

```
process AIRPLANE
  call TOWER giving GATE yielding RUNWAY
  work TAXI.TIME (GATE, RUNWAY) minutes
  request 1 RUNWAY
  work TAKEOFF.TIME (AIRPLANE) minutes
  relinquish 1 RUNWAY
end " process AIRPLANE
```

```
process AIRPLANE
```

```
  call TOWER
```

```
  work
```

```
  request
```



**Programming Language**

 **CACI**  
Products Company

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# Preface

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SIMSCRIPT II.5 is a rich and versatile computer programming language enhanced with computer graphics, designed to solve general programming problems. This book, which describes the SIMSCRIPT II.5 language, is divided into chapters describing non-graphical language "levels" which provide an organized path through the language:

**Level 1** (Chapters 1 and 2): General purpose language statements.

**Level 2** (Chapters 3 and 4): The entity-attribute-set features of SIMSCRIPT II.5. These features have been updated and augmented to provide a more powerful list-processing capability. This level also contains a number of new data types and programming features.

**Level 3** (Chapter 5): The simulation-oriented part of SIMSCRIPT II.5, containing statements for time advance, event-processing, generation of statistical variates, and accumulation and analysis of simulation-generated data. The powerful new modeling constructs of processes and resources are described in great detail.

Chapter 6 is a collection of various topics which need not be understood for initial use of SIMSCRIPT II.5. This chapter also describes several features of the language which are obsolete, but are being supported for compatibility.

A companion text, *Building Simulation Models with SIMSCRIPT II.5*, teaches the fundamentals of simulation methodology through the use of SIMSCRIPT II.5 case studies. The material in this book relates closely to the short course given regularly by the CACI Products Company.

A third book, *SIMSCRIPT II.5 Reference Handbook*, provides a description and examples of each of the language elements in alphabetical order.

Interactive simulation graphics for SIMSCRIPT II.5 is described separately, in the *SIMGRAPHICS II User's Guide for SIMSCRIPT II.5*. Other features of SIMSCRIPT II.5 are covered in the user's manual for each specific system.

SIMSCRIPT II.5 is available for PCs running WindowsNT and Windows95. It is also available for VMS systems and most UNIX workstations.

## Free Trial Offer

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# 1. SIMSCRIPT II.5 Basic Concepts

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## 1.1 Introduction

A computer program is a list of instructions directing a computer to perform certain operations on data. A programming language is used by a programmer to describe the data and the actions to be performed. SIMSCRIPT II.5 is one such programming language. Here is a simple example of a SIMSCRIPT II.5 program:

```
read X and Y
add X to Y
print 1 line with Y thus
The Sum is: *****
stop
```

This program consists of four SIMSCRIPT II.5 statements. The statements are instructions to:

1. Read the values of two variables called **x** and **y** from input data
2. Add these variables together
3. Print the sum of the variables along with the explanatory message, **The Sum is:**, and
4. Stop.

The example illustrates the basic computer operations of input (reading data), computation (in this case, addition), and output (printing results).

In program examples throughout this book, SIMSCRIPT words and commands will be printed in lower case characters. Variable names, routine names, and other user-supplied terms will be printed in upper case characters. Thus, in the above example, **read**, **and**, **add**, **to**, **print**, **line**, **with**, **thus**, and **stop** are all SIMSCRIPT words. **x**, **y**, and the phrase, **The Sum is:** are expressions provided by the programmer. SIMSCRIPT words which appear in the text (apart from those in program examples) will appear in **bold** characters. Again, variable names appear in upper case characters. Finally, small segments of code are presented in the ‘courier’ font as shown above.

Although SIMSCRIPT does support string variables, the rest of this chapter focuses on integers and reals. See paragraph [2.19](#).

## 1.2 Variables

As shown in the above example, programs use identifying names to refer to values of program variables. A variable is a data item that may take on different values as it is acted upon by operations. A program statement such as:

```
add X to Y
```

means **add** the current value of **x** to the current value of **y**, giving **y** a new value.

A variable identifying name is any combination of letters, digits, and periods that contains at least one letter, so that it may be distinguished from a number. For example, **x**, **COST**, **ACCOUNTS.RECEIVABLE**, **SIZE**, **MAN3**, **PART1**, **5Y**, and **1A** are all legal names, whereas **27**, **1**, and **4.6** are not. A slight restriction on variable naming is that any periods appearing as the last characters of a name are completely ignored. Upper and lower case distinctions are also ignored. Thus, **Myvar**, **MyVar**, and **MYVAR** all refer to the same quantity. It will be shown later in this manual how this rule may be used as a notational aid.

Hereafter, whenever a variable name is used in a statement, it is understood to refer to the value of the variable identified by that name, not to the name itself. The values given to numeric variables may be whole numbers (integers) or numbers with a fractional part (decimal numbers). Thus, the value associated with a variable named **x** may at various times be **0** or **125** or **16.72** or **-0.00001**, or whatever number has most recently been assigned to **x**. The range in magnitude of numbers that can be internally represented in a computer and the accuracy with which numbers can be represented are, of course, subject to limits. These limits depend on the particular machine but, for the present, may be taken to be sufficiently generous not to be the subject of concern.

At the start of program execution, the value of each numeric variable is set equal to zero. These variables are said to be "initialized to zero."

### 1.3 Reading Input Data

One way in which specific numeric values can be assigned to program variables is by reading numbers as input data. An example of the **read** statement is:

```
read X, Y and QUANTITY
```

**x**, **y**, and **QUANTITY** are variable names. They are used in this statement in a variable name list.

In general, a SIMSCRIPT II.5 list consists of a string of quantities separated by either a comma, or the word **and**, or a comma followed by the word **and**. Some examples of variable name lists as they might appear in **read** statements are:

```
read PRICE, QUANTITY, DISCOUNT
read PLACE and DISTANCE
read NAME, DATE, PLACE and TIME
read NAME, and DATE, PLACE and TIME
```

The general form of a **read** statement is:

```
read variable name list
```

When a SIMSCRIPT program executes a read statement, it **reads** as many fields from the input data as there are variable names listed in the statement. Successive numeric values are read and

assigned to corresponding variables in the read list. The numbers can be entered in the input data in integer or decimal form. For example, the numbers 5, 5.0, and 5.000 are equivalent.

Data items read into or printed by a computer are treated in physical groupings called records. Examples of a record are a single line typed on a computer terminal, a record, or a line printed on a printer. Within a record, data items are considered to be separated into fields. A field is a contiguous string of symbols delimited at the beginning and the end by at least one blank. Numeric data fields may also be delimited by the beginning or the end of a record. Each numeric value occupies one data field.

Successive read statements do not necessarily read new input records, because a SIMSCRIPT II.5 program can treat input data as a continuous stream of data fields. The precise location, then, of a number within a record is not considered. An example illustrates this "free-form" concept: **Read X, Y, Z** sets **X** to the value **3**, **Y** to the value **2.1**, and **Z** to the value **67.33** when each of the sets of input data records in table 1-1 is read.

**Table 1-1. Sample Data Records**

<u>Record Number</u>	<u>Values</u>
(1) record 1	3.0    2.1    67.33
(2) record 1	3.00
record 2	2.1    67.33
(3) record 1	3
record 2	2.1
record 3	67.33

## 1.4 Constants

Program statements may use numbers directly, such as the "2" in **add 2 to SUM**, or the number "3.14" in **add 3.14 to VOLUME**. These numbers are called constants. When used, they refer to their literal values. They are not names of variables and do not represent other values.

Constants may have the same range of numeric values as variables, and where appropriate, may be used interchangeably in all computations. Constants differ from variables in that their values cannot be changed. **Add 5 to X** is a legal use of the variable **X** and the constant **5**. **Add 5 to 4** is not a legal use of the constant **4** because it is giving a new value of 9 to the constant **4**.

Whole numbers and fractional numbers, signed or unsigned, are allowed as constants. When equivalent representations of a number exist, they have the same value; 2.5 and 002.500 both represent the same number. The statements **add 1 to COUNTER** and **add 1.00 to COUNTER** have the same effect.

## 1.5 Arithmetic Expressions

Arithmetic expressions are formed by combining variables and constants with arithmetic operators. The arithmetic operators are + (add), - (subtract), \* (multiply), / (divide), and \*\* (exponentiate).

Two of these operators, plus and minus, can be used as unary operators, that is, with a single variable or constant. The constants +1 and -1 are examples of the use of plus and minus as unary operators on the constant 1. All of the operators can be used as binary operators, that is, with two variables (or constants or a variable and constant). If we let **A** and **B** represent either a variable or a constant, then + **A** and - **A** are examples of plus and minus as unary operators, and **A** + **B**, **A** \*\* **B** are examples of arithmetic expressions that use binary operators.

The simplest expression consists of a single constant, or a single variable, perhaps preceded by a unary plus or minus operator. An expression, + **A**, may be written as **A**, with the unary plus implied. This is not possible, of course, with the unary minus operator.

All binary operators must be explicitly expressed, and no two operators can appear consecutively. For example, multiplication of the variables **A** and **B** must be written as **A** \* **B**, and not **AB**. The latter would be interpreted as the value of a variable called **AB**. Addition of the expressions **A** and -**B** can be written as **A** + (-**B**) or **A** - **B**, but not **A** + -**B**. This last example shows that parentheses must be used to separate unary and binary operators. Parentheses may also be used (1) to clarify the operations in an expression to make it more readable, or (2) to specify the order in which the operations in an expression are to be performed.

Simple expressions can be connected by any of the arithmetic operators (+, -, \*, /, \*\*) to form compound expressions. The "parentheses rule" states that expressions are evaluated from left to right, removing parentheses before applying operator hierarchy rules. Imbedded parentheses are evaluated from the inside out. Thus:

$$a + (b * c) + d$$

is evaluated by first computing the value of (**b\*c**) and then adding this value to **a** and **d**.

When parentheses are omitted, the hierarchy of operations is:

- |                                |         |
|--------------------------------|---------|
| 1. Exponentiation              | **      |
| 2. Multiplication and division | * and / |
| 3. Addition and subtraction    | + and - |

This hierarchy specifies the order in which the different operations are performed relative to one another. Exponentiation is performed before multiplication or division, and either of these before addition or subtraction. For example, the expression **A** + **B/C** + **D\*\*E** \* **F** - **G** is taken to mean **A** + (**B/C**) + (**D<sup>E</sup>** \* **F**) - **G**. If precedence is not completely specified by these rules, the operation specified farthest to the left in the expression is performed first, as in **A** \* **B/C**, which is computed as (**A** \* **B**) / **C**.

An expression is written as a string of variable names, constants, arithmetic operators, and parentheses. Any number of spaces from zero upward may be used to separate the parts of an expression. Therefore, **A+B**, **A+ B**, **A + B** and **A +B** are treated identically. The exponentiation operator, **\*\***, is treated as a single unit and no spaces may appear between its two asterisks. Some example expressions are given in table 1-2.

