked before an entry is made for a new variable name. The number associated with KEYTAB is entered as a row and column to metrix

TRAVERSE_STACK	to sort and examine the variable that kept in the INDXTAB.
METRIX_ENTRY	to make an information transfer to the METRIX table.

APPENDIX B

IFC PROGRAM LISTING

```
PROGRAM IFC;

CONST COMMA    = ',';
      EQUAL    = '=';
      ENDSTMT  = ';';
      COLON    = ':';
      BLANK    = ' ';
      MAXTABSIZE = 20;

TYPE

      TYPREC      = RECORD
                        TYPNAME:STRING;
                        FIRSTFIELD:INTEGER;
                        END;

      INFOTYPE    = RECORD
                        INFONAME : STRING;
                        NEXTINFO : INTEGER;
                        POINTOINDEX : INTEGER;
                        PARAMTYP :0..1;
                        SCOPE    : INTEGER;
                        END;

      PROCTYP     = RECORD
                        PROCNAME:STRING;
                        TOINFO  :INTEGER;
                        PARAMCT : INTEGER;
                        PROC_TYPE : 0..1;
                        END;

      INDXTYP     = RECORD
                        BLOCK   : 0..1;
                        MODE    : INTEGER;
                        NEXT    : INTEGER;
                        INDXARRAY:ARRAY 1..10  OF INTEGER;
                        END;

      STATUSKIND =(SVAR,STYPE,SPROC,SFUNCT,MAIN);
      OPKIND   = (WHILES,WRITES,WRITES_LN,READS,READS_LN,
                  ENDS,ENDD,END_ELSE,REPEATS,UNTILS,FORS,
                  WITHS,IFS,NONE);
```

```
VAR

    IPFILE,OUTFILE:TEXT;
    PROCTAB    : ARRAY[ 1..MAXTABSIZE ] OF PROCTYP;
    INDXTAB    : ARRAY[ 1..MAXTABSIZE ] OF INDXTYP;
    TYPTABLE   : ARRAY[ 1..MAXTABSIZE ] OF TYPREC;
    INFOTABLE  : ARRAY[ 1..MAXTABSIZE ] OF INFOTYPE;
    NAMESPACE  : ARRAY[ 1..10 ] OF STRING;
    MATRIX : ARRAY[ 1..MAXTABSIZE, 1..MAXTABSIZE ] OF INTEGER;
    KEYTAB : ARRAY[ 1..20 ] OF STRING;
    BUFF   : ARRAY[ WHILES..IFS ] OF STRING;
    WITH_STMT,CALL, FLAG    : BOOLEAN;
    RECNAME,NAME,LN,WORD : STRING;
    OP, OPERATOR : OPKIND;
    ACTION,STATUS  : STATUSKLIND;
    ALPHA, LETTERS, NUMBERS : SET OF CHAR;
    KEYINDX, INXX, PROCIDX, TYPINDX, INFOINDEX : INTEGER;
    FIELDENTRY, PARAM_ENTRY : INTEGER;


PROCEDURE READALINE; FORWARD;
PROCEDURE GETFIRSTWORD; FORWARD;
PROCEDURE ACCESS_CALL(ENTRY:INTEGER;ST:STRING)FORWARD;
```

```
(*************************************************************)
(**********                                         **********)
(**********          ROUTINES USED TO               **********)
(**********                                         **********)
(**********     ANALYZE PREFIX DECLARATIONS         **********)
(**********                                         **********)
(*************************************************************)


PROCEDURE CHOPALINE(VAR CT:INTEGER; CLN:STRING) ;
(*** GLOBAL    : NAMESPACE                          ***)
(*** CALLED BY : ACCESSLINE,ACCESSRECORD            ***)

VAR P:INTEGER;
    DONE:BOOLEAN;

BEGIN
    DONE:=FALSE;
    CT  := 0;
    REPEAT
        CT := CT+1;
        P :=POS(COMMA,CLN);
        IF P=0
        THEN BEGIN NAMESPACE[CT] := CLN;
                   DONE := TRUE;
                   END
        ELSE BEGIN NAMESPACE[CT] := COPY(CLN,1,P-1);
                   DELETE(CLN,1,P);
                   END;
    UNTIL DONE;
END(*CHOPALINE*);


FUNCTION SAMESTATUS:BOOLEAN;
(*** GLOBAL    : WORD                               ***)
(*** CALLED BY : PROCESSVAR_TYPE                   ***)

BEGIN IF (WORD='TYPE') OR (WORD='VAR')
      OR (WORD='PROCEDURE') OR (WORD ='BEGIN')
      OR (WORD = 'FUNCTION')
      THEN SAMESTATUS := FALSE
      ELSE SAMESTATUS := TRUE;
END(*SAMESTATUS*);
```

```
PROCEDURE INFOENTRY(I,NEXTFIELD,LOCATIONINFO:INTEGER);
(*** GLOBAL    : INFOTABLE,INFOINDEX,NAMESPACE,***)
(***          STATUS, ACTION                   ***)
(*** CALLED BY : ACCESSLINE, ACCESSRECORD      ***)

BEGIN
    INFOINDEX := INFOINDEX+1;
    IF INFOINDEX > MAXTABSIZE
    THEN WRITELN('INFOTABLE TOO SMALL')
    ELSE WITH INFOTABLE INFOINDEX  DO  ]
                BEGIN
                INFONAME := NAMESPACE[I];
                NEXTINFO := NEXTFIELD;
                POINTOINDEX := LOCATIONINFO;
                IF ACTION=MAIN THEN SCOPE := 0
                ELSE  SCOPE := PROCIDX;
                END;
 END(*INFOENTRY*);


PROCEDURE CHECKTYP(VAR MATCH:BOOLEAN; VAR TOINDEX:INTEGER;
                       TOKEN : STRING; VAR INDEX : INTEGER);
(*** GLOBAL    : TYPTABLE, TYPINDEX            ***)
(*** CALLED BY : ACCESSLINE, ACCESSRECORD      ***)

VAR    J : INTEGER;
    NAME : STRING;
    DONE : BOOLEAN;

BEGIN MATCH := FALSE;
    J := 0;
    DONE := FALSE;
    TOINDEX:=0;
    INDEX:=0;
    WHILE  NOT DONE DO
    IF (TYPINDEX=0) THEN DONE:=TRUE
    ELSE BEGIN J:=J+1;
                IF J>TYPINDEX THEN DONE:=TRUE
                ELSE BEGIN NAME := TYPTABLE[J].TYPNAME;
                      IF TOKEN=NAME
                      THEN BEGIN MATCH:=TRUE;
                            TOINDEX:=TYPTABLE[J].FIRSTFIELD;
                            DONE:=TRUE;
                            INDEX:=J;
                            END;
                      END;
                END;

END(*CHECKTYPE*);
```

```
PROCEDURE TYPENTRY(TOKEN:STRING; NEXTFIELD:INTEGER);
(*** GLOBAL    : TYPTABLE,TYPINDEX                    ***)
(*** CALLED BY :  ACCESSLINE, ACCESSRECORD            ***)

BEGIN
        TYPINDEX := TYPINDEX+1;
        IF TYPINDEX > MAXTABSIZE
        THEN WRITELN('TYPE_TABLE TOO SMALL')
        ELSE WITH TYPTABLE[TYPINDEX  DO
                  BEGIN
                    TYPNAME := TOKEN;
                    FIRSTFIELD := NEXTFIELD;
                    END;

END(*TYPENTRY*);


PROCEDURE GETTYPE (VAR TYTOKEN:STRING; GSIGN,GLN:STRING);
(*** CALLED BY : ACCESSLINE,ACCESSRECORD,             ***)
(***             PROCESSPROC                          ***)

VAR P,Q:INTEGER;

BEGIN
        IF POS('ARRAY',GLN) > 0
        THEN P := POS(' OF ',GLN) + 4
        ELSE BEGIN
                P := POS(GSIGN,GLN) + 1;
                IF GLN[P] = BLANK
                THEN P := P+1;
                END;
        Q := POS(';',GLN);
        TYTOKEN := COPY(GLN,P,Q-P);

END(*GETTYPE*);
```

```
PROCEDURE ACCESSLINE(ASIGN,ALN:STRING; VAR COUNT:INTEGER);
(*** GLOBAL     : TYPTABLE, STATUS                    ***)
(*** CALLED BY : PROCESSVAR_TYPE, PROCESSPROC ***)

   VAR MATCH:BOOLEAN;
       INDEX,I,J,LOCOFINFO:INTEGER;
       TOKEN,STR:STRING;

   BEGIN
       GETTYPE(TOKEN,ASIGN,ALN);
       CHECKTYPE(MATCH,LOCOFINFO,TOKEN,INDEX);
       I := POS(ASIGN,ALN)-1;
       WHILE ALN[I]=BLANK DO I:=I-1;
       CASE STATUS OF
       STYPE    : BEGIN
                  IF MATCH
                  THEN BEGIN
                         TOKEN:=COPY(ALN,1,I);
                         LOCOFINFO:=TYPTABLE[INDEX].FIRSTFIELD;
                         TYPENTRY(TOKEN,LOCOFINFO);
                         END;
                   END;
       SVAR,
       SPROC,
       SFUNCT   : BEGIN
                     STR := COPY(ALN,1,I);
                     CHOPALINE( COUNT, STR);
                     IF MATCH
                     THEN LOCOFINFO :=TYPTABLE[INDEX].FIRSTFIELD;
                     FOR I := 1 TO COUNT DO
                             INFOENTRY(I,0,LOCOFINFO);
                     END;

       END(*CASE*);

END(*ACCESSLINE*);
```

```
PROCEDURE ACCESSRECORD(POSITN:INTEGER;PSIGN:STRING);
(*** GLOBAL     : INFOTABLE,INFOINDEX,TYPTABLE,***)
(***              STATUS,LN                     ***)
(*** CALLED BY :  PROCESSVAR_TYPE               ***)

    VAR NEXTFIELD, I, J, N : INTEGER;
        INDEX, COUNT, LOCOFINFO : INTEGER;
        TOKEN, STR : STRING;
        FIND : BOOLEAN;

    BEGIN
       I := POS(PSIGN,LN)-1;
        IF LN[I]=BLANK THEN I:=I-1;
        CASE STATUS OF
           STYPE : BEGIN
                     TOKEN :=COPY(LN,1,I);
                     NEXTFIELD := INFOINDEX+1;
                     TYPENTRY(TOKEN,NEXTFIELD);
                     END;
           SVAR  : BEGIN
                     STR := COPY(LN,1,I);
                     CHOPALINE(COUNT,STR);
                     NEXTFIELD := INFOINDEX+COUNT+1;
                     FOR I:= 1 TO COUNT DO