**Table 1-2. Sample Mathematical Expressions**

<u>Expression</u>	<u>Comment</u>
<b>PRICE</b>	A variable is itself an expression
<b>53</b>	A constant is also an expression
<b>(PRICE)</b>	Parentheses are optional
<b>DUEIN - DUEOUT</b>	
<b>PRICE * QUANTITY</b>	
<b>PRICE * (ORDER - SALES)</b>	Parentheses change precedence order
<b>A + B + C + D</b>	
<b>X ** 2</b>	In mathematical notation, this is $x^2$
<b>A + X ** 2 + X ** 4</b>	Equivalent to the following: $A + (X ** 2) + (X ** 4)$
<b>X + Y / Z</b>	This means $X + (Y/Z)$ , not: $(X + Y)/Z$
<b>- A ** B</b>	This means $-(A^B)$ , not $(-A)^B$

## 1.6 Computing Variable Values

One way of assigning a value to a program variable is to use a **read** statement. Another way is to use a **let** statement. The general form of this statement is:

```
let variable = expression
```

as in the statements:

```
let X = 0
let X = (Y + 1)/15
let PRICE = QUANTITY * SALES.PRICE
let BALANCE = STOCK - PURCHASE
let UNIT.COST = TOTAL.COST / NUMBER.OF.UNITS
let AREA = 3.14 * RADIUS ** 2
```

When a **let** statement is executed, the current values of the variables on the right of the equal symbol (=) are used to compute the value of the arithmetic expression. This value is then assigned to the variable on the left of the equal symbol.

Used in this way, in conjunction with the word **let**, the equal symbol is an assignment operator. In the statement:

```
let X = Y * 2
```

the value of the expression  $Y * 2$  is computed and assigned to the variable **x**. The previous value of **x** is replaced by the new value; and in:

```
let X = X + 1
```

a new value of **x** is computed by adding 1 to the current value of **x** and assigning this new value to **x**. Use of the word **let** is optional. That is, the = operator is enough for assigning an expression to a variable.

## 1.7 Specialized Computation Statements

Because addition and subtraction are such frequently used operations, two special statements, combining both expression evaluation and assignment operations, may be used. The **add** and **subtract** statements are used to add or subtract the value of an arithmetic expression to or from a program variable. The statement forms are:

```
add arithmetic expression to variable
subtract arithmetic expression from variable
```

The statements are equivalent to the **let** statements:

```
let variable = variable + arithmetic expression
let variable = variable - arithmetic expression
```

The **add** and **subtract** statements have the virtues of being easy to write and being straightforward in meaning. Some examples of these statements are:

```
add 1 to COUNTER
add ITEM * COST to BILL
subtract 3 * X + 6 * Y from Z
subtract COST from CASH
```

## 1.8 Displaying the Results of Computation

The **print** statement was used in the first example in paragraph 1 to display the result of a computation. This statement may be used either to display some predefined text, or to display both predefined text together with the current values of program variables or arithmetic expressions, as in:

```
print I lines as follows
```



or

```
print I lines with arithmetic expression list as follows
```

followed by **I** lines of descriptive text and format information. The line count **I** is a positive integer constant. The word **line** can be used instead of **lines** to improve readability. **Thus** and **like this** may be used as alternatives to the phrase. Some sample **print** statements are:

```
print 2 lines as follows
print 1 line thus
print 2 lines with X and Y like this
print 4 lines with X, X**2, Y, Y**2, X*Y, N as follows
```

The **I** lines, called format lines, that follow the **print** statement can contain as many as 80 columns of textual information and formats for variables or arithmetic expressions whose values are to be printed. There can be either text, or formats, or both in any format line. The length of a format line is measured as the number of columns from column 1 to the last nonblank column in the line.

Textual information appearing in format lines is printed exactly as it appears. Thus, the statement:

```
print 1 line as follows
.....This is a Sample Format Line.....
```

prints a single line of output containing the above message. The statement:

```
print 2 lines thus
                Summary Report
INCOME                                EXPENSE DATA
```

prints two lines of output as they appear in the format lines. Any character except an (\*) or a vertical bar (|) can appear in a format line as a textual message. Blanks are "printed" as empty columns.

When **print** statements are used to display the value of arithmetic expressions, the expressions are listed in the **print** statement, and descriptive formats are provided for their values. The expressions are first evaluated, and then printed in the display formats in left-to-right order. The display formats are described using asterisk (\*) characters to indicate the desired positioning of the printed values.

The general format description for a numeric value is of the form **\*\*\*.\*\***, where the asterisks indicate the number of print positions before and after the decimal point. The decimal point and following asterisks may be omitted if no fractional part is to be printed. If necessary, the value is rounded before printing. Blank print positions to the left of the decimal point, although not filled with asterisks, may be used if required by the magnitude of the number. A complete list of print formats is given in [Appendix A](#).

The variables **PRICE** and **ITEMS** appearing in the following **print** statements are assumed to have the values **100.899** and **27**, respectively:

1.     print 1 line with PRICE/ITEMS thus  
           PRICE/ITEM = \$\*.\*\*\*

is printed as:

```
PRICE/ITEM = $3.737
```

2.     print 1 line with PRICE/ITEMS as follows  
           PRICE/ITEM = \$\*.\*\*

is printed as:

```
PRICE/ITEM = $3.74
```

3.     print 3 lines with PRICE, ITEMS, PRICE/ITEMS thus

```
PRICE = $***.*
ITEMS =      *
PRICE/ITEM = $*.***
```

is printed as:

```
PRICE = $100.9
ITEMS =      27
PRICE/ITEM = $3.737
```

When several values are to be printed contiguously, the single parallel (|) is used in place of an asterisk to terminate a format on the left. If this is not done, two contiguous formats merge into one another. Thus, two contiguous three-digit integer fields can be expressed as **\*\*\*|\*\***, and six contiguous one-digit integer fields as **|||||**.

Blank lines can be included in the **print** format lines, or the **skip** statement may be used. If **E** is any arithmetic expression, the statement:

```
skip E output lines
```

skips a number of lines equal to the value of **E** rounded to an integer. The word **output** is optional. The words **line** and **lines** are synonymous. Some examples of the usage are:

```
skip 1 output line
skip N lines
skip X + 3 * Y output lines
```

If **E** is negative, it is treated as zero. At most, one complete page will be skipped.

Pages can be ejected before printing, so that the next **print** statement starts at the top of a new page, by using the statement:

```
start new page
```

The **print**, **skip**, and **start new page** statements can be used together to produce attractively labeled output reports.

As a final caution, note that whereas a **print** statement can appear on a line with previous statements, each of its following format lines must appear on a separate line. Format lines should, in general, not be indented.

## 1.9 Skipping Unwanted Input Data

Input data records may contain more information than is required by a program. For example, data collected from a laboratory experiment or a population survey may be analyzed in several different ways by different programs.

A **skip** statement may also be used to allow unwanted input data fields or records to be bypassed. A statement of the form:

```
skip E fields
```

passes over **E** data fields. The arithmetic expression **E** is rounded to an integer, if necessary. If **E** is negative, it is treated as an error, causing the program to terminate. For example:

```
skip 2 fields
```

skips the next two data fields, and:

```
skip I/J fields
```

skips no data fields if **I/J** is equal to 0, skips 3 fields if **I/J** = **2.7**, or skips 4 fields if **I/J** = **4.13**.

When a data field (value) is read, SIMSCRIPT II.5 waits at the end of the data field in preparation for the next **read** statement. Hence, when a field at the end of a data record is read, the record is retained until the next **read** statement is executed.

The **skip** statement can also be used to skip the remainder of a current data record when it is written as:

```
skip 1 record
```

An equivalent statement:

```
start new record
```

or

```
start new input record
```

is somewhat more descriptive. Note that the word **input** is optional. If **input** is not specified, this usage of the **skip** statement is distinguished by context from that used to skip output print lines. The word **records** implies **input**, while **lines** implies **output**.

The **skip record** statement can be generalized to the form:

```
skip E records
```

in which case the current data record and the following  $E - 1$  records are bypassed. If the expression ( $E$ ) is zero, no records are skipped. If it is negative, the program terminates with an error message. The statement:

```
skip 3 records
```

skips the remainder of the current data record and also the next two data records. (See paragraph [3.5.2](#) for program termination on end-of-file.)

## 1.10 Logical Expressions

Normally, computation proceeds from statement to statement in the order in which statements physically appear in a program listing. For example, in the four-statement example in paragraph [1](#), the program first executes the **read** statement, then the **add** statement, then the **print** statement, and halts when it reaches the **stop** statement. A fundamentally important extension of the concepts developed so far is the ability to specify, in a program, conditions under which alternative actions should be performed.

Arithmetic expressions may be combined, using relational operators, to form logical expressions, which may be determined to be either true or false and then may be used to choose between alternative actions. A logical expression is formed by joining two arithmetic expressions with a binary relational operator. The relational operators are:

=	equal
≠	not equal
<	less than
≤	less than or equal
>	greater than
≥	greater than or equal

When a logical expression is encountered during the execution of a program, the current values of the variables or arithmetic expressions that make up the logical expression are used to determine its truth or falsity. Thus, if  $x = 1$  and  $y = 0$ , the logical expression:

$X = Y$	is false
$X \geq Y$	is true
$X < Y$	is false
$X + Y = X * Y$	is false

For readability in different contexts, SIMSCRIPT II.5 provides alternative ways of writing logical expressions. Table 1-3 relates the mathematical symbol of each relational operator with keyboard symbols, English abbreviations, and "literary English" equivalents permitted in SIMSCRIPT II.5 comparisons.

Unless the keyboard symbols (column 2, table 1-3) are used, each relational operator must be separated from the arithmetic expressions on either side by a parenthesis, or at least one blank.

Typical logical expressions are:

1.  $Y > 0$
2. AGE less than RETIREMENT
3. CODE not equal to ZIP
4. LEVEL < THRESHOLD
5. (FIXED + NUMBER \* UNITS) greater than LOWBID
6.  $A \geq (B * X ** 2 + 3.57/C)$
7.  $(X ** 2 + Y ** 2)$  greater than  $Z ** 2$
8.  $X ** 2 + Y ** 2 > Z ** 2$

Examples 5, 6, and 7 demonstrate that the arithmetic expressions may be enclosed in parentheses for clarity without changing their meaning. Examples 7 and 8 illustrate the use of equivalent forms of a relational operator.