                         INFOENTRY(I,0,NEXTFIELD);
                     END;
         END(*CASE*);
         N := POSITN+6;
         DELETE(LN,1,N);
         WHILE POS('END;',LN)=0 DO
         BEGIN
            GETTYPE(TOKEN,COLON,LN);
            CHECKTYPE(FIND,LOCOFINFO,TOKEN,INDEX);
            I:= POS(COLON,LN)-1;
            IF LN[I]=1LANK THEN I:=I-1;
            STR:= COPY(LN,1,I);
            CHOPALINE(COUNT,STR);
            IF FIND
            THEN LOCOFINFO:=TYPTABLE[INDEX].FIRSTFIELD;
            FOR I := 1 TO COUNT DO
                BEGIN NEXTFIELD:=INFOINDEX+2;
                      INFOENTRY(I,NEXTFIELD,LOCOFINFO);
                      END;
            READALINE;
            END;
         INFOTABLE[INFOINDEX].NEXTINFO:=0;
END(*ACCESSRECORD*);
```

```
PROCEDURE PROCESSVAR_TYPE;
(*** GLOBAL     : FLAG, WORD, LN, STATUS          ***)
(*** CALLED BY :  MAIN                           ***)

VAR DONE:BOOLEAN;
    SIGN:STRING;
    P,Q,COUNT :INTEGER;

BEGIN
      DONE := FALSE;
      IF STATUS=STYPE
      THEN SIGN := EQUAL
      ELSE SIGN := COLON;
      DELETE(LN,1,POS(BLANK,LN));
      WHILE NOT DONE DO
      BEGIN
          P:= POS('RECORD',LN);
          Q:= POS('ARRAY',LN);
          IF ( (P>0)  AND ( Q>0) OR (P>0))
          THEN ACCESSRECORD (P, SIGN)
          ELSE ACCESSLINE( SIGN, LN, COUNT);
          READALINE;
          GETFIRSTWORD;
          IF NOT SAME STATUS OR FLAG T
          THEN DONE := TRUE;
       END;
END (* PROCESSVAR_TYPE *)


PROCEDURE PARAMTEST(VAR PARMSTR:STRING);

    VAR STR:STRING;

    BEGIN   WHILE POS(';',PARMSTR)>0
            DO BEGIN STR:= (COPY(PARMSTR,1,POS(';',PARMSTR)));
                     ACTUALPARAM(STR);
                     DELETE(PARMSTR,1,LENGTH(STR));
                     PARAMTEST(PARMSTR);
                     END;
END(* PARAMTEST *);
```

```
PROCEDURE PROCESSPROC;
(*** GLOBAL    : LN, PROCTAB, PROCIDX,          ***)
(***             INFOTABLE, INFOINDEX           ***)
(*** CALLED BY : MAIN                           ***)

VAR CT,P :INTEGER;

    PROCEDURE ACTUALPARAM (S:STRING);
    VAR I,PARAM,COUNT:INTEGER;
        STR:STRING;
    BEGIN STR:=S;
        IF POS('VAR ',STR)>0
        THEN BEGIN PARAM:=1;
                   DELETE(STR,1,POS('VAR ',STR)+3);
                   END
        ELSE PARAM:=0;
        I:=1;
        WHILE STR[I]=BLANK DO I:=I+1;
        IF I>1 THEN DELETE(STR,1,I-1);
        ACCESSLINE(COLON,STR,COUNT);
        IF COUNT>1 THEN FOR I:=1 TO COUNT-1 DO
             INFOTABLE[INFOINDEX-I].PARAMTYP := PARAM;
        INFOTABLE[INFOINDEX].PARAMTYP := PARAM;
        CT := CT+COUNT;
    END;(*ACTUALPARAM*)

BEGIN(* PROCESSPROC*)
        DELETE(LN,1,LENGTH(WORD)+1);
        P := 1;
        WHILE LN[P] IN LETTERS + NUMBERS DO P := P+1;
        NAMESPACE[1] := COPY(LN,1,P-1);
        CT   := 0;
        PROCIDX := PROCIDX+1;
        WITH PROCTAB[PROCIDX] DO
        BEGIN PROCNAME := NAMESPACE[1];
              IF ACTION = SFUNCT
              THEN BEGIN INFOENTRY(1,0,0);
                         PROC_TYPE := 0; END
              ELSE PROC_TYPE := 1;
              TOINFO := INFOINDEX+1;
              END;
        IF POS('(',LN)>0
        THEN BEGIN
        LN:=( COPY(LN,POS('(',LN)+1,POS(')',LN)-POS('(',LN)-1));
                   LN:=CONCAT(LN,';');
                   PARAMTEST(LN);
                   END;
        PROCTAB[PROCIDX].PARAMCT := CT;
        READALINE;
        GETFIRSTWORD;
 END(*PROCESSPROC*);
```

```
(*************************************************************)
(**********                                         **********)
(**********            ROUTINES USED TO             **********)
(**********                                         **********)
(**********         ANALYZE ROUTINE BODY            **********)
(**********                                         **********)
(*************************************************************)
```

```
PROCEDURE MATRIX_ENTRY(R,C:INTEGER);
(*** GLOBAL    : MATRIX                              ***)
(*** CALLED BY : TRAVERSE_STACK,ASSIGNMENT,          ***)
(***             ACCESSUNTIL,ACCESS_CALL,IO_STMT***)

BEGIN
        MATRIX[R,C] := MATRIX[R,C] + 1;
END;
```

```
PROCEDURE INDIRECT(INBLOCK,INMODE:INTEGER);
(* GLOBAL  : INDXTAB, INDX                          *)
(* CALLED BY : ASSIGNMENT,ACCESSFOR                 *)
(*           ACCESSUNTIL, ACCESS_IF_STMT            *)
(*           IO_STMT, ACCESS_CALL,                  *)
(*           ACCESSBLOCK,PROCESSBEGIN               *)

BEGIN
        INDX := INDX + 1;
        WITH INDXTAB[INDX] DO
        BEGIN
                BLOCK := INBLOCK;
                MODE  := INMODE;
                NEXT  := 0;
        END;
END;(*INDIRECT*)
```

```
PROCEDURE EXPLICITFLOW( I,NUM:INTEGER);
(* GLOBAL  : INDXTAB, INDX                              *)
(* CALLED BY :  ASSIGNMENT, IO_STMT, ACCESS_CALL *)

VAR J,M,K,ROW : INTEGER;

    PROCEDURE TRAVERSE_STACK;

    BEGIN
     WITH INDXTAB|I| DO
     BEGIN IF NEXT >1
        THEN BEGIN M := 1;
             WHILE M< NEXT DO
               BEGIN J := M;
                 WHILE J<> NEXT DO
                 BEGIN IF INDXARRY|J|=INDXARRAY|J+1[
                    THEN BEGIN K:= J+1;
                         WHILE K<> NEXT DO
                         BEGIN
                           INDXARRAY|K|:= INDXARRAY|K+1|;
                            K := K+1;
                            END;
                         NEXT := K-1;
                         END;
                 IF J <> NEXT THEN J := J+1;
                 END;
            M :=M+1;
            END;
       END;
       IF NEXT>0 THEN
       FOR J:= 1 TO NEXT DO
       BEGIN ROW := INDXARRAY[J];
             MATRIX_ENTRY(ROW,NUM);
             END;
     END;
    END(*TRAVERSE-STACK*);

BEGIN
      WHILE (INDXTAB[I].MODE < 6) DO
       BEGIN
           CASE INDXTAB[I].MODE OF
                1,2,3    : TRAVERSE_STACK;
                   5       : WITH INDXTAB[I] DO
                             BEGIN
                                 NEXT := NEXT + 1;
                                 INDXARRAY[NEXT] := NUM;
                             END;
           END(* CASE *);
           I := I-1;
       END;
END( * EXPLICITFLOW *);
```

```
PROCEDURE TABLE_LOOKUP(N:INTEGER;LTOKEN:STRING;
                              VAR KEY,J:INTEGER);
(*** GLOBAL    : INFOTABLE, PROCTAB, KEYTAB, KEYINDX    ***)
(*** CALLED BY : ANALY SIS                              ***)
VAR ST:STRING;


     PROCEDURE KEY_ENTRY(KSTR:STRING; VAR KEY_EN : INTEGER);

     VAR M : INTEGER;

     BEGIN
        M := 1;
        WHILE (KEYTAB[M] <> KSTR)  AND (M <=KEYINDX)
            DO M := M+1;
        IF KEYTAB[M] = KSTR  THEN KEY_EN := M
        ELSE BEGIN
                  KEYINDX := KEYINDX+1;
                  KEYTAB[KEYINDX] := KSTR;
                  KEY_EN := KEYINDX;
             END;
    END(* KEY_ENTRY *);


    PROCEDURE FINDTOKEN(OBJECT:STRING; VAR L:INTEGER);

    BEGIN
       IF INFOTABLE[L].INFONAME = OBJECT THEN L:=L
       ELSE BEGIN
            WHILE (INFOTABLE[L].INFONAME<> OBJECT) AND (L<>1)
                          DO L := L-1;
            IF L=1 THEN IF INFOTABLE[L].INFONAME=OBJECT
                        THEN L:=1 ELSE L:=0
             END;
    END(*FINDTOKEN*)


    PROCEDURE DEFINEKEY;

    VAR K:INTEGER;

        STR:STRING;
    BEGIN
         K := INFOTABLE[N].SCOPE;
         IF K=0 THEN STR:='MAIN'
         ELSE WITH PROCTAB[K] DO
              IF PROC_TYPE=1
              THEN STR := CONCAT('PROC/',PROCNAME)
              ELSE BEGIN
```

```
                    IF (PARAMCT>0 ) AND
                       (PROCNAME = LTOKEN)
                        AND (ACTION<>SFUNCT)
                    THEN J := K;
                    STR := CONCAT('FUNCT/',PROCNAME);
                    END;
      STR := CONCAT(STR,'...');
      STR := CONCAT(STR,LTOKEN);
      KEY_ENTRY(STR,KEY);
END;(*DEFINEKEY*)


PROCEDURE CKRECFIELD(STR:STRING);

VAR J:INTEGER;

BEGIN
    J:= FIELDENTRY;
    WHILE J<>0 DO WITH INFOTABLE|J| DO
    BEGIN IF INFONAME=STR
          THEN BEGIN STR:=CONCAT(RECNAME,'.',LTOKEN);
                KEY_ENTRY(STR,KEY);
                J:=0;
                END
          ELSE BEGIN J:=NEXTINFO;
                IF J=0
                THEN BEGIN FINDTOKEN(STR,N);