**Table 1-3. Relational Operators**

Mathematical <u>Symbol</u>	Keyboard <u>Symbol</u>	Permitted English <u>Abbreviation</u>	Permitted "Literary English" <u>Equivalent</u>
=	=	eq	Equal or Equals
≠	<>	ne	Not Equal To
<	<	ls/lt	Less Than
>	>	gr/gt	Greater Than
≤	<=	le	No Greater Than or Not Greater Than
≥	>=	ge	No Less Than or Not Less Than

### 1.11 Changing the Flow of Computation Using Logical Expressions

The **if** statement is used to test the truth or falsity of a logical expression and to choose between alternative sequences of instructions accordingly. The general form of the **if** statement is:

```

if logical expression
    first group of statements
else
    second group of statements
always

```

and may be flowcharted as shown in figure 1-1. In this figure, the first group of statements is executed when the logical expression is true, and the second group of statements is executed when the 'logical expression' is false. The term "flow of control" is used to denote the sequence of instructions followed under specific conditions, chosen from among the possible such sequences. The keywords **else** and **always** may be replaced by alternative synonyms to improve the readability of the **if** statement:

**Else** may also be expressed as **otherwise**

**Always** may also be expressed as **regardless** or **endif**

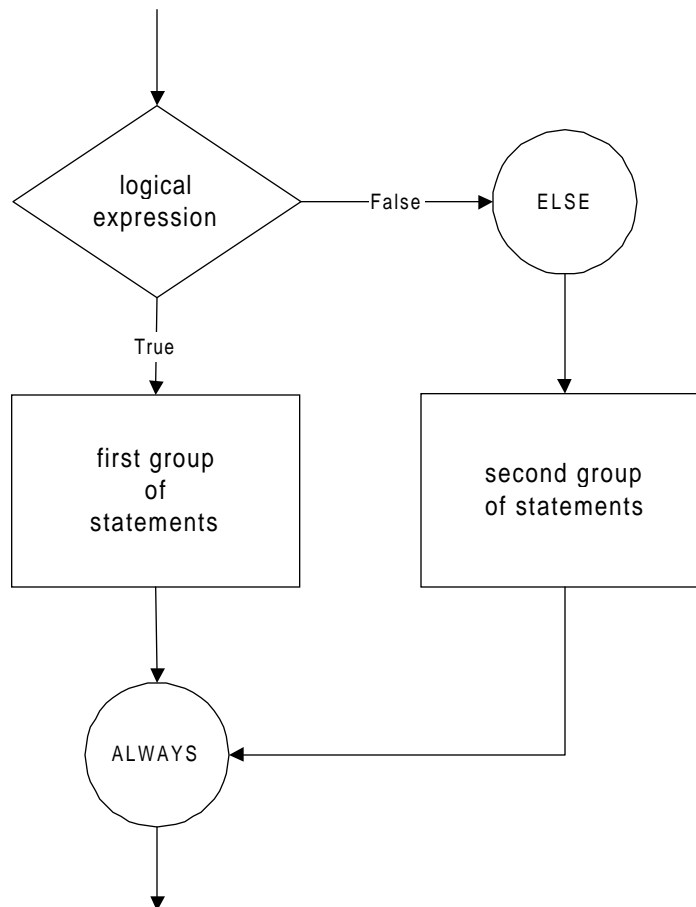
An example of the **if** statement is:

```

if STATUS = BUSY
    add 1 to NO.IN.QUEUE
else
    let STATUS = BUSY
always

```

Here, a **STATUS** variable is tested against a value denoting **BUSY** status. The variable **NO.IN.QUEUE** is incremented if the status flag is busy and the flow of control passes to **always**. Otherwise, the status flag is set to reflect the now **BUSY** status and control naturally passes to the **always** statement.



**Figure 1-1. Flow of Control After an if Statement**

The **else** statement and 'second group of statements' are optional. There are cases when the choice is simply whether or not to perform an action. This shortened form of the **if** statement is:

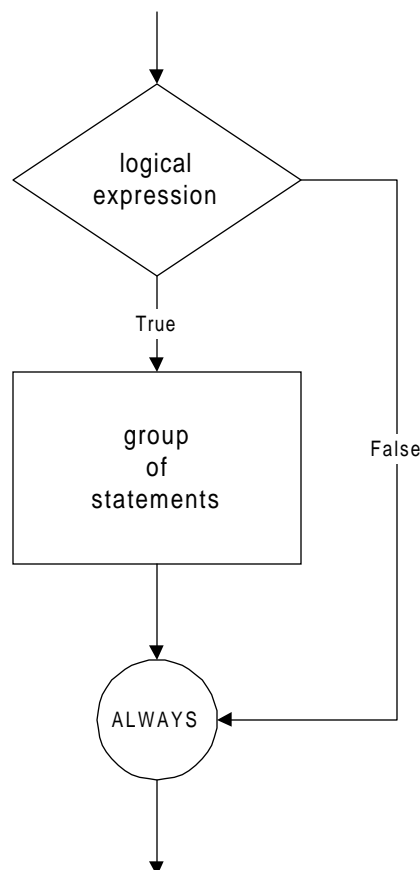
```

if logical expression
    group of statements
always

```

and is flowcharted in figure 1-2. When the logical expression is true, the group of statements is executed and flow of control continues through the **always** statement. When the logical expression is false, control transfers directly to the **always**. For example:

```
If X less than A
    let A = X + Y
    let B = X - Y
always
```



**Figure 1-2. Flow of Control After Shortened if Statement**

To improve program readability, the logical expression appearing in an **if** statement may be optionally followed by a comma. The word **is** may also be used before the "English" versions of the relational operators in logical expressions. Examples are:

```
if STATUS is not equal to BUSY,
if X is less than A,
```

Also, because logical comparisons with the value zero occur frequently in programming, the words **zero**, **positive**, and **negative** may be combined with the words **is** and **is not**, replacing



both the conditional operator and the right hand arithmetic expression, to form more readable logical expressions in these special cases. Examples are:

if X is zero	equivalent to	if X = 0
if X-Y is positive	equivalent to	if X-Y > 0
if Z is not negative	equivalent to	if Z >= 0

**Zero, positive, and negative** may be thought of as properties associated with an arithmetic expression. SIMSCRIPT II.5 allows for the expression of a number of such logical tests against predefined properties. These will be presented in later sections as the context demands.

**If** statements can be "nested" by putting **if** statements within the statement group of other **if** statements, thus allowing complex conditions to be specified. The statement group in an **if** statement can contain any number of statements. The only qualification on this group is that it must be self-contained with respect to other **if** statements appearing within it. Each **if** is matched by a corresponding **always**, as left parentheses are matched with right parentheses in an expression. For example, the following program segment might be used to classify persons by age into one of the groups **CHILD**, **TEEN**, or **ADULT** defined by the age groups under 11 years, between 12 and 17 years, and over 18 years:

```

if AGE less than 12
    add 1 to CHILD.COUNT
else
    if AGE less than 18
        add 1 to TEEN.COUNT
    else
        add 1 to ADULT.COUNT
    always
always

```

To indicate program structure and flow of control, it is helpful to indent and align each **if** in a column with its corresponding **else**, **always**, **otherwise**, **regardless**, or **endif**. Obviously, an out-of-place **else** or **always** in a program can greatly alter the flow of control and thereby the meaning.

A feature of one particular construct of nested **if** statements is that a failure to satisfy any one of the logical conditions specified by any of the nested **if** statements effectively causes a transfer of control out of the range of the entire nest. Such a structure is illustrated below:

```

if VALUE > 1000.00
    let PRIORITY = 2
    if TIME.DUE < 3
        add 1 to PRIORITY
        if WORKTIME < 1
            add 1 to PRIORITY
        always
    always
always

```

The failure of any test causes a transfer to one of the cascaded **always** statements, and hence a transfer out of the structure. Successive **if** statements add further logical tests to that of the first **if** statement. This structure may be simplified for readability by prefixing the word **then** to the second and subsequent **if** statements, and eliminating all but one of the consecutive **always** statements. The example shown above could be written as:

```

if VALUE > 100.00
  let PRIORITY = 2
  then if TIME.DUE < 3
    add 1 to PRIORITY
    then if WORKTIME < 1
      add 1 to PRIORITY
  always

```

Note that the **then if** construct is only applicable to nested logical tests in which the false condition for any of the tests is to have the same effect — a transfer of control out of the nest structure. While the use of **then if** may reduce the number of statements required, the programmer must judge whether such use obscures the logical intent of the structure.

## 1.12 More on Logical Expressions

The logical expressions described above have used relational operators to specify comparison between two arithmetic expressions, or between one such expression and defined properties such as **zero** or **negative**. This section elaborates on the structure of logical expressions.

A logical expression may be negated by following it with the phrase **is false**, as in the expression:

```
value < LIMIT is false
```

The **is false** phrase may be used to improve readability by stating a desired condition without forcing an unnatural transposition of logic. For example, a test may be written as:

```

if QUANTITY > INVENTORY
  let ORDER = ORDER - 1
always

```

or:

```

if QUANTITY <= INVENTORY is false
  let ORDER = ORDER - 1
always

```

with equal effect. For symmetry, the phrase **is true** is permitted. The form selected depends on how the programmer wants a logical expression to appear to a reader.

Simple logical expressions containing arithmetic expressions and relational operators may be combined using logical operators to form compound logical expressions. The logical operators are **and**

and **or**. (In this context, a comma cannot be substituted for the word.) If **E1** and **E2** are logical expressions, then:

**E1 and E2** is true if both **E1** and **E2** are true

**E1 or E2** is true if either or both of **E1** and **E2** are true

Compound logical expressions may contain more than two simple logical expressions, as in the logical expression:

**E1 and E2 or E3 and E4**

When more than two simple logical expressions appear in an unparenthesized compound logical expression with the operators **and** or **or**, the operator **and** is evaluated first. Parentheses can be used, however, to indicate a specific order of evaluation. In the absence of parentheses, the above expression is, by convention, evaluated, as though it had been written:

(1) **(E1 and E2) or (E3 and E4)**

If a program requires some other logic, the statement can be written as:

(2) **E1 and (E2 or E3) and E4**

which means something quite different. Version (1) is true either if both **E1** and **E2** are true or if both **E3** and **E4** are true. Version (2) is true if **E1** is true and **E4** is true, and either **E2** or **E3** is true.

Compound logical expressions can be used with **is false** and **is true** phrases. An **is false** or **is true** phrase always applies to the logical expression preceding it. If this logical expression is compound, it must be enclosed in parentheses, as shown in the logical expression:

**E1 is false and (E2 or E3) is true**

A few simple rules that govern the writing and evaluation of logical expressions are given below.

1. A logical expression enclosed in parentheses remains a logical expression.
2. In the absence of parentheses, **and** is evaluated before **or**. Successive logical expressions are used as operands of **and** operators, and these evaluated expressions are then used as operands of **or** operators. Parentheses can always be used to indicate specific operator hierarchies.
3. **Is true** and **is false** phrases apply to logical expressions preceding them. If such a logical expression is compound, it must be enclosed in parentheses. Otherwise, the phrase only applies to the expression adjacent to it.

Some examples that illustrate the writing and evaluation of complex logical expressions are given below. In these examples, the variables **I**, **J**, **K**, **M**, and **N** are positive numbers; the variables **Q**, **R**, **S**, and **T** are negative numbers; and the variable **Z** is zero.

- |     |   |   |
|-----|---|---|
| 1.  | <b>I equals J</b>                                       | is true or false depending on the values <b>I</b> , <b>J</b>  |
| 2.  | <b>I equals Q</b>                                       | is always false   |
| 3.  | <b>M + N is positive</b>                                | is always true  |
| 4.  | <b>M + T is positive</b>                                | is true or false depending on the values <b>M</b> , <b>T</b>  |
| 5.  | <b>I &gt; 0 and J &gt; 0</b>                            | is always true  |
| 6.  | <b>I &gt; 0 or R &gt; 0</b>                             | is always true  |
| 7.  | <b>I eq J and Z eq 0</b>                                | is true if <b>I</b> equals <b>J</b> , and false otherwise   |
| 8.  | <b>I eq J or Z eq 0</b>                                 | is always true  |
| 9.  | <b>I = J and K &gt; N and R = S</b>                     | is true if all three conditions are true, and false otherwise; it is evaluated as (( <b>I = J</b> ) <b>and</b> ( <b>K &gt; N</b> ) <b>and</b> ( <b>R = S</b> )) |
| 10. | <b>I = J or K &gt; N or R = S</b>                       | is true if any one of the three conditions is true; it is false only if all are false   |
| 11. | <b>I = J and K &gt; N or R = S</b>                      | is true if either of the two conditions around the <b>or</b> is true; it is evaluated as ( <b>I = J and K &gt; N</b> ) <b>or</b> ( <b>R = S</b> )               |
| 12. | <b>Z is zero and(I &lt; 0 or S &lt; 0)and Q = T</b>     | is true if <b>Q = T</b>   |
| 13. | <b>Z is zero and(I &gt; 0 or S &lt; 0)and Q = T</b>     | is true if <b>Q = T</b>   |
| 14. | <b>J &lt; K and(I = Q or S &lt; 0) and J + K &lt; I</b> | is true if <b>J &lt; K</b> and <b>J + K &lt; I</b>  |

When a statement containing a compound logical expression is executed, it does not always follow that all logical conditions in the statement are examined. For example, in the segment:

```
if X > Y**2 and COUNT > N
    add ...
always
```

both logical expressions have to be true for the **add** statement to be executed. If the first logical expression (**X > Y\*\*2**) is false, there is no need to evaluate the second (**COUNT > N**), as the compound logical expression **X > Y\*\*2 and COUNT > N** can never be true regardless of the values of **COUNT** and **N**. In normal circumstances, the fact that all the parts of a compound logical expression may not be evaluated each time will cause no difficulty.

It should be noted that compound logical expressions formed using the logical operator **and** may be written in an alternative way. Using **e** to represent an arithmetic expression and **R** to represent a relational operator, such compound logical expressions may be written as:

<u>Form</u>	<u>Example</u>
<b>e R e</b>	<b>1 &lt; X</b>
<b>e R e R e</b>	<b>1 &lt; X &lt; N</b>

e R e R e R e	$1 < X < N = \text{SUM}$
e R e R e R e R e	$1 < X < N = \text{SUM}$ is greater than 5

In each of these cases, all of the expressed logical relationships must be true in order for the compound expression to be true. For example, in the second illustration,  $X$  must be greater than 1 and less than  $N$ . Thus, the expression  $1 < X < N$  is equivalent to  $1 < X$  and  $X < N$ .

### 1.13 Repetition Using Control Phrases

Another important concept is that of repetition. Much of the power of the computer lies within its ability to repeat a sequence of instructions. A SIMSCRIPT II.5 statement can be executed more than once by prefixing it with a control phrase. An example of a control phrase prefixed to a statement is:

```
for I = 1 to 3 by 1
  print 1 line with I and I ** 2 thus
  THE SQUARE OF * IS *
```

The control phrase, **for I = 1 to 3 by 1**, controls the execution of the **print** statement to which it is prefixed, causing this statement to be repeated three times, first with  $I = 1$ , next with  $I = 2$ , then with  $I = 3$ . To demonstrate, the example uses the value of the variable  $I$  within the **print** statement, displaying the lines:

```
THE SQUARE OF 1 IS 1
THE SQUARE OF 2 IS 4
THE SQUARE OF 3 IS 9
```

The general form of a control phrase is:

```
for V = E1 to E2 by E3
```

where **E1**, **E2**, and **E3** are arithmetic expressions, and **V** is a variable. **E3** must be greater than zero, or an error results.

The first time the control phrase prefixed to a statement is executed the control phrase variable **V** is set equal to the value of **E1**. If the value of **E1** is not greater than that of **E2**, the controlled statement is executed. After execution, the value of **E3** is added to the control phrase variable, and if this new value is again less than **E2**, the controlled statement is repeated. This process continues, with the control phrase variable taking on successively larger values until it exceeds the value of **E2**.

If the phrase **by E3** is omitted from the control phrase, a value of 1.0 is assumed for **E3**. This form is convenient when the control phrase is used simply to count the number of times a statement is executed. A comma at the end of a control phrase is optional.

The following examples illustrate some control phrases and the successive values of their corresponding control phrase variable:

Examples ofControl PhrasesSuccessive Values of v`for I = 1 to 5,``1,2,3,4,5``for I = -5 to 5,``-5,-4,-3,-2,-1,0,1,2,3,4,5,``for I = 0.0 to 2.0 by 0.5``0.0,0.5,1.0,1.5,2.0``for I = 10 to N by M,`If **N** is less than 10, the controlled statement will not be executed.If **N** is at least equal to 10, the controlled statement will be executed with **I=10, 10+M, 10+2\*M, ..., 10+n\*M** until **I** exceeds **N**.

As stated earlier, the value of the expression **E3** is added to the control phrase variable each time the statement is repeated. A variant of the control phrase format causes the value of **E3** to be subtracted, and thus allows the control phrase variable to step backward:

`for V back from E1 to E2 by E3`

Everything applicable to the forward stepping control phrase applies to this phrase. The only difference is in the direction in which the control phrase variable changes value. Again, **E3** must be greater than zero.

Control phrases can be nested together, providing more complex control over the repetition of statements:

```
for NUM = 1 to 12,
  for MULT = 1 to 10,
    print 1 line with MULT, NUM, and MULT * NUM  thus
  ** TIMES ** IS **
```

This example computes and prints the multiplication tables for each of the numbers from 1 to 12 and for multipliers from 1 to 10. Both control variables are used within the controlled statement, producing the displayed result:

```
1 TIMES 1 IS 1
2 TIMES 1 IS 2
3 TIMES 1 IS 3
.
.
10 TIMES 1 IS 10
1 TIMES 2 IS 2
2 TIMES 2 IS 4
3 TIMES 2 IS 6
.
.
10 TIMES 12 IS 120
```

Used in this way, the first control phrase is said to be an outer phrase, and the second phrase an inner phrase. The controlled statement is repeated so that the inner phrase steps through the entire range of values for the inner control phrase variable **MULT** for each new value of the outer control phrase variable **NUM**.

An indefinite number of phrases can be nested together in this way. Each successive phrase is an outer phrase of the following phrase and an inner phrase of the preceding phrase. Control variables of outer phrases can be used in the expressions **E1**, **E2**, and **E3** of inner phrases, as their values are defined within these phrases. This usage will be explored in more detail in [Chapter 2](#).

### 1.14 Control Phrases Extended To Cover More Than One Statement

The concept of a control phrase can be expanded to permit the phrase to control an arbitrary number of statements. Statements to be controlled as a group are enclosed between the words **do** and **loop**. A control phrase controls grouped statements in exactly the same way it controls a single statement. As an example, consider a program, similar to the very first example, but extended to calculate the sum of any 10 numbers supplied as input data. The variable **TOTAL** can be assumed to be initialized to zero. However, it is explicitly assigned a zero value here to clarify the steps in this computation:

```

let TOTAL = 0
for COUNT = 1 to 10 by 1
do
    read NUMBER
    add NUMBER to TOTAL
loop
print 1 line with TOTAL as follows
THE SUM IS : ****
stop

```

The two grouped statements **read** a new value from the input data, assign its value to the variable **NUMBER**, and then add this value to **TOTAL**. This group executes 10 times, after which the incremented value of the control phrase variable, **COUNT**, halts the repetition. The flow of control passes to the following statement that displays the result. Note that in this example **COUNT** is not used anywhere within the controlled statements, but only to control the number of times the statements are repeated.

A **do** loop (as we shall call this expanded structure hereafter) can also be constructed from a backward iterating **for** phrase. Thus, we can write:

```

for I back from 10 to 1
do
.
.
loop

```

It is common to indent in some regular way the statements that are to be repeated within the control structure of a **do** loop (as for the statement groups in an **if** statement) drawing attention to the departure from normal sequential flow of control.

The following program uses a number of terms from an infinite series to estimate an approximate value for the irrational number PI. The value of PI, approximately 3.14159..., can be represented by the infinite series:

$$\text{PI}/4 = 1 - 1/3 + 1/5 - 1/7 + 1/9 \dots$$

The accuracy of the approximation is controlled by a variable read from input data. This data value sets a limiting value on the size of the divisor in the terms of the series. The summation is halted when the values of subsequent terms become too small to affect the desired accuracy of the result. For example:

```

read LIMIT
let VALUE = 0
let SIGN = +1
for DIVISOR = 1 to LIMIT by 2
do
    add SIGN/DIVISOR to VALUE
    let SIGN = -SIGN
loop
print 1 line with VALUE*4 as
    The Approximate Value of Pi is *.*****
stop

```

The variable **DIVISOR** takes the values **1,3,5,...** until it exceeds the limiting value. Note the use of the unary operators to control the sign of successive terms.

## 1.15 Logical Control Phrases

Normally, a **do** loop, controlled by a **for** statement, is executed over the entire range of values of the control variable generated. An alternative is to control the repetition of statements using some logical condition that may be evaluated during the execution of the controlled statements.

A logical control phrase contains a logical control operator and a logical expression and may be used to control a **do** loop. The logical control phrases are:

```

while logical expression
and
    until logical expression

```

The following example illustrates the use of a logical control phrase in a program:



```

while TOTAL.WEIGHT < LIMIT
do
    read PASSENGER.NO, FARE, and BAGGAGE.WEIGHT
    add BAGGAGE.WEIGHT to TOTAL.WEIGHT
    add FARE to TOTAL.REVENUE
loop

```

In this example, the value of the variable **TOTAL.WEIGHT** is incremented for each set of passenger data read. As long as **TOTAL.WEIGHT** does not equal or exceed the value **LIMIT**, the statements in the **do** loop are repeated. When the logical condition becomes untrue, that is, **TOTAL.WEIGHT** equals or exceeds **LIMIT**, the repetition terminates and control transfers to the statement following **loop**.