                           DEFINEKEY;
                           END;
                END;
      END;
END;(*CKRECFIELD*)


PROCEDURE RECENTRY(STR:STRING; M:INTEGER; VAR K:INTEGER);
VAR TMP:STRING;
BEGIN
   K:=0;
   DELETE(STR,1,POS('.',STR));
   IF POS('.',STR)>0
   THEN TMP:=COPY(STR,1,POS('.',STR)-1)
   ELSE TMP:=STR;
   WHILE M<>0 DO WITH INFOTABLE]M| DO
   IF INFONAME=TMP
   THEN BEGIN IF TMP=STR THEN K:= POINTOINDEX
              ELSE RECENTRY(STR,POINTOINDEX,K);
              M:=0;
              END
   ELSE M:=NEXTINFO;
END;(*RECENTRY*)
```

```
    PROCEDURE RECORDFLOW;

    VAR P:INTEGER;
        NAMEFIELD:STRING;

    BEGIN
        IF RECNAME=''
        THEN BEGIN
           IF POS('.',LTOKEN)>0
           THEN BEGIN
                FINDTOKEN(COPY(LTOKEN,1,POS('.',LTOKEN)-1),N);
                DEFINEKEY;
                RECENTRY(LTOKEN,INFOTABLE[N].POINTOINDEX,P);
                FIELDENTRY:=P;
                INDX-1;
                END
           ELSE IF POS('.',LTOKEN)>0
                THEN BEGIN
                     NAMEFIELD:=COPY(LTOKEN,1,POS('.',LTOKEN)-1);
                     CKRECFIELD(NAMEFIELD);
                     END
         ELSE CKRECFIELD(LTOKEN);
    END;(*RECORDFLOW*)


BEGIN (*TABLE_LOOKUP*)
   J:=0;
   KEY:=0;
   CASE WITH_STMT OF
   FALSE : BEGIN
           IF POS('.',LTOKEN)>0
           THEN FINDTOKEN(COPY(LTOKEN,1,POS('.',LTOKEN)-1),N)
           ELSE FINDTOKEN(LTOKEN,N);
           IF N>0 THEN DEFINEKEY;
           END;
   TRUE  : RECORDFLOW;
   END; (*CASE*)
END(* TABLE_LOOKUP*);
```

```
PROCEDURE ANALYSIS(GSTR:STRING; VAR KEY:INTEGER);

VAR FNCALL,TEMP,I,K    : INTEGER;
    STR,LTOKEN : STRING;


     PROCEDURE SKIP;

     VAR P:INTEGER;

      BEGIN
         IF POS(' ',GSTR)>0
         THEN BEGIN P:=POS(' ',GSTR);
                    DELETE(GSTR,P,POS(' ',GSTR)-P+1);
                    SKIP;
                    END
         ELSE IF POS('''',GSTR)>0
              THEN BEGIN P:=POS('''',GSTR);
                         DELETE(GSTR,P,1);
                         DELETE(GSTR,P,POS('''',GSTR)-P+1);
                         SKIP;
                         END;
         GSTR:=CONCAT(GSTR,' ');
     END;(* SKIP *)


     PROCEDURE PARAMPASSING;

     VAR  J,ROW,COL:INTEGER;
          PARAM_NAME:STRING;

     BEGIN
        ROW := KEY;
        PARAM_NAME := INFOTABLE[PARAM_ENTRY].INFONAME;
        TABLE_LOOKUP(PARAM_ENTRY,PARAM_NAME,COL,J);
        MATRIX_ENTRY(ROW,COL);
        IF INBFOTABLE[PARAM_ENTRY].PARAMTYP = 1
        THEN BEGIN
                    METRIX_ENTRY(COL,ROW);
                    EXPLICITFLOW(INDX-1,ROW);
                    END;
     END; (*PARAMPASSING*)
```

```
     BEGIN (* ANALYSIS *)
        I:=1;
        SKIP;
        WHILE I<=LENGTH(GSTR) DO
        BEGIN
        IF GSTR[I] IN LETTERS
        THEN BEGIN K:=I;
                  WHILE GSTR[I+1] IN ALPHA DO I:=I+1;
                  LTOKEN := COPY(GSTR,K,I-K+1);
                  TABLE_LOOKUP(INFOINDEX,LTOKEN,KEY,FNCALL);
                  IF FNCALL>0
                  THEN IF (GSTR|I+1[='(') OR (GSTR|I+2[='(')
                       THEN BEGIN
                            STR:=COPY(GSTR,I+1,POS(')',GSTR)-I);
                            TEMP := KEY;
                            ACCESS_CALL(FNCALL,STR);
                            KEY:=TEMP;
                            I:=I+POS(')',STR);
                            END
                        ELSE CALL:=FALSE;
                  IF CALL
                  THEN BEGIN IF KEY>0 THEN PARAMPASSING;
                             PARAM_ENTRY:=PARAM_ENTRY+1;
                             END
                  ELSE IF KEY>0
                       THEN WITH INDXTAB[INDX]
                            DO BEGIN
                                  NEXT := NEXT + 1;
                                  INDXARRAY[NEXT] := KEY;
                                  END;
                END;
           I:=I+1;
     END;
 END;(* ANALYSIS *)

PROCEDURE ACCESSWITH;
VAR N,NUM : INTEGER;

BEGIN
        DELETE(LN,1,LENGTH(WORD)+1);
        IF POS('BEGIN',LN)>0
        THEN INDIRECT(1,4)
        ELSE INDIRECT(0,4);
        WITH_STMT:=TRUE;
        ANALYSIS(COPY(LN,1,POS(' DO',LN)-1),NUM);
        IF INDXTAB[INDX].BLOCK = 1
        THEN DELETE(LN,1,POS('BEGIN',LN)+5)
        ELSE DELETE(LN,1,POS(' DO ',LN)+3);
        GETFIRSTWORD;
END; (*ACCESSWITH*)
```

```
PROCEDURE ELSE_STMT;
(* GLOBAL  : WORD, INDXTAB                          *)
(* CALLED BY : ASSIGNMENT, IO_STMT, ACCESSBLOCK *)

BEGIN
   GETFIRSTWORD;
   WITH INDXTAB[INDX ] DO
      IF WORD ='BEGIN'
      THEN BEGIN BLOCK := 1;
                 MODE  := 1;
                 DELETE(LN,1,LENGTH(WORD)+1) ;
                 GETFIRSTWORD;
                 END
      ELSE BEGIN BLOCK :=0;
                 MODE := 1;
                 END;
END(*END_ELSE*) ;


 PROCEDURE CKELSE;

 BEGIN
   IF POS(' ELSE ',LN)>0
   THEN BEGIN WHILE (INDXTAB[INDX].MODE<>2) AND
              (INDXTAB[INDX].BLOCK<>1) DO
              BEGIN IF INDXTAB[INDX].MODE=4
                    THEN BEGIN RECNAME:='';
                               WITH_STMT:= TRUE;
                               END;
                    DELETE(LN,1,POS(' ELSE ',LN)+5);
                    ELSE_STMT
                    END
   ELSE BEGIN WHILE (INDXTAB[INDX].BLOCK=0)
              DO BEGIN IF INDXTAB[INDX].MODE =4
                       THEN BEGIN RECNAME:='';
                                  WITH_STMT:= TRUE;
                                  END;
                       INDX := INDX-1;
                       END;
               READALINE;
               GETFIRSTWORD;
               END;
 END;(*CK ELSE*)
```

```
PROCEDURE ACCESS_CALL(*ENTRY:INTEGER;*);
(* GLOBAL  : CALL, LETTERS, PROCTAB, INFOTABLE,INDX*)
(* CALLED BY : ACCESSBLOCK                        *)

VAR M,NUM:INTEGER;

BEGIN
    M:= POS('(',ST);
    IF M>0
    THEN BEGIN
           INDIRECT(0,0);
           CALL := TRUE;
           PARAM_ENTRY := PROCTAB[ENTRY].TOINFO;
           WRITELN('PAR ENTRY..',PARAM_ENTRY);
           ANALYSIS(COPY(ST,M,POS(')',ST)-M),NUM);
           CALL := FALSE;
           INDX:=INDX-1;
           IF ST=LN THEN CKELSE;
           END
     ELSE IF ST=LN THEN BEGIN READALINE; GETFIRSTWORD; END;

END(*ACCESS_CALL*);


PROCEDURE POP_END(VAR PROC_DONE : BOOLEAN);
(* GLOBAL  : INDXTAB, INDX, ACTION        *)
(* CALLED BY :  ACESSBLOCK   *)

BEGIN    PROC_DONE := FALSE;
         CASE INDXTAB[INDX].MODE  OF
         1,2,3,4 : BEGIN
                   INDX:=INDX-1;
                   WHILE (INDXTAB|INDX|.BLOCK=0 )
                   DO BEGIN
                       INDX := INDX-1;
                       IF INDXTAB|INDX|.MODE=4
                       THEN BEGIN RECNAME:='';
                                  WITH_STMT := FALSE; END;
                    END;
                    READALINE;
                    GETFIRSTWORD;
                    END;
         6       : BEGIN INDX := INDX -1;
                         PROC_DONE := TRUE;
                         ACTION := MAIN; END;
         END;
END (* POP_END*);
```

```
PROCEDURE ASSIGNMENT;
(* GLOBAL  : LN, LETTERS, INDXTAB, INDX   *)
(* CALLED BY : ACCESSBLOCK                *)

VAR     P,Q,R,ROW,N,NUM:INTEGER;
        STR, TOKEN : STRING;

BEGIN
        INDIRECT(0,0);
        WHILE LN[1]=BLANK DO DELETE(LN,1,1);
        P := POS(':=',LN);
        R := 0;
        IF POS(' ELSE ',LN)  > 0
             THEN BEGIN
                  Q := POS(' ELSE ',LN);
                  ROW := INDXTAB|INDX|.INDXARRAY
                  MATRIX_ENTRY(ROW,NUM);
                  END;
        INDX := INDX - 1;
        EXPLICITFLOW(INDX,NUM);
        IF R=0 THEN BEGIN
         WHILE  INDXTAB[INDX].BLOCK = 0
                DO WITH INDXTAB[INDX] DO
                BEGIN INDX := INDX-1;
                      IF MODE=4
                      THEN BEGIN RECNAME:='';
                                 WITH_STMT := FALSE;
                                 END;
                END;
                READALINE;
                GETFIRSTWORD;
                END;
        IF R > 0 THEN BEGIN
                        WHILE (INDXTAB[IND X].BLOCK=0) AND
                              (INDXTAB[INDX].MODE<>2)
                        DO WITH INDXTAB[INDX]
                        DO BEGIN INDX:= INDX-1;
                                 IF MODE=4
                                 THEN BEGIN RECNAME:='';
                                            WITH_STMT:=FALSE;
                                            END;
                                 END;
                        DELETE(LN,1,R);
                        ELSE_STMT;
                        END;
END (* ASSIGNMENT *);
```

```
PROCEDURE ACCESSWHILE;
(* GLOBAL  : LN, LETTERS, WORD        *)
(* CALLED BY : ACCESSFOR, ACCESSBLOCK *)

VAR P,N,NUM : INTEGER;

BEGIN   P := POS(' DO ',LN);
        ANALYSIS(COPY(LN,1,P),NUM);
        DELETE(LN,1,P+3);
        GETFIRSTWORD;
        IF WORD='BEGIN'
       .THEN BEGIN
                INDXTAB[INDX].BLOCK := 1;
                DELETE(LN,1,LENGTH(WORD)+1);
                GETFIRSTWORD;
                END;

END (* ACCESSWHILE *);


PROCEDURE ACCESSFOR;
(* GLOBAL  : LN, LETTERS   *)
(* CALLED BY : ACCESSBLOCK *)

VAR P,Q,NUM : INTEGER;

BEGIN   INDIRECT(0,3);
        Q := POS(' DO ',LN);
        ANALYSIS(COPY(LN,POS(':=',LN),Q-P),NUM);
        P := POS(':=",LN);
        ANALYSIS(COPY(LN,1,P),NUM);
        WITH INDXTAB[INDX] DO
        IF NEXT>1
        THEN BEGIN
              FOR P:=1 TO NEXT-1 DO
                 MATRIX_ENTRY(INDXARRAY[P],NUM);
              NEXT := NEXT-1;
              END;
         DELETE(LN,1,Q+3);
         GETFIRSTWORD;
         IF WORD='BEGIN'
         THEN BEGIN INDXARRAY[INDX].BLOCK := 1;
                    DELETE(LN,1,LENGTH(WORD)+1);
                    GETFIRSTWORD;
                    END;

END;(* ACCESSFOR *)
```

```
PROCEDURE ACCESSUNTIL;
(* GLOBAL  : WORD, LN, LETTERS,   *)
(*           FLAG, INDXTAB,INDX   *)
(* CALLED BY :  ACCESSBLOCK       *)

VAR   M,N,I,J,ROW,COL,NUM : INTEGER;

BEGIN INDIRECT(1,5);
      DELETE(LN,1,LENGTH(WORD)+1);
      ANALYSIS(COPY(LN,1,POS(';',LN)),NUM);
      M := INDXTAB[INDX-1].NEXT;
      N := INDXTAB[INDX].NEXT;
      IF (N>0) AND (M>0)
      THEN BEGIN
                FOR I:=1 TO N DO
                BEGIN ROW := INDXTAB[INDX].INDXARRAY[I];
                      FOR J:= 1 TO M DO
                      BEGIN COL := INDXTAB[INDX-1].INDXARRAY[J];
                            MATRIX_ENTRY(ROW,COL);
                            END;
                      END;
           END;
     INDX := INDX-2;
     WHILE (INDXTAB[INDX].BLOCK = 0)
     DO BEGIN  INDX := INDX-1;
               WITH INDXTAB[INDX] DO
               IF MODE=4 THEN BEGIN RECNAME:='';
                                    WITH_STMT:=FALSE;
                                    END;
               END;
     READALINE;
     GETFIRSTWORD;
 END(* ACCESS UNTIL *);
```

```
 PROCEDURE ACCESS_IF_STMT;
 (*** GLOBAL   : LN, LETTERS, INDXTAB, INDX ***)
 (*** CALLED BY: ACCESSBLOCK                ***)

 VAR N,NUM:INTEGER;

 BEGIN INDIRECT(0,2);
     ANALYSIS(COPY(LN,4,POS(' THEN ',LN)-4), NUM);
     DELETE(LN,1,POS(' THEN ',LN)+5);
     GETFISTWORD;
     IF WORD = 'BEGIN'
     THEN BEGIN
               INDXTAB[INDX].BLOCK := 1;
               DELETE(LN,1,LENGTH(WORD)+1);
               GETFIRSTWORD;
          END;
END(* ACCESS IF_STMT *);

PROCEDURE IO_STMT;
(* GLOBAL  : OPERATOR, LETTERS, INDXTAB, INDX, *)
(*           CALL                              *)
(* CALLED BY :  ACCESSBLOCK                    *)

VAR N,NUM,KEY,I,J  :INTEGER;

BEGIN
    I :=  POS('(',LN);
    IF I>0
    THEN BEGIN
         INDIRECT(0,0);
         IF POS(' ELSE',LN)>0 THEN J:=POS(' ELSE ',LN)
         ELSE J:=POS(';',LN);
         ANALYSIS(COPY(LN,I+1,J-I),NUM);
         WITH INDXTAB[INDX] DO
         IF NEXT > 0
         THEN IF (OPERATOR = WRITES) OR (OPERATOR = WRITES_LN)
              THEN BEGIN FOR I := 1 TO NEXT DO
                   MATRIX_ENTRY(INDXARRAY[I],2);
                   CALL := TRUE;
                   EXPLICITFLOW(INDX-1,2);
                   CALL := FALSE;
                   END
              ELSE FOR I := 1 TO NEXT DO
                   BEGIN MATRIX_ENTRY(1,INDXARRAY[I]);
                         CALL := TRUE;
                         EXPLICITFLOW(INDX-1,INDXARRAY[I]);
                         CALL := FALSE;
                         END;
              CKELSE;
           END
         ELSE BEGIN READALINE; GETFIRSTWORD; END;
END(*IO_STMT*);
```

```
PROCEDURE CHECK_CALL(CTOKEN:STRING; VAR PROC_CALL:BOOLEAN;
                     VAR AT_PROC_ENTRY: INTEGER);
(* GLOBAL : PROCTAB, PROCIDX     *)
(* CALLED BY :  ACCESSBLOCK      *)

VAR I : INTEGER;

BEGIN
    PROC_CALL := FALSE;
    AT_PROC_ENTRY := 0;
    IF PROCIDX>0 THEN FOR I := 1 TO PROCIDX DO
       IF PROCTAB[I].PROCNAME = CTOKEN
        THEN BEGIN
                PROC_CALL := TRUE;
                AT_PROC_ENTRY :=I;
                I := PROCIDX +1;
             END;
END(*CHECK_CALL*);



PROCEDURE ACCESSBLOCK;
(* GLOBAL  : LN, WORD, OPERATOR, OP, LETTERS      *)
(* CALLED BY :  PROCESSBEGIN                      *)

VAR DONE,YES := BOOLEAN;
    I, ENTRY:INTEGER;
    STR:STRING;



    PROCEDURE CK_OPERATOR(TOKEN:STRING);

    BEGIN FOR OP:=WHILES TO IFS DO
          IF BUFF[OP]=TOKEN
          THEN BEGIN OPERATOR:=OP
                     OP := NONE;
                     END
          ELSE OPERATOR := NONE;
    END(* CK_OPERATOR *);
```

```
BEGIN (* ACCESSBLOCK *)
        DONE := FALSE;
        DELETE(LN,1,LENGTH(WORD)+1);
        GETFIRSTWORD;
        CK_OPERATOR(WORD);
        WHILE (NOT DONE) DO
        BEGIN
            CASE OPERATOR OF
               WHILES       : BEGIN
                                  INDIRECT(0,3);
                                  DELETE(LN,1,LENGTH(WORD)+1);
                                  ACCESSWHILE;
                                  END;
        WRITES,WRITES_LN,
         READS,READS_LN     : IO_STMT;
               ENDS,ENDD    : POP_END(DONE);
                                END;
               END_ELSE     : BEGIN
                                DELETE(LN,1,POS(' ELSE ',LN)+5);
                                ELSE_STMT;
                              END;
               REPEATS      : BEGIN
                                  INDIRECT(1,5);
                                  DELETE(LN,1,LENGTH(WORD)+1);
                                  GETFIRSTWORD;
                              END;
               UNTILS       : ACCESSUNTIL;
               FORS         : ACCESSFOR;
               WITHS        : ACCESSWITH;
               IFS          : ACCESS_IF_STMT;
               NONE: BEGIN
                     CHECK_CALL(WORD,YES,ENTRY);
                     IF YES AND ((ACTION=MAIN)
                        OR (ACTION=SPROC))
                     THEN ACCESS_CALL(ENTRY,LN)
                     ELSE IF (POS(':=',LN)>0
                          THEN ASSIGNMENT
                          ELSE
                          WRITELN('**ERROR**INVALID STATEMENT');
                     END;
        END (* CASE *);
        IF NOT DONE THEN CK_OPERATOR(WORD);
        END;
 END (* ACCESSBLOCK *);
```

```
PROCEDURE MARK_UNUSED;
(* GLOBAL  : PROCTAB, PROCIDX    *)
(* CALLED  BY : PROCESS BEGIN    *)

VAR I,J : INTEGER;

BEGIN
        IF PROCIDX >0
        THEN WITH PROCTAB[ PROCIDX ] DO
             IF PARAMCT>0 THEN INFOINDEX:= TOINFO + PARAMCT -1;
END (* MARK_UNUSED *);


PROCEDURE PROCESSBEGIN;
(* GLOBAL  : INDXTAB, INDX *)
(* CALLED BY :  MAIN       *)

BEGIN
        CASE ACTION OF
         SFUNCT, SPROC  :  BEGIN INDIRECT(1,6);
                                 INDXTAB[ INDX ].NEXT := PROCIDX;
                           END;
                MAIN    :  INDIRECT(1,6);
        END;
        ACCESSBLOCK;
        MARK_UNUSED;
        IF NOT FLAG THEN BEGIN
                             READALINE;
                             GETFIRSTWORD;
                          END;
END (* PROCESSBEGIN *);
```

```
(*************************************************************)
(**********                                         **********)
(**********          ROUTINES USED TO               **********)
(**********        ANALYZE MAIN ROUTINE             **********)
(**********                                         **********)
(*************************************************************)


PROCEDURE INITIALIZE;

    .

    PROCEDURE MATRIXINIT;

    VAR     I,J  : INTEGER;

    BEGIN
        FOR I := 1 TO MAXTABSIZE DO