An **until** phrase is similar to a **while** phrase, but the terminating condition may be expressed as the logical complement of that used in the **while** phrase. The phrase:

```

until TOTAL.WEIGHT >= LIMIT

```

could be substituted for the **while** phrase in the above example with an identical effect. In the example in the previous section, the calculation of an approximate value for PI, the accuracy of the computation was controlled by an input data value limiting the magnitude of the divisor in included terms of the series. It might seem more straightforward to specify directly a lower bound on the size of the terms to be included in the summation. The following example uses an **until** phrase to control the **do** loop:

```

read LOW.BOUND
let VALUE = 0
let SIGN = +1
let TERM = 1
let DIVISOR = +1
until TERM less than LOW.BOUND
do
    add (TERM * SIGN) to VALUE
    let DIVISOR = DIVISOR + 2
    let SIGN = -SIGN
    let TERM = 1/DIVISOR
loop
print 1 line with VALUE*4 as
    The Approximate Value of Pi is *.*****
stop

```

Recalling that **for** control phrases may control the repetition of single statements as well as **do** loops, note that **while** and **until** statements may be used in the same way. Because a single statement may not, for the present, appear to offer much scope for altering the logical condition, the usefulness of this construction may not be immediately appreciated. It is mentioned here for completeness and will be expanded on in later chapters.

Because there is no automatic termination of a **do** loop controlled by a **while** or **until** phrase, as there is with a **for** phrase, care must be taken not to program a nonterminating loop, as in the following program segment:

```
while NUMBER.OF.SEATS is not zero
do
    read PASSENGER.NO, FARE, and BAGGAGE.WEIGHT
    add BAGGAGE.WEIGHT to TOTAL.WEIGHT
loop
```

This loop is not terminal, as the value of **NUMBER.OF.SEATS** is not affected by any statement within the **do** loop, and hence, if the logical expression is true when the loop is initiated, the condition will never become false. One means of avoiding this problem is to use a combination of a **for** control phrase modified by a logical control phrase. A **while** phrase, for example, may be used to allow a **for** phrase to direct the sequence of program control as long as a specified logical expression is true. The logical expression is reevaluated each time the **for** phrase changes the value of its control variable. Thus, the loop in the following example may be terminated either when all seats have been allocated or when the total baggage weight exceeds the allowable limit:

```
for COUNT = 1 to NUMBER.OF.SEATS,
    while TOTAL.WEIGHT not greater than LIMIT
do
    read PASSENGER.NO, FARE, and BAGGAGE.WEIGHT
    add BAGGAGE.WEIGHT to TOTAL.WEIGHT
loop
```

This example could have been written equally well using an **until** phrase:

```
for COUNT = 1 to NUMBER.OF.SEATS
    until TOTAL.WEIGHT > LIMIT
do
    .
    .
```

Two additional logical control phrases, with a rather different effect, may be used to modify statement repetition, as so far discussed. These are:

*with logical expression*

and

*unless logical expression*

Unlike **while** and **until** phrases that control the termination of repetition, a **with** phrase may be used to selectively control whether or not the statements are executed at each repetition. For example, a **with** phrase modifies the sequence of values that pass from a **for** phrase to the statements that it controls. The logical expression is tested each time a new value of the **for** phrase control variable is generated, and if the expression is false, then execution for this value of the control vari-

able is skipped. This operation effectively passes control around the statements for a selected control variable value or set of values. The phrase is useful for screening values before they pass into **for**-phrase-controlled statements. A store, for example, that does business every weekday, except Wednesday, might, in accounting for the weeks' sales, use the program statements:

```

for DAY = 1 to 6
  with DAY not equal 3
do
  read SALES.QUANTITY,...
.
.
loop

```

In this example, the **with** phrase causes the statements within the loop to be skipped for the value 3, which is generated as a value for **DAY** in the **for** sequence, and for which value the loop would normally be executed.

The word **when** can be used as a synonym for **with**. The words **unless** or **except when** can be used equivalently to show that the items passing the indicated test are screened from the loop, rather than accepted. Hence, the above example could be written:

```

for DAY = 1 to 6
  unless DAY = 3
do
.
.

```

**With**, **unless**, **while**, and **until** phrases can be attached to nested **for** statements. When this is done, each **with** or **unless** phrase applies to the **for** statement immediately preceding it, and each **while** or **until** phrase applies to all preceding **for** phrases. The example statement illustrates this:

```

for DELTA = 1 to 100 by 0.5,
  for Q = L1 to L2 by DELTA,
    while (DELTA/Q) less than LIMIT
      for V = -Q to Q by STEP,
        with V ne 0
do
  add ... to SUM
.
.
loop

```

The outer **for** phrases step the variables **DELTA** and **Q** through a sequence of values as long as the logical expression in the **while** phrase is true. A false condition ends the **for** phrase control by transferring to the next statement after the **loop** statement. Each time the variables are stepped and the logical expression is true, the inner **for** steps the variable **V** through a sequence of values. Only

those values in the sequence, however, for which the logical expression in the **with** phrase is true (i.e., all values but zero) are passed on to the statements in the **do** loop.

Sequences of **with**, **unless**, **while**, and **until** phrases can be attached to **for** phrases in any combination. More than one of each type of phrase is permitted. **while** and **until** control phrases may also be modified by **with** and **unless** phrases, and may be nested with other independent **while** and **until** phrases to control statement repetition. Again, the use of such combinations of control phrases will become more apparent in later examples.

### 1.16 Altering the Flow of Control Within a Loop

There are occasions when it may be necessary to exercise more explicit direction on the flow of control than may readily be specified using the control structures discussed so far. Consider the previous example:

```
for COUNT = 1 to NUMBER.OF.SEATS,
  while TOTAL.WEIGHT < LIMIT
do
  read PASSENGER.NO, FARE, and BAGGAGE.WEIGHT
  add BAGGAGE.WEIGHT to TOTAL.WEIGHT
loop
```

Examination of the statements within the loop shows that if the loop is terminated by the **while** phrase, the weight of the last passenger's baggage must have overflowed the **LIMIT** value. This may not be quite what was intended. The problem arises because the test of the condition is made only at the beginning of the loop, and all the statements in the loop are executed at each iteration. There are occasions when the test should logically be made within the loop. The following example uses a **leave** statement to transfer control out of the loop when the **LIMIT** is about to be exceeded:

```
for COUNT = 1 to NUMBER.OF.SEATS
do
  read PASSENGER.NO, FARE, and BAGGAGE.WEIGHT
  if TOTAL.WEIGHT + BAGGAGE.WEIGHT > LIMIT
    leave
  otherwise
    add BAGGAGE.WEIGHT to TOTAL.WEIGHT
loop
let LOAD.FACTOR = (COUNT-1)/NUMBER.OF.SEATS
.
.
```

The **leave** statement, which may only be used within a **do** loop, causes the flow of control to pass to the statement immediately following the **loop** statement that delimits the **do** loop. This addition to the construction of a **do** loop proves useful in those cases where the terminating condition is dependent on some of the actions performed within the loop. Note the use of **otherwise** in this example. This usage is discussed in the next paragraph. Note also that the value of the control phrase

variable **COUNT** remains set to the value assigned at the last evaluation of the control phrase, and may be used in subsequent computation.

The **cycle** statement bypasses any further statements within the **do** loop, beginning the evaluation of the control phrases determining the next repetition. Again, this statement can be useful where the tested condition is dependent on some evaluation made within the loop. Although one or more **if** statements could be used to achieve a similar effect, the **cycle** statement makes it clear that there is to be no further computation within this iteration of the loop.

```

for COUNT = 1 to NUMBER.OF.SEATS
do
    read PASSENGER.NO, FARE, and BAGGAGE.WEIGHT
    add BAGGAGE.WEIGHT to TOTAL.WEIGHT
    if FARE is not equal to FIRST.CLASS.FARE
        cycle
    otherwise
        read MENU.CHOICE, SEAT.SELECTION
        if MENU.CHOICE = VEGETARIAN
            .
            .
        always
loop

```

### 1.17 Changing the Flow of Control By Direct Order

The **leave** and **cycle** statements are two special cases of a generalized capability to directly control the order in which statements are executed. Any statement in a program may be prefixed with a label. A label is a name enclosed in single quotation marks (apostrophes). The flow of control may then be directed to continue from this statement by executing a **go to** statement referencing the label. The **go to** statement is of the form:

```
Go to 'label'
```

or

```
Go to label
```

The quotation marks are mandatory when the label is defined (i.e., when it appears in front of a referenced statement), but optional when the label is referenced in a **go to** statement. The word **to** is also optional. In Program 1-1, **go to** is used both to transfer out of the loop control if an error condition is detected, and to transfer to a group of common statements after performing selective processing for individual cases.

Note that the second group of statements and the terminating **always** is omitted when the first statement group of an **if** group ends with an unconditional transfer of control (i.e., **leave**, **cycle**, **go to**). In other words, an **else** or **otherwise** immediately preceded by **go to** is equivalent to an **always** statement.

### Program 1-1.

---

```

for COUNT = 1 to NUMBER.OF.SEATS
do
  read PASSENGER.NO, FARE, and BAGGAGE.WEIGHT
  let CHECK.SUM = ...
  if CHECK.SUM <> CHECK.VALUE
    go to 'CHECK.ERROR'
  otherwise
    if FARE = FIRST.CLASS.FARE
      add 1 to CHAMPAGNE.COUNT
      go to 'TOTALS'
    otherwise
      if FARE = EXECUTIVE.CLASS.FARE
        .
        .
        go to 'TOTALS'
      otherwise
        if FARE = ECONOMY.CLASS.FARE
          .
          .
          go to 'TOTALS'
        otherwise
          if FARE = STANDBY.FARE
            .
            .
            go to 'TOTALS'
          otherwise
'TOTALS'
      add BAGGAGE.WEIGHT to TOTAL.WEIGHT
      add 1 to MEALS.REQUIRED
    loop
    let LOAD.FACTOR = (COUNT-1)/NUMBER.OF.SEATS
    .
    .
'CHECK.ERROR'

  print 1 line with PASSENGER.NO  thus
  ERROR IN TICKET NO.  *****

```

---

The **otherwise** (or the synonym **else**) in this example could be replaced by **always**, **endif** or **regardless** with exactly the same meaning. This structure has been retained to provide compatibility with earlier versions of the SIMSCRIPT language. To clearly identify this anomaly in control structure, it is suggested that the **otherwise** synonym for **else** be reserved for this usage.