            FOR J := 1 TO MAXTABSIZE DO
                MATRIX[I,J] := 0;
    END (*MATRIXINIT *);


    PROCEDURE BODYINIT;

    BEGIN
        BUFF[WHILES]    := 'WHILE';
        BUFF[WRITES]    := 'WRITE';
        BUFF[WRITE_LN]  := 'WRITELN';
        BUFF[READS]     := 'READ';
        BUFF[READS_LN]  := 'READLN';
        BUFF[ENDS]      := 'END;';
        BUFF[ENDD]      := 'END.';
        BUFF[END_ELSE]  := 'END';
        BUFF[REPEATS]   := 'REPEAT';
        BUFF[UNTILS]    := 'UNTIL';
        BUFF[FORS]      := 'FOR';
        BUFF[WITHS]     := 'WITH';
        BUFF[IFS]       := 'IF';

    END;(* BODYINIT *)
```

```
BEGIN (* INITIALIZE ROUTINE *)

    WRITELN('ENTER FILE NAME WHICH TO BE MEASURE?');
    READLN(NAME);
    NAME := CONCAT(NAME,'.TEXT');
    RESET(IPFILE,NAME);
    REWRITE(OUTFILE,'PRINTER:');
    INFOINDEX := 0;
    TYPINDEX  := 0;
    PROCIDX   := 0;
    INDX      := 0;
    PARAM_ENTRY:=0;
    FIELDENTRY  := 0;
    KEYTAB[1] :='IN';
    KEYTAB[2] := 'OUT';
    KEYINDX   := 2;
    STATUS    := MAIN;
    ACTION    := MAIN ;
    CALL      := FALSE;
    FLAG      :=FALSE;
    WITH_STMT := FALSE;
    LETTERS   := ['A'..'Z'];
    NUMBERS   := ['0'..'9'];
    ALPHA     := LETTERS+NUMBERS+['_'];
    RECNAME   := '';
    BODYINIT;
    MATRIXINIT;

 END(*INITIALIZE*);



PROCEDURE PRINTOUT;

(*** PROCEDURE P1 IS USED FOR PRINT  INFOTABLE              ***)
(*** PROCEDURE P2 IS USED FOR PRINT  TYPTABLE AND PROCTAB ***)
(*** PROCEDURE P2 IS USED FOR PRINT  KEYTAB AND METRIX    ***)
(***                                                      ***)
(*** GLOBAL  : INFOTABLE, TYPTABLE, PROCTAB,KEYTAB, MATRIX***)
(***           INFOINDEX, TYPIDNDX, PROVIDX,KEYINDX.      ***)
(*** CALLED BY : MAIN                                     ***)


VAR Q,I,J,K : INTEGER;



PROCEDURE P1;

BEGIN
    READ(Q);
```

```
    FOR I:= 1 TO 2 DO WRITELN(OUTFILE);
    WRITELN(OUTFILE,'INFOTABLE');
    WRITELN(OUTFILE);
    WRITELN(OUTFILE,'INDEX',' ':5,'INFONAME',' ':5,
            'NEXTINFO',' ':5,'POINTOINDEX',' ':4,'SCOPE');
    WRITELN(OUTFILE);
    FOR I:=1 TO INFOINDEX DO
    WITH INFOTABLE[I] DO
    BEGIN IF I<10 THEN J:=1 ELSE J:=5;
          IF NEXTINFO<10 THEN K:=1 ELSE K:=2;
          WRITELN(OUTFILE,' ':2,I,' ':10-J,INFONAME,'..',
          ' ':15-LENGTH(INFONAME)-2,NEXTINFO,' ':14-K,
          POINTOINDEX,' ':11,SCOPE);
    END;
END;(* P1 *)


PROCEDURE P2;

BEGIN
     IF TYPINDEX >0
     THEN BEGIN
            FOR I:= 1 TO 2 DO WRITELN(OUTFILE);
            WRITELN(OUTFILE,'TYPTABLE');
            WRITELN(OUTFILE,'INDEX',' ':8,'TYPE NAME',
                    ' ':5,'TO INFOINDEX');
            FOR I:=1 TO TYPINDEX DO
            WITH TYPTABLE[I] DO
            BEGIN
               IF I<10 THEN J:=1 ELSE J:=2;
               WRITELN(OUTFILE,' ':2,I,' ':15-J,TYPNAME,
                ' ':15-LENGTH(TYPNAME),FIRSTFIELD);
               END;
          END;
   IF PROCIDX > 0
   THEN BEGIN
          FOR I:= 1 TO 2 DO WRITELN(OUTFILE);
          WRITELN(OUTFILE,'PROC_TABLE');
          WRITELN(OUTFILE,'INDEX',' ':10,'PROCNAME',' ':7,
           'TOINFO',' ':5,'PARAM COUNT',' ':3,'PROC TYPE');
          WRITELN(OUTFILE);
          FOR I:= 1 TO PROCIDX DO
          WITH PROCTAB[I] DO
          BEGIN
             IF I<10 THEN J:=1 ELSE J:=2;
             WRITELN(OUTFILE,' ':2,I,' ':15-J,
             PROCNAME,' ':15-LENGTH(PROCNAME),TOINFO,
                  ' ':12,PARAMCT,' ':14,PROC_TYPE);
             END;
      END;
END;(* P2 *)
```

```
PROCEDURE P3;

BEGIN
     FOR I:= 1 TO 3 DO WRITELN(OUTFILE);
     WRITELN(OUTFILE,'KEY TABLE');
     WRITELN(OUTFILE) ;
     FOR I := 1 TO KEYINDX DO
         BEGIN IF I<10 THEN K := 4 ELSE K := 3;
               WRITE(OUTFILE,I,' ':K,KEYTAB[ I ]) ;
               END;
     FOR I :=1 TO 3 DO WRITELN(OUTFILE)
     WRITELN(OUTFILE,'METRIX');
     WRITELN (OUTFILE);
     FOR I:=1 TO KEYINDX DO
     BEGIN IF I< 9 THEN K:=4 ELSE K:=3;
           WRITE(OUTFILE,I,' ':K) ;
           END;
     WRITELN(OUTFILE);
     FOR I:= 1 TO KEYINDX DO
     BEGIN IF I<10 THEN K:=5 ELSE K:=4;
           WRITE(OUTFILE,I,' ':K) ;
           FOR J := 1 TO KEYINDX DO
           WRITE(OUTFILE,METRIX[ I,J ],' ':4) ;
           WRITELN(OUTFILE) ;
           END;
     FOR I:= 1 TO 3 DO WRITELN(OUTFILE) ;
END; (* P3 *)


BEGIN (* PRINTOUT *)
    FOR I:= 1  TO 16  DO WRITELN;
    WRITELN('IFC PRINTOUT:');
    WRITELN;
    WRITELN('  1.   PRINTOUT KEYTAB AND METRIX.');
    WRITELN;
    WRITELN('  2.   PRINTOUT KEYTAB, METRIX,
                    INFOTABLE, TYPETAB AND PROCTAB');
    FOR I:=1 TO 3 DO WRITELN;
    WRITELN ('ENTER NUMBER YOU WANT TO BE PRINTED ?');
    READ (I);
    IF  I=1 THEN P3 ELSE
    IF I=2 THEN BEGIN P1;P2;P3 END
    ELSE BEGIN
         WRITELN('**ERROR**:ENTER NUMBER EITHER 1 OR 2');
         PRINTOUT;
         END;
END(*PRINTOUT *);
```

```
PROCEDURE READALINE;
{*** GLOBAL     : LN, IPFILE,OUTFILE                          ***}
{*** CALLED BY : ACCESSRECORD,PROCESSVAR_TYPE                 ***}
{***             PROCESSPROC,ASSIGNMENT,ACCESSUNTIL,          ***}
{***             IO_STMT,ACCESS_CALL,PROCESSBEGIN,            ***}
{***             MAIN                                         ***}

VAR LINE:STRING;
    P,Q,R:INTEGER;
    MARK, DONE:BOOLEAN;

BEGIN
      IF EOF(IPFILE) THEN FLAG:=TRUE
      ELSE BEGIN
      LN:='';
      MARK:=FALSE;
      DONE:=FALSE;
      WHILE NOT DONE DO
      BEGIN
        READLN(IPFILE,LINE);
        WRITELN('READ......',LINE);
        WRITELN(OUTFILE,'    ',LINE);
        IF (LENGTH(LINE)>0) OR (LINE <>'')
        THEN BEGIN
             R := 1;
             WHILE LINE[R]=BLANK DO R:=R+1;
             DELETE(LINE,1,R-1);
             IF  (POS('(*',LINE)=0)
             THEN BEGIN
                    P:=POS('END.',LINE);
                    Q:=POS(';',LINE);
                    IF P>0 THEN BEGIN
                                DONE:=TRUE;
                                LN  :=CONCAT(LINE,BLANK);
                                END
                    ELSE IF Q>0
                         THEN BEGIN
                              LINE:=CONCAT(LINE,BLANK);
                              IF MARK
                              THEN LN:=CONCAT(LN,LINE)
                              END;
                  END;
            END;
      END;
      WHILE POS('  ',LN)>0 DO DELETE(LN,POS('  ',LN),1);
      END;
END (*READALINE*);
```

```
PROCEDURE GETFIRSTWORD;

(*** GLOBAL     : WORD,LN,FLAG                          ***)
(*** CALLED BY :  PROCESSPROC,ELSE_STMT,               ***)
(***             ASSIGNMENT,ACCESSWHILE,ACCESSUNTIL,***)
(***             ACCESS_IF_STMT,IO_STMT,ACCESS_CALL,***)
(***             ACCESSBLOCK,PROCESSBEGIN,MAIN        ***)

VAR P:INTEGER;

BEGIN
    P:=1;
    WHILE LN[P] = BLANK DO P := P+1;
    DELETE(LN,1,P-1);
    P := POS(BLANK,LN);
    WORD := COPY(LN,1,P);
    IF WORD='END. '
    THEN BEGIN
              WORD:='END.';
              FLAG:=TRUE
              END
    ELSE IF (WORD='END; ') OR  (WORD='END ')
         THEN  DELETE(WORD,LENGTH(WORD),1)
         ELSE BEGIN
         P:=1;
         WHILE (WORD[P] IN LETTERS)
                AND (P<=LENGTH(WORD)) DO P:=P+1;
         WORD:=COPY(WORD,1,P-1);
         END;

END;(*GETFIRSTWO RD*)
```

```
PROCEDURE BODY;

BEGIN
     READALINE;
     GETFIRSTWORD;
     WHILE NOT FLAG DO
     BEGIN
        IF WORD='TYPE'
        THEN BEGIN STATUS:=STYPE;
                   PROCESSVAR_TYPE ; END
        ELSE IF WORD='VAR'
             THEN BEGIN STATUS := SVAR;
                        PROCESSVAR_TYPE ; END
             ELSE IF WORD='PROCEDURE'
                  THEN BEGIN ACTION:=SPROC;
                             STATUS:=SPROC;
                             PROCESSPROC; END
                  ELSE IF WORD = 'FUNCTION'
                       THEN BEGIN ACTION:=SFUNCT;
                                  STATUS:=SFUNCT;
                                  PROCESSPROC; END
                        ELSE IF WORD='BEGIN'
                             THEN PROCESSBEGIN
                             ELSE BEGIN READALINE;
                                        GETFIRSTWORD; END
    END(* WHILE *)
END(*BODY*);


BEGIN (* MAIN *)
    INITIALIZE;
    BODY;
    PRINTOUT;
    END.
```

APPENDIX C

USER's GUIDE.

This section serves to instruct the user on how to operate the P-system. The user should read and understand this short manual before he attempts to operate the P-system. The following briefly describes the necessary characteristics and features of the P-system and illustrates how to run the IFC program step by step.

The operation of the P-system is based on the command level modes. The example are F(ile mode and E(dit mode. Each mode has a different set of subcommands that must only be used in that mode. The user may type "?" on the keyboard to have more subcommands displayed on the screen. IF a different mode is desired, user must exit the current mode before entering to the new mode. After booting the system, the case for the command mode will display on the screen:

COMMAND: E(dit,R(un,F(ile,C(omp,X(ecute,A(ssem,H(alt?

The follwing section will breifly explain some subcommands and their use in the file mode and the editor mode. Since the input program to IFC needs to be error free, the user may use the C(ompile command to check for syntax errors that might occur in his input program before executing IFC program.

THE FILE SYSTEM.

Pressing "F" for F(ile will enable user to enter the file mode. The file system is used to maintain the storing and retrieving of information or items on the disk storage. The information stored on the disk may be given by the disk directory command L(dir. In this case, a file name with the prefix "IP" refers to an input Pascal program to IFC program

F(ile : G(et, S(ave, W(hat, N(ew,L(dir, R(em, C(hng, Q(uit ?

L(dir	list all the files kept in the disk directory User may request for IFC input file listing by typeing "IP*.text" on the keyboard after the prompt line: disk what vol?
G(et	get the requested file name from disk into the current workfile.
C(hng	to change the name of the file in the directory to a new name.
N(ew	create a new work file, clear the current work file.
R(em	removes files from the disk library.
Q(uit	exits from FILER mode.

THE EDITOR

The user presses "E" for the E(dit command at the command level. The editor allows the user to enter, change and modify the program (Standard Pascal). The editor will ask for the name of the file the user wants to keep on the disk library. In this report, a file with the prefix of "IP##" is recommended, where "##" is the user file name. E(dit:A(djust, C(py, D(elete, F(ind, I(nsert, J(ump, Q(uit ?

I(nsert	insert characters in to the text buffer as they are typed in.
D(elete	deletes characters from the text buffer.
J(ump	moves the cursor to the beginning, ending or from marker to marker where a marker is pre defined using the "set" instruction.
F(ind	locate a string of characters in the text buffer
Q(uit	exits the EDITOR with options, one of the the four options must be selected by typing U, E, R or W.

INPUT SPECIFICATION

* input a Standard Pascal program.
* use a ';' to seperate every program statements, 80 characters per input line.
* comments must start at the new line.
* use only lowercase characters.
* no nested record structure in the type declaration.
* acceptable input program statements.
  - assignment statement
  - BEGIN-END
  - repetition statements:
    FOR, WHILE_DO, REPEAT_UNTIL
  - conditional statement
    IF THEN ELSE
  - call statement:
    call by name only
    use function call in the assignment only
  - WITH statement
  - I/O statement:
    READ, READLN, WRITE, WRITELN

OPERATION CONCEPTS

In an attempt to demonstrate a sample program and describe the concepts to operate the IFC program, IP9 is selected as an input program to IFC.