The **go to** statement provides great flexibility in directing the flow of control. However, it can detract from the clarity of the logic and the readability of the program. Unwisely used, it can multiply the possible paths through the program, rendering comprehension and testing of the logic unnecessarily difficult. Structured programming principles suggest that the logic of a program should be expressed in restricted control flow structures. In particular, the concepts of conditional action and iteration should be represented using the **if** and **do** loop structures.

### 1.18 The Logical End of a Program

The **stop** statement is used to terminate a program. Because there may be more than one **stop** statement in a program, and control flow may be diverted around any **stop** statement, it does not always appear as the last statement of a program listing. The following program segment illustrates the use of the **stop** statement in conjunction with an **if** statement:

```
if X is zero
    print 1 line as follows
    ZERO IS AN ILLEGAL VALUE FOR X
    stop
otherwise
    let Z = Y/X
```

**Note:** The **stop** statement is considered to be an unconditional transfer of control.

### 1.19 The Physical End of a Program

The last statement in every SIMSCRIPT II.5 program must be **end**. It signals that the entire source program has been read. The example programs at the end of this chapter illustrate the use of the **end** statement.

### 1.20 A Note on SIMSCRIPT II.5 Program Form

SIMSCRIPT II.5 programs are composed of sequences of conventionally arranged symbols — some are standardized key words such as **let** and **read** and others are programmer-constructed variable names and numeric constants. The basic symbolic units recognized by the SIMSCRIPT II.5 compiler in scanning program statements are names and numbers, the special characters **+**, **-**, **'**, **\***, **/**, **\*\***, **(**, **)**, **"**, **>**, **<**, **|**, **\$**, **=**, the punctuation marks period, comma, and blank, and other special characters.

Commas are required in some places in SIMSCRIPT II.5 statements and are optional in others. In particular, they are required to separate items in a list of any sort. To aid readability, they may be used optionally after the logical condition of an **if** statement or the end of a control phrase. Whenever a comma may or must be used in a particular statement, its use is made clear in the section of the text that defines the statement.

Because SIMSCRIPT II.5 statements are not written in any specific format, but spaced across and between lines as a programmer wishes, blanks are needed to separate words (names, numbers, and

key words) in statements. Two adjacent statement words must always be separated by at least one blank unless one of them is a special character. Thus:

```
let X = Y
```

can be written as:

```
let X=Y
```

but not:

```
letX=Y,
```

and:

```
if (SIGN + 5) is greater than DELTA
```

can be written as:

```
if(SIGN+5) is greater than DELTA
```

but not as:

```
if(SIGN+5) isgreaterthanDELTA.
```

Merely looking at a statement usually makes it clear whether a blank is needed or not. Because multiple blanks are treated as single blanks, blank characters can be freely used to improve the readability of statements, as many of the illustrations in this book demonstrate.

Statements can be typed as desired in a program, with one slight restriction. A statement can be written on more than one input line, or several statements can be written on the same line, but statement words (names, numbers, and key words) cannot be split between lines. Consequently, names and constants are restricted to the length of one record. (Remember that the exponentiation symbol **\*\*** is a single unit and cannot be split.) Statement labels, where used, must precede the statement but need not appear on the same line as the statement. More than one label may be prefixed to a single statement.

The logical structure of a program should be reflected in the physical layout. The use of indenting to draw attention to a departure from sequential execution of statements is one example. The use of appropriate control structures, rather than ad hoc direction of control flow through **go to**, can contribute greatly to this goal.

### 1.21 Clarifying Comments In a Program

Whenever it appears that a clarifying remark would be helpful to the reader, a comment should be used. A comment is delimited on the left by two single apostrophes ( ' ' ). Comments can appear anywhere in a program except within a word. They may appear on the same line as program statements or on separate lines. Comments serve only as documentation, but they should be used wher-



ever the logical intent of a program is not immediately evident from its SIMSCRIPT II.5 instruction sequences. The use of comments will be illustrated in many of the example programs below.

## 1.22 Some Sample SIMSCRIPT II.5 Level 1 Programs

The following programs illustrate the SIMSCRIPT II.5 concepts and statements presented in this chapter. The programs are printed as they might appear before being submitted for compilation. The flexibility of SIMSCRIPT II.5 makes many program statement formats possible. Those used here are examples only.

### 1.22.1 Roots of a Quadratic Expression

The following example, demonstrating the use of nested **if** statements, calculates the roots of a quadratic equation, which may be expressed in the general form:

$$AX^2 + BX + C = 0$$

First, the coefficients, **A**, **B**, and **C**, are read from input data. They are printed so that they may be checked for any input errors. The coefficients are then tested for the trivial zero, constant, or linear cases. Otherwise, the roots, alpha and beta, may be calculated from the familiar formulae:

$$\text{alpha} = \frac{-B + (B^2 - 4AC)^{(1/2)}}{2A}$$

$$\text{beta} = \frac{-B - (B^2 - 4AC)^{(1/2)}}{2A}$$

Before obtaining the square root, the sign of the sub-expression **B<sup>2</sup> - 4AC** is evaluated. If this value is less than zero, the roots have complex values; otherwise, real values. Notice how the **print** statement, as used in the example, can be used to print both the program title and the labeled variable names.

**Program 1-2.**


---

```

'' Program To Compute The Roots of a Quadratic Equation
'' of the Form  AX**2 + BX + C = 0
    read A,B,C
    print 2 lines with A,B,C as follows
    ROOTS OF THE QUADRATIC EQUATION WITH COEFFICIENTS:
        A=***.**      B=***.**      C=***.**
    if A eq 0
    if B eq 0
        if C eq 0
            print 1 line as follows
            TRIVIAL CASE, COEFFICIENTS ALL ZERO
        else
            print 1 line with C as follows
            EQUATION STATES ***.** = 0
            always
        else
            print 1 line with -C/B as follows
            LINEAR, ONE ROOT  ALPHA = ***.**
            always
    else
        let X = B**2 - 4*A*C
        if X ls 0
            let IMAG = ( (-X)**0.5 )/(2*A)
            let REAL = -B/(2*A)
            print 2 lines with REAL,IMAG as follows
            EQUATION HAS COMPLEX ROOTS
            REAL PART = ***.**  IMAGINARY PART = ***.**
        else
            let X = X ** 0.5
            let ALPHA = (-B+X)/(2*A)
            let BETA = (-B-X)/(2*A)
    print 2 lines with ALPHA,BETA as follows
    EQUATION HAS REAL ROOTS
    ALPHA = ***.**      BETA = ***.**
    always
    always
    stop
end

```

---

**1.22.2 Finding the Area of a Triangle**

This program demonstrates nested **if** statements, using more complex logical expressions. The program calculates the area and perimeter of a triangle with the lengths of the sides **A**, **B**, and **C** as input data. The first **if** statement verifies that none of the sides is of zero or negative length. The

second **if** statement checks that the values read will form a triangle, based on the condition that the sum of the lengths of any two sides is greater than the length of the remaining side. All three conditions of the **if** statement must prove false before control is passed to the group of statements that calculates the area and perimeter.

### Program 1-3.

---

```

''Program to Compute the Area and Perimeter of a Triangle
''Given the Lengths of the Sides
read A,B,C
print 2 lines with A,B,C as follows
    CALCULATE AREA OF A TRIANGLE WITH FOLLOWING SIDES:
    A=**.**    B=**.**    C=**.**
if A <= 0 or B <= 0 or C <= 0
    print 1 line as follows
        TRIANGLE CONTAINS SIDE OF ZERO OR NEGATIVE LENGTH.
else
    if A+B <= C or B+C <= A or C+A <= B
        print 1 line thus
        SIDES DO NOT FORM A TRIANGLE.
    else
        let S = (A+B+C)/2
        let AREA = (S*(S-A)*(S-B)*(S-C))**0.5
        print 1 line with AREA, 2*S as follows
            THIS AREA IS **.** PERIMETER = **.**
    always
always
end

```

---

### 1.22.3 Finding the Maximum and Minimum of a Set of Numbers

This program demonstrates the simple use of a **do** loop to repeat the same sequence of statements with different data values. The program reads **N** input numbers and records the maximum and minimum values encountered. When all the numbers have been processed, the average value and the maximum and minimum values are printed.

Note that the first value is read outside the control of the **do** loop and used to initialize the variables **MAX**, **MIN**, and **SUM**. Subsequent values are compared with the values of **MAX** and **MIN**, replacing either where appropriate.

**Program 1-4.**


---

```

''Program to Compute the Maximum, Minimum and Average
''  of a Set of Numbers
read NUMBER          '' NUMBER OF DATA OBSERVATIONS
if NUMBER < 1
    go to FINISH
otherwise
    read VALUE
    let MAX = VALUE
    let MIN = VALUE
    let SUM = VALUE
    for COUNT = 2 to NUMBER by 1
    do
        read VALUE          '' DATA VALUE
        add VALUE to SUM
        if VALUE > MAX
            let MAX = VALUE
        always
        if VALUE < MIN
            let MIN = VALUE
        always
    loop
print 3 lines with SUM / NUMBER, MAX, MIN thus
    THE AVERAGE VALUE IS ***.****
    THE MAXIMUM VALUE IS ***.****
    THE MINIMUM VALUE IS ***.****
'FINISH'
stop
end

```

---

**1.22.4 Computing Square Roots**

The square root of a number is required in many calculations. In fact, in two of the preceding examples, square roots were obtained using exponentiation. The following is an implementation of Newton's method to approximate square roots.

The example demonstrates the use of a logical control phrase to control an iterative computation. The logical condition specifies a relative precision of the estimated square root as a stopping criterion. Note that the first statement within the loop calculates a new estimate for the square root, using the last estimated value. This technique is fundamental to such iterative procedures. Note also the explanatory comment appearing beside the statement to invert the sign of **DELTA**, should it be negative.

**Program 1-5.**


---

```

''Program to Calculate Approximate Square Roots
read NUMBER
if NUMBER is not positive
    print 1 line thus
    CANNOT EVALUATE SQUARE ROOT: VALUE NOT POSITIVE
else
    let SQRT = NUMBER/2.0
    let DELTA = SQRT
    until DELTA < (0.00001 * SQRT)
    do
        let SQRT = (SQRT + NUMBER/SQRT)/2.0
        let DELTA = NUMBER/SQRT - SQRT
        if DELTA is not positive
            let DELTA = -DELTA  '' USE THE ABSOLUTE VALUE
        always
    loop
    print 1 line with NUMBER, SQRT thus
    THE SQUARE ROOT OF *****.***** IS *****.*****
always
stop
end

```

---



## 2. Programming Language Concepts

---

### 2.1 Variable and Label Names Revisited

Chapter 1 defined variable and label names separately. A variable name is any combination of letters and digits that contains at least one letter. A label is any combination of letters and digits without the "at least one letter" constraint. These rules can be expanded easily to permit more readable programs by incorporating periods into the definition of names and labels.

Let a name be any combination of letters, digits, and periods that contains at least one letter or two or more nonterminal periods. A constant is any combination of digits, possibly containing one period. A variable name must look like a name and a label can look like a name or a constant. Thus, variables can be distinguished from numbers while maintaining the widest latitude in name formation. Some examples of variable and label names are shown in table 2-1.

**Table 2-1. Variable and Label Names**

<u>Variable Names</u>	<u>Label Names</u>
PART . NUMBER	LABEL
NUMBER . OF . PARTS	SECTION . 1
TOTAL	PART . 4
. PAGE	ERROR

As mentioned previously, it must be stressed that terminal periods cannot be used in distinguishing names. The names **x**, **x . . .**, and **x . . .** all represent the same variable value; the labels **'5'** and **'5.'** are identical.

Although SIMSCRIPT II.5 does not prohibit the use of any particular words (the one exception is the word **and**, which should not be used as a name) or names, there are a number of special names that are recognized in certain contexts. Guard against using any of these names incorrectly by remembering the special naming conventions used for them. Some of these names are listed in [Appendix B](#), under various headings. Each of these names either begins with a letter followed by a period or ends with a period followed by a letter, so it is good practice to not name your own variables the same way!

### 2.2 Variable Modes

In the previous discussion, it was assumed that variables in SIMSCRIPT II.5 take on numeric values. No explicit restrictions have been placed on the magnitude or precision of the numbers represented by variable names. Complete freedom from concern over the expression of numeric

quantities is an attractive idea. However, both the range and number of real numbers are infinite, while a computer has a finite range of representations.

The enumeration of items, or iterations, requires the exact representation of a sizable range of integer numbers. Many other calculations require the representation of a potentially greater range in magnitude of the real numbers but are necessarily limited in accuracy.

Most computer systems, therefore, provide two internal representations for numeric data — one trading some exactness of representation for increased range. These representations may vary between different computer systems. The precise limitations pertaining to any SIMSCRIPT II.5 implementation may be found in the appropriate user's guide. A programming language is used to describe both the actions and the data on which these actions are to be performed. In this chapter, some of the ways in which data are described are discussed.

A variable definition statement serves to declare the properties of a variable. This information is used to determine the way in which the variable may be manipulated.

## 2.2.1 REAL and INTEGER Variables

SIMSCRIPT II.5 numeric variables may be declared to be **integer** or **real**. Variables declared as **integer** represent only whole numbers. Variables declared as **real** represent numbers that can have fractional values. Note that a whole number, lying within an established range of the integer values, may be represented either by an **integer** or **real** variable. It is the possibility of a fractional value, and not any particular value, that makes a variable require a **real** definition. The numbers 56, -6745, 91, -1, and 0 are **integer**-valued. The numbers 56.0, 35.7846, 0.999876, -27.45, and 0.0. are **real**-valued.

Every SIMSCRIPT II.5 program has a **preamble** that contains variable definition information. In some cases, as in the previous examples, this **preamble** is implied but need not be written as all variables are treated as **real**. Whenever a variable has a property that differs from one that SIMSCRIPT II.5 assumes, a variable definition statement must be used. Programs containing an explicit preamble begin with the one-word statement **preamble**. This section, containing variable definition statements, is separated from succeeding program action statements by the word **end**.

As stated, the mode of a numeric variable is assumed **real** unless otherwise specified. The "normal form" of SIMSCRIPT II.5 variables is real numbers. The assumed **real** condition can be changed by using the statement:

```
mode is integer
```

This statement resets the compiler's "background conditions" so that all following program variables are assumed **integer** unless otherwise specified. Mode is but one of several properties that can be used to describe variables. Hence, the general form of the **normally** statement is:

```
normally, specification phrase list
```



Specification phrases may appear in the list in any order, separated, as usual, by commas or **and**. The comma after the word **normally** is optional. The equals symbol (=) may replace the word **is**. As additional specification phrases are added in later sections, phrase choices will be increased but these rules will not change.

Another possibility is to force explicit definition of all variables by use of the form:

```
normally, mode is undefined
```

This will produce a diagnostic for every undefined variable. This form is strongly recommended in order to guard against inadvertent background definition of misspelled variables.

Individual variables that differ from the implied or **normally** defined mode can have their mode specified in a **define** statement. This statement lists one or more variable names and defines their common mode. The statement:

```
define X, Y, Z as integer variables
```

illustrates the way in which the **define** statement is used to declare that the variables **x**, **y**, **z** represent only **integer** values. If the background conditions were declared to be **integer**, a similar **define** statement using the word **real** might be used to define some variables as **real**.

The **define** statement has a number of alternative forms. The only words that must appear are **define**, the variable names being defined, **as**, and the word **variable** or **variables**. The words **a**, **an**, **integer**, and **real** are included when needed. Some examples of the **define** statement are:

```
define X as a real variable
define X and Y as integer variables
define X, Y, Z as variables
define X as a variable
```

The description of the **define** statement, like the **normally** statement, will be expanded in later paragraphs to include more than variable mode definition.

Some computer systems provide an internal numeric representation of **real** numbers with an increased precision, usually achieved by doubling the size of the internal binary representation. SIMSCRIPT II.5 allows variables to be declared with this representation, by the use of the variable mode **double**. On these systems, the normal background condition is **double** to allow the maximum precision for decimal values. The appropriate SIMSCRIPT II.5 user's manual should be consulted to determine whether this variable mode is implemented. In general, on those systems that do not support this mode, **double** is interpreted as **real**.

Throughout this book, the behavior ascribed to **real** variables may be assumed to extend to **double** variables. Examples of declarations are:

```
define AMOUNT, INTEREST as double variables
```

and

normally, mode is double

## 2.3 Expression Modes

Although statements that combine **integer** and **real** variables are allowed, a programmer should be aware of the way in which computations are carried out whenever using "mixed mode" expressions. When *A* and *B* represent two variables, constants, or sub-expressions, then:

1. Arithmetic expressions of the form *A op B*, where *A* and *B* represent variables of specified mode, or constants of that mode, and *op* is any of the arithmetic operations  $+$ ,  $-$ , and  $*$ , are **integer** if both *A* and *B* are **integer**, and **real** if either *A* or *B* is **real**.
2. Expressions of the form *A/B* are always **real** (Two integer expressions can be divided to yield a truncated **integer** result by a library function called **div.f**. Library functions are described in paragraph 2.15).
3. Expressions of the form *A\*\*B* are always **real**.

Compound expressions are evaluated from left to right as a sequence of simple expressions that are evaluated according to the above rules. In the following examples, if *A*, *B*, and *C* are **integer**, then:

```
A/B + C      is real
A + B + C    is integer
A**B + C     is real
```

When an expression appears on the right-hand side of a **let** statement or in an **add** or **subtract** statement, and its mode differs from the mode of the variable on the left-hand side, the expression is converted to the mode of the variable before the value of the variable is changed. When the arithmetic expression constituents of logical expressions differ in mode, all **integer** expressions are converted to **real** before evaluating the logical expression as true or false.

Conversions from **integer** to **real** are straightforward. An **integer** to **real** conversion takes the whole number that is the value of an **integer** variable and converts it to a **real** number with the same value; 25 becomes 25.0, -11 becomes -11.0, and so forth.

**Real** to **integer** conversions are more complex. Obviously, any fractional part cannot be represented by the **integer**. **Real** values are rounded to whole numbers by adding +0.5 to the variable if its value is positive or -0.5 if it is negative, and truncating the result. If *x* is **integer** and *e* is some **real**-valued expression (formed according to the above rules), then:

```
let x = e sets x = 0 if e = 0.2 since 0.2 + 0.5 = 0.7 → 0
let x = e sets x = 1 if e = 1.4999 since 1.4999 + 0.5 = 1.9999 → 1
let x = e sets x = 2 if e = 1.50000 since 1.50000 + 0.5 = 2.0000 → 2
```

Where **double** variables are supported, conversions between **double** and **integer** modes follow the same procedures as conversions between **integer** and **real**. Hence, expressions mixing **integer** and **double** arithmetic operations follow the procedure outlined above for mixed **integer** and **real** expressions.

Expressions containing mixed **double** and **real** variables are evaluated to yield a **double** precision result, which may be automatically converted to the **real** mode, if necessary. When required by context, as in mixed **real** and **double** mode expressions, **real** values are automatically converted to **double** before evaluation.

If, in the following examples, **R** has been defined as a **real** variable and **D** as a **double** variable, then in executing the statement:

```
let D = D + R
```

**R** is converted to **double** before the addition, which produces a **double** precision result, while:

```
let R = R * D
```

converts **R** to **double** before the multiplication, but the result is truncated to **real** before reassignment.

As may be seen, the provision of different modes of variable representation brings with it some additional complexity. A variable defined with a certain mode can only be used in ways consistent with its definition. In some cases, automatic conversion between modes is performed as indicated above, although information may be lost as in the case of **real** to **integer** conversion, where the fractional value may no longer be represented. Be aware of such implied conversions and their effect on program behavior.

One particular potential source of error, however, is the attempted assignment of variable values read from input data to variables defined with conflicting internal representation. Specifically, a data field containing a noninteger format number should not be assigned to an **integer** variable in a **read** statement. This will result in loss of information and is therefore treated as an error condition.

Table 2-2 specifies the actions taken when different combinations of data and variable definitions occur.

**Table 2-2. Real-Integer Input Data Conversions**

<u>Input Data Format</u>	<u>Variable Defined as</u>	<u>Action</u>
<b>integer</b>	<b>integer</b>	Data value stored in variable
<b>integer</b>	<b>real</b>	Data value converted to decimal representation and then stored in variable; e.g., 55 stored as 55.0
<b>real</b>	<b>real</b>	Data value stored in variable
<b>real</b>	<b>integer</b>	Program terminates with error message; not possible to store fractional value in integer representation.

## 2.4 System-Defined Constants

Scientific and engineering calculations often involve standard scientific constants. Mathematical computations frequently require values of numeric constants. Numbers such as  $\text{PI} = 3.14159\dots$ , and  $e = 2.718\dots$  are examples of well-known and often-used constants. SIMSCRIPT II.5 maintains a library of standard values. When the name of a library constant is used in a SIMSCRIPT II.5 program, the correct numeric value of the constant is inserted in its place. These constants may be used wherever a numeric literal constant could be used.

Library constants have names that look like variable names except that they end in the characters **.c** (a naming convention used by the SIMSCRIPT II.5 system). The library constants and their values are listed in table 2-3.