(1) Booting the P-system

the following prompt line will appear on the screen

Command: E(dit, R(un, F(ile, C(omp, L(ink, S(ubmit,
X(ecute. ?

(2) To create and update a text file

2.1 Enter to FILER mode.....F(ile.

2.2 To create a text file:

Clear work file.....N(ew.

continue to step 2.4

2.3 To update an existing file:

Get existing file.....G(et.

2.4 Exit FILER mode.....Q(uit.

2.5 Enter EDIT mode.....E(dit.

(modify your program)

2.6 Exit EDIT mode.....Q(uit.

(3) User presses the key "X" on the keyboard.

the following prompt line will appear on the screen:

Execute what file?

3.1 User types "IFC" on the keyboard.

the following prompt line will appear on the screen:

Enter input filename to be run on IFC?

3.2 User types: "IP9" on the keyboard.
The following prompt lines display the echo of the input source program. After the IFC program has finished scanning the input source program, the following prompt lines will appear on the screen:

IFC printout:

1. printout: KEYTAB, METRIX.

2. printout: KEYTAB, METRIX, INFOTABLE, TYPTAB and PROCTAB.

Enter number you wish to have the printout?

3.3 User presses either "1" or "2" on the keyboard, the input source program listing and the tables according to the number pressed will be printed on the printer.

(4) repeat the first step if the user wants to test more input programs.

(5) Press H(alt to leave the system.

APPENDIX D

Sample Program Listings

```
PROGRAM SAMPLE;
(* IP1 *);
VAR A,B,C,D,E : INTEGER;

BEGIN
     READ (A,B);
     REPEAT
         READ(C);
         IF A>10 THEN WHILE B <>0
                      DO BEGIN D:= 2*E;
                         END;
     UNTIL (C=0);
END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	A..	0	0	0
2	B..	0	0	0
3	C..	0	0	0
4	D..	0	0	0
5	E..	0	0	0

KEY TABLE

1	IN
2	OUT
3	MAIN..A
4	MAIN..B
5	MAIN..C
6	MAIN..E
7	MAIN..D

MATRIX

	1	2	3	4	5	6	7
1	0	0	1	1	1	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	1
4	0	0	0	0	0	0	1
5	0	0	0	0	1	0	1
6	0	0	0	0	0	0	1
7	0	0	0	0	0	0	0

```
PROGRAM IP2;

VAR SA : ARRAY[1..10] OF STRING;
    IA : ARRAY[1..10] OF INTEGER;
    K,LN,MAX,KMAX : INTEGER;
    CH : CHAR;

  (* MAIN PROGRAM *)

BEGIN
    K := 1;
    MAX := 0;
    REPEAT
        WRITE('SCORE');
        READ(IA[K]);
        IF NOT EOF THEN
        BEGIN
            WRITE('NAME');
            READ(SA[K]);
            LN := IA[K];
            IF IA[K] > MAX THEN
            BEGIN
                MAX := IA[K];
                KMAX := K;
            END;
            K := K+1;
        END;
    UNTIL EOF OR (K > 10);
    WRITELN;
    WRITELN('BEST SCORE:',IA[KMAX],'  ',SA[KMAX]);
END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	SA..	0	0	0
2	IA..	0	0	0
3	K..	0	0	0
4	LN..	0	0	0
5	MAX..	0	0	0
6	KMAX..	0	0	0
7	CH..	0	0	0

KEY TABLE

1	IN
2	OUT
3	MAIN. . . K
4	MAIN. . . MAX
5	MAIN. . . IA
6	MAIN. . . SA
7	MAIN. . . LN
8	MAIN. . . KMAX

MATRIX

	1	2	3	4	5	6	7	8
1	0	0	0	0	1	1	0	0
2	0	0	0	0	0	0	0	0
3	0	0	2	1	1	1	1	2
4	0	0	0	1	0	0	0	1
5	0	1	0	2	0	0	1	1
6	0	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0

```
PROGRAM IP3;
VAR X,Y,Z,W : INTEGER;

BEGIN
    READ(X,Y);
    IF X<10 THEN BEGIN
                    READ(Z);
                    IF Y>5 THEN WRITELN('YY := ',Y)
                           ELSE W := Z+Y;
                    END
            ELSE BEGIN
                    READ(W);
                    IF Y>0 THEN WRITELN('YY := ',Y+W)
                           ELSE Z := W + Y;
                    END;
    WRITELN(X,Y,Z,W);
END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	X. .	0	0	0
2	Y. .	0	0	0
3	Z. .	0	0	0
4	W. .	0	0	0

KEY TABLE

1	IN
2	OUT
3	MAIN. . X
4	MAIN. . Y
5	MAIN. . Z
6	MAIN. . W

MATRIX

	1	2	3	4	5	6
1	0	0	1	1	1	1
2	0	0	0	0	0	0
3	0	3	0	0	2	2
4	0	5	0	0	2	2
5	0	1	0	0	0	1
6	0	2	0	0	1	0

```
PROGRAM IP4;
CONST
                MAXLENGTH = 1000;
TYPE
                INDEX = 1..MAXLENGTH;
                ROWTYPE = ARRAY[INDEX] OF INTEGER;
VAR
                INROW : ROWTYPE;
                COUNT : 0..MEXLENGTH;
                IX : INDEX;
PROCEDURE SORT (VAR ROW: ROWTYPE; LENGTH : INDEX);
VAR
                JUMP,M,N : INDEX;
                TEMP : INTEGER;
                ALLDONE : BOOLEAN;
BEGIN
      JUMP := LENGTH;
      WHILE JUMP > 1 DO
      BEGIN
           JUMP := JUMP DIV 2;
           REPEAT
                ALLDONE := TRUE;
                FOR M := 1  TO LENGTH - JUMP DO
                BEGIN
                     N := M+ JUMP;
                     IF ROW[M] > ROW[N]
                     THEN BEGIN
                               TEMP := ROW[M];
                               ROW[M] := ROW[N];
                               ROW[N] := TEMP;
                               ALLDONE := FALSE;
                          END;
                END;
            UNTIL ALLDONE;
       END;
END;
BEGIN
      COUNT := 0;
      READ(INROW[COUNT + 1]);
      WHILE NOT EOF DO
      BEGIN
           COUNT := COUNT+1;
           READ(INROW[COUNT+1]);
      END;
      IF COUNT > 0
      THEN BEGIN
                SORT(INROW,COUNT);
                FOR IX := 1 TO COUNT DO
                     WRITE(INROW[IX]);
           END
      ELSE WRITE('NO INPUT');
  END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	INROW. .	0	0	0
2	COUNT. .	0	0	0
3	IX. .	0	0	0
4	ROW. .	0	0	1
5	LENGTH. .	0	0	1

PROC_TABLE

INDEX	PROCNAME	TOINFO	PARAM COUNT	PROC TYPE
1	SORT	4	2	1

KEY TABLE

1	IN
2	OUT
3	PROC/SORT. . . LENGTH
4	PROC/SORT. . . JUMP
5	PROC/SORT. . . ALLDONE
6	PROC/SORT. . . M
7	PROC/SORT. . . N
8	PROC/SORT. . . ROW
9	PROC/SORT. . . TEMP
10	MAIN. . . COUNT
11	MAIN. . . INROW

MATRIX

	1	2	3	4	5	6	7	8	9	10	11
1	0	0	0	0	0	0	0	0	0	0	2
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1	1	0	1	2	1	0	0
4	0	0	0	2	3	0	3	4	2	0	0
5	0	0	0	0	2	0	1	2	1	0	0
6	0	0	0	0	0	0	1	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	0	0	3	2	0	1
9	0	0	0	0	0	0	0	1	0	0	0
10	0	2	1	0	0	0	0	0	0	1	1
11	0	1	0	0	0	0	0	1	0	0	0

```
PROGRAM IP5;

VAR A, B, C, D, E  :INTEGER;

BEGIN
     READ(A, B, C, D);
     REPEAT
        IF A>B THEN
           IF C>0 THEN BEGIN
                          WRITE(D, E);
                          WHILE (B>0) DO D:= A -1;
                       END
                  ELSE READ (E);
     UNTIL (E=0);
 END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	A. .	0	0	0
2	B. .	0	0	0
3	C. .	0	0	0
4	D. .	0	0	0
5	E. .	0	0	0

KEY TABLE

```
1     IN
2     OUT
3     MAIN. . A
4     MAIN. . B
5     MAIN. . C
6     MAIN. . D
7     MAIN. . E
```

MATRIX

	1	2	3	4	5	6	7
1	0	0	1	1	1	1	1
2	0	0	0	0	0	0	0
3	0	1	0	0	0	2	1
4	0	1	0	0	0	2	1
5	0	1	0	0	0	1	1
6	0	1	0	0	0	0	0
7	0	2	0	0	0	1	1

```
PROGRAM IP6;

VAR A, B, C : INTEGER;

FUNCTION D(X, Y:INTEGER):INTEGER;

VAR M, N:INTEGER;
BEGIN
          READ(M, N);
          IF A THEN D := C * M
               ELSE D := C * N;
END;

BEGIN
         READ (A, C);
         B := D(A, C) + 1;
END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	A. .	0	0	0
2	B. .	0	0	0
3	C. .	0	0	0
4	D. .	0	0	1
5	M. .	0	0	1
6	Y. .	0	0	1

PROC_TABLE

INDEX	PROCNAME	TOINFO	PARAM COUNT	PROC TYPE
1	D	5	2	0

KEY TABLE

1	IN
2	OUT
3	FUNCT/D. . . M
4	FUNCT/D. . . N
5	MAIN. . . A
6	MAIN. . . C
7	FUNCT/D. . . D
8	FUNCT/D. . . X
9	FUNCT/D. . . Y
10	MAIN. . . B

MATRIX

	1	2	3	4	5	6	7	8	9	10
1	0	0	1	1	1	1	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	1	0	0	0
4	0	0	0	0	0	0	1	0	0	0
5	0	0	0	0	0	0	2	1	0	0
6	0	0	0	0	0	0	2	0	1	0
7	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0

```
PROGRAM IP7;

VAR B, C : INTEGER;
    X, Y, Z, W: INTEGER;


FUNCTION D(VAR M:INTEGER; N:INTEGER):INTEGER;
BEGIN
          IF W THEN D := C
               ELSE D := C * 2;
END;

BEGIN
         READ(X, Y, C);
         IF X<10 THEN BEGIN
                         Z := 1 + C;
                      END
         ELSE BEGIN
                 Z :=2;
                 IF Y > 5 THEN W:= D(X, Y) + Z
                          ELSE W := X+Y;
                          END;
        WRITELN(W, X, Y, Z);


END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	B. .	0	0	0
2	C. .	0	0	0
3	X. .	0	0	0
4	Y. .	0	0	0
5	Z. .	0	0	0.
6	W. .	0	0	0
7	D. .	0	0	1
8	M. .	0	0	1
9	N. .	0	0	1

PROC_TABLE

INDEX	PROCNAME	TOINFO	PARAM COUNT	PROC TYPE
1	D	8	2	0

KEY TABLE

```
1     IN
2     OUT
3     MAIN. . . W
4     MAIN. . . C
5     FUNCT/D. . . D
6     MAIN. . . X
7     MAIN. . . Y
8     MAIN. . . Z
9     FUNCT/D. . . M
10    FUNCT/D. . . N
```

MATRIX

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	1	0	1	1	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	1	0	0	2	0	0	0	0	0
4	0	0	0	0	2	0	0	1	0	0
5	0	0	1	0	0	0	0	0	0	0
6	0	1	3	0	0	1	0	2	1	0
7	0	1	2	0	0	1	0	0	0	1
8	0	1	1	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0

```
PROGRAM IP8;

TYPE
   ATYPE = RECORD AA : STRING;
                  AB : INTEGER;
                  AC : BOOLEAN;
                  END;
   BTYPE = RECORD BA : STRING;
                  BC : INTEGER;
                  END;
VAR A:ATYPE;
    B:BTYPE;
    C,D :INTEGER;
    E : BOOLEAN;
 BEGIN
     READ (C,D);
     IF C > D THEN
     WITH A DO
     BEGIN
        READ(AA,AB);
        B.BA := AA;
     END;
  END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	AA. .	2	0	0
2	AB. .	3	0	0
3	AC. .	0	0	0
4	BA. .	5	0	0
5	BC. .	0	0	0
6	A. .	0	1	0
7	B. .	0	4	0
8	C. .	0	0	0
9	D. .	0	0	0
10	E. .	0	0	0

TYPTABLE

INDEX	TYPE NAME	TO INFOINDEX
1	ATYPE	1
2	BTYPE	4

KEY TABLE

```
1     IN
2     OUT
3     MAIN. . . C
4     MAIN. . . D
5     MAIN. . . A. AA
6     MAIN. . . A. AB
7     MAIN. . . B. BA
```

MATRIX

	1	2	3	4	5	6	7
1	0	0	1	1	1	1	0
2	0	0	0	0	0	0	0
3	0	0	0	0	1	1	1
4	0	0	0	0	1	1	1
5	0	0	0	0	0	0	1
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

```
PROGRAM IP9;

TYPE
   ATYPE = RECORD AA : STRING;
                  AB : INTEGER;
                  AC : BOOLEAN;
                  END;
VAR A,B:ATYPE;
    C,D :INTEGER;
    E : BOOLEAN;
 BEGIN
     READ (C,D);
     IF C > D THEN
     WITH A DO
     BEGIN
        READ(AA,AB);
        B.AA := AA;
        C := D + AB;
     END;
     WRITELN(B.AC);
     A.AB := C + B.AB;
 END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	AA. .	2	0	0
2	AB. .	3	0	0
3	AC. .	0	0	0
4	A. .	0	1	0
5	B. .	0	1	0
6	C. .	0	0	0
7	D. .	0	0	0
8	E. .	0	0	0

TYPTABLE

INDEX	TYPE NAME	TO INFOINDEX
1	ATYPE	1

KEY TABLE

```
1     IN
2     OUT
3     MAIN. . C
4     MAIN. . D
5     MAIN. . A. AA
6     MAIN. . A. AB
7     MAIN. . B. AA
8     MAIN. . B. AC
9     MAIN. . B. AB
```

MATRIX

	1	2	3	4	5	6	7	8	9
1	0	0	1	1	1	1	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	1	0	1	2	1	0	0
4	0	0	2	0	1	1	1	0	0
5	0	0	0	0	0	0	1	0	0
6	0	0	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	1	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0

```
PROGRAM IP10 ;
CONST
        FIRST = 2;
VAR
        NUMERA, DENOMINA, LAST, COUNT : INTEGER;
        I : INTEGER;


PROCEDURE LOWTERM(VAR NUM, DEN : INTEGER);
VAR
        NUMCOPY, DENCOPY, REMAINDER : INTEGER;
BEGIN
        NUMCOPY := NUM;
        DENCOPY := DEN;
        WHILE DENCOPY <> 0 DO
        BEGIN
                REMAINDER := NUMCOPY MOD DENCOPY;
                NUMCOPY := DENCOPY;
                DENCOPY := REMAINDER;
        END;
        IF NUMCOPY > 1
        THEN BEGIN
                NUM := NUM DIV NUMCOPY;
                DEN := DEN DIV NUMCOPY;
             END;
END;


PROCEDURE ADDRATIONALS(VAR NUM1, DEN1 : INTEGER; NUM2, DEN2 : INTEGER);
BEGIN
        NUM1 := NUM1 * DEN2 + NUM2 * DEN1;
        DEN1 := DEN1 * DEN2;
END;


BEGIN
        NUMERA := 1;
        DENOMINA := 1;
        READ(LAST, COUNT);
        FOR I := FIRST TO LAST DO
        BEGIN
                ADDRATIONALS(NUMERA, DENOMINA, LAST, COUNT);
                LOWTERM(NUMERA, DENOMINA);
                WRITELN(NUMERA:1, '/', DENOMINA:1);
        END;
END.
```

INFOTABLE

INDEX	INFONAME	NEXTINFO	POINTOINDEX	SCOPE
1	NUMERA. .	0	0	0
2	DENOMINA. .	0	0	0
3	LAST. .	0	0	0
4	COUNT. .	0	0	0
5	I. .	0	0	0
6	NUM. .	0	0	1
7	DEN. .	0	0	1
8	NUM1. .	0	0	2
9	DEN1. .	0	0	2
10	NUM2. .	0	0	2
11	DEN2. .	0	0	2

PROC_TABLE

INDEX	PROCNAME	TOINFO	PARAM COUNT	PROC TYPE
1	LOWTERM	6	2	1
2	ADDRATIONALS	8	4	1

KEY TABLE

1	IN
2	OUT
3	PROC/LOWTERM. . . NUM
4	PROC/LOWTERM. . . NUMCOPY
5	PROC/LOWTERM. . . DEN
6	PROC/LOWTERM. . . DENCOPY
7	PROC/LOWTERM. . . REMAINDER
8	PROC/ADDRATIONALS. . . NUM1
9	PROC/ADDRATIONALS. . . DEN2
10	PROC/ADDRATIONALS. . . NUM2
11	PROC/ADDRATIONALS. . . DEN1
12	MAIN. . . NUMERA
13	MAIN. . . DENOMINA
14	MAIN. . . LAST
15	MAIN. . . COUNT

MATRIX

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
4	0	0	2	0	2	0	1	0	0	0	0	0	0	0	0
5	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0
6	0	0	0	2	0	1	2	0	0	0	0	0	0	0	0
7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
9	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
10	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0
12	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0
13	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0
14	0	1	0	0	0	0	0	0	0	1	0	2	2	0	0
15	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

INFORMATION FLOW COMPLEXITY

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AN ABSTRACT OF MASTER'S REPORT

submitted in partial fulfillment of

the requirement for the degree

MASTER OF SCIENCE

Department of Computer Science

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1984

ABSTRACT

The areas of control flow and information flow are frequently mentioned in techniques for measuring software complexity. Control flow refers to the execution sequence of the statements and information flow refers to the dependency of a variable on the values of other variables. The various measures usually cover either intermodule or intramodule flow. The features of the information flow can be either explicit flow caused by simple statements or implicit flow caused by control statements.

A tool, the information flow complexity (IFC) program was designed to report the overall information transfer between objects (program variables) in a Pascal program. The IFC was written in UCSD Pascal and runs under the P-system on the PDQ-3 microcomputer. A metric which represents the information flow is the output. A flow graph can be derived from this metric and may be used to analyze the complexity of the information flow among the program variables. In addition, this metric can be used to identify the program variables which are dependent or independent. This may lead to an improved understanding of the design.

Presented in this report is an overview of the recent work, a description of IFC, the IFC source code and sample input program listings.