Table 2-3. System-Defined Constants

<u>Name</u>	<u>Symbol</u>	Standard <u>Value</u>	<u>Units</u>	<u>Mode</u>
<b>pi.c</b>	<b>p</b>	3.141159265	--	Real*
<b>Exp.c</b>	<b>e</b>	2.718281828	--	Real*
<b>inf.c</b>	$\infty$	Largest value computer can store	--	Integer
<b>Rinf.c</b>	$\infty$	Largest value computer can store	--	Real*
<b>Radian.c</b>	-	57.29577	Degrees/radian	Real*

\* On systems that support additional precision, these constants are of **double** mode.

2.5 Subscripted Variables

Variables as described above may represent single, numeric data items in SIMSCRIPT II.5. A feature of many programming languages is the facility to represent and manipulate data in a way that reflects the natural structure of the data. Data occurring in the form of lists or tables, for example, have a regular structure. SIMSCRIPT II.5 provides a structure by which a number of similar data items, the array elements, may be collectively referenced by a single name, while each individual element may be referenced by subscripting the array name with an index value.

A simply ordered collection of data items, such as a list (figure 2-1), is represented by a one-dimensional array. The elements of this array can be referenced by an identifying name, **LIST**, for example, and an index number, called the array subscript, which can assume integer values from 1 up to the total number of elements in the list. The array name is used to identify the collection of elements. The subscript, enclosed in parentheses after the array name, is used to denote particular elements. Thus, the name of the variable that is the first element in the array **LIST** is **LIST(1)**, the fifth element is called **LIST(5)**, and the **i<sup>th</sup>** element is **LIST(i)**. Figure 2-2 shows the list of figure 2-1 with the individual element names inserted.



Figure 2-1. A List Structure: One-dimensional Array

LIST(1)	LIST(2)	LIST(3)	LIST(4)	LIST(5)	LIST(6)	LIST(7)	LIST(8)	LIST(9)
---------	---------	---------	---------	---------	---------	---------	---------	---------

**Figure 2-2. Elements of a One-dimensional Array Called LIST**

To demonstrate the use of such a structure, consider the problem of determining the date as the day of the month, given the day number within the year. Clearly, the number of days within each month are 12 items of data that might be used in some orderly, repetitive computation. These values could be represented as the elements of a one-dimensional **integer** array, **DAYS**, indexed by month. Thus, **DAYS(1)** would have a value of 31, **DAYS(2)** a value of 28 (ignoring the complication of leap years for the present), and so forth. The program segment:

```

read DAYNUM
for MONTH = 1 to 12 by 1
    while DAYNUM gt DAYS(MONTH)
do
    subtract DAYS(MONTH) from DAYNUM
loop
print 1 line with DAYNUM, MONTH thus...
The **th day of the **th month

```

successively subtracts the values of **DAYS(1)**, **DAYS(2)**, and so on from the input value, **DAYNUM**, until it comes within the range of the number of days in some month. In this case, the use of the array provides representation of the data in a way that matches the repetitive processing capability of the **do... loop**.

The array elements need not, of course, be accessed in order. The array structure provides immediate access to any individual element, selected by subscript. Consider a computer program to maintain an inventory of goods. Each item in the inventory is allocated a code number. An **integer** array, **STOCK**, holds in each element, indexed by the item code, account of the number of such items currently in stock. This information might be updated, during the processing of an order, by the program statements:

```

read ITEM.CODE and QUANTITY
subtract QUANTITY from STOCK(ITEM.CODE)

```

Although all elements of a one-dimensional array must be similar, these elements may themselves be arrays. A table of data items (figure 2-3), for example, may be represented by a one-dimensional array where each element represents a row of the table as a one-dimensional array of data items ordered by column number. Such a structure is termed a two-dimensional array.

	Column 1	Column 2	Column 3	Column 4	Column 5
Row 1					
Row 2					
Row 3					

**Figure 2-3. A Table Structure: A Two-dimensional Array**

Variables with a two-dimensional array structure are referenced by an identifier and a pair of subscripts. The first subscript identifies a selected one-dimensional array. The second identifies a particular element within this array. Figure 2-4 shows the two-dimensional array of figure 2-3, here called **TABLE**, with the individual element names inserted. Note how the subscript values indicate each element's position in the structure of the table. The identifier (as before) is the name of the complete array structure. The subscripts are enclosed in parentheses and separated by a comma. Each subscript is associated with an element location in one coordinate dimension. In figure 2-4, the first subscript is used as the element location in the row direction, and the second as the element location in the column direction.

This data structuring is not limited to two dimensions. In general, a data collection that has  $n$  reference indices can be represented as an  $n$ -dimensional array structure. A three-dimensional array called **CUBE** might have elements **CUBE(I,J,K)**. A seven-dimensional array called **SEVEN.DIM** might have elements **SEVEN.DIM(A,B,C,D,E,F,G)**.

Subscripted variables (the elements of arrays) share the same range of possible modes as unsubscripted variables. All elements of any one array, however, must be of the same mode. If their mode differs from that of the background conditions set within a program, it can be declared in a **define** statement in the same way as with unsubscripted variables. For instance, if the assumed mode of all as yet undeclared variables has been set to **real**, write the statement:

```
define LIST and TABLE as integer arrays
```

	Column 1	Column 2	Column 3	Column 4	Column 5
Row 1	<b>TABLE(1,1)</b>	<b>TABLE(1,2)</b>	<b>TABLE(1,3)</b>	<b>TABLE(1,4)</b>	<b>TABLE(1,5)</b>
Row 2	<b>TABLE(2,1)</b>	<b>TABLE(2,2)</b>	<b>TABLE(2,3)</b>	<b>TABLE(2,4)</b>	<b>TABLE(2,5)</b>
Row 3	<b>TABLE(3,1)</b>	<b>TABLE(3,2)</b>	<b>TABLE(3,3)</b>	<b>TABLE(3,4)</b>	<b>TABLE(3,5)</b>

**Figure 2-4. Elements of a Two-dimensional Array Called TABLE**

The dimensionality of an array, whether it has 0, 1, 2, 3 or more subscripts, should also be declared in the preamble. A dimensionality specification phrase can be included in either **normally** or

**define** statements, depending on whether it is to apply as a background condition or to specifically named arrays. The phrase is written somewhat differently in each case.

An n-dimensional array background condition may be declared with a **normally** statement using the phrase:

```
dimension is n
```

as in the statements:

```
normally dimension is 1
normally, mode is integer, dimension is 2
```

In a **define** statement, a dimensionality specification can be made for a list of subscripted variables with the dimensionality phrase **n-dimensional** as in the statements:

```
define LIST as an integer, 1-dimensional array
define LIST and VECTOR as real, 1-dimensional arrays
define CUBE as a 3-dimensional, integer array
```

In general, if a majority of program variables share some definable property, this may be declared as a background condition, using a **normally** statement. **Define** statements may then be used to override this specification for specific variables, as in the example:

```
preamble
  normally, mode is integer, dimension is 2
  define X, Y, Z and Q as real variables
  define VECTOR as a 1-dimensional array
end
```

A variable must not, however, be used in more than one **define** statement. It is permissible to write:

```
normally, mode is real, dimension is 1
define X as an integer, 0-dimensional variable
```

It is not permissible to write:

```
normally, mode is real, dimension is 1
define X as an integer variable
.
.
define X as a 0-dimensional variable
```

Each unsubscripted (zero-dimensional) variable requires a location in computer memory in which to record its current value at any time. Similarly, each element of each array requires a distinct memory location where its value can be stored. A one-dimensional array with 10 elements uses 10 such memory locations, a two-dimensional array with 3 rows and 5 columns uses  $(3*5) = 15$  memory locations, and so forth.



The allocation of space within computer memory to unsubscripted variables is done automatically. This automatic allocation cannot be made for subscripted variables. An array may have any number of elements, and space cannot be allocated until this number is known.

The **reserve** statement is used to explicitly allocate computer memory space for arrays. The dimensionality of each array is indicated by asterisks in subscript positions. Subscript size expressions declare the largest value that each subscript position index can assume. The maximum subscript values may also be referred to as the array dimensions or bounds. The product of these expressions is used to determine the total space requirement of the array. Thus, the statement:

```
reserve LIST(*) as 9
```

allocates memory space for the 9 elements, **LIST(1)**, **LIST(2)**, ..., **LIST(9)** of the one-dimensional array called **LIST**, and the statement:

```
reserve TABLE(*,*) as 3 by 5
```

allocates space for the elements of the two-dimensional array **TABLE**.

A **reserve** statement is an executable statement, rather than a declaration, and thus can not appear in the **preamble** of a SIMSCRIPT II.5 program. Until a **reserve** statement for an array has been executed, storage is not allocated for that array, and its element values are not defined. Each subscripted variable must, therefore, be reserved before it can be used. Any attempt to reference a subscripted variable before space for it has been allocated will cause an error in program execution. All the element values of an array are initialized to zero at the time memory space is allocated.

If a **reserve** statement specifying an array to which space is already allocated is encountered, no action is taken and no further space is allocated. Even if the second **reserve** statement specifies a different size, the amount of space allocated is as given by the first **reserve**.

More than one array allocation may be made by a single **reserve** statement. The effect of the two statements shown could be achieved by executing the statement:

```
reserve LIST(*) as 9, TABLE(*,*) as 3 by 5
```

If an array name appears in a **reserve** statement without asterisks to indicate its subscript positions, the dimensionality previously declared in a **define** statement is understood. If no dimensionality declaration has been made, the number of subscript size expressions is used to determine the dimensionality. Thus, if an array has been declared as two-dimensional by the statement:

```
define MATRIX as a 2-dimensional, integer array
```

or, if no dimensionality declaration has been made for the array, the statement:

```
reserve MATRIX as 5 by 7
```

is understood to mean:

```
reserve MATRIX(*,*) as 5 by 7
```

The dimensionality of an array, then, is frozen either by explicit declaration in a **define** statement, or when it is first referenced in an executable statement — which, of course, should be a **reserve** statement. Although the dimensionality of an array may be apparent from the context, the explicit declaration is recommended as an aid to program documentation. Once the array dimensionality has been frozen, the array must be referenced consistently. Any inconsistent reference is detected as an error during program compilation.

Subscript size expressions may be arithmetic expressions containing variables, including other subscripted variables. If such expressions are **real**, they are rounded to **integer** before they are used as array dimension specifiers. Thus, the statement:

```
reserve LIST(*) as N, TABLE (*,*) as N by 2*M
```

allocates space for the arrays **LIST** and **TABLE** where the space requirement is dependent on the values of the variables **N** and **M**.

A subscript size expression should not evaluate to zero or a negative value. An attempt to reserve space using a zero- or negative-valued size expression will cause a program to terminate with an error message. If any subscript expression in a **reserve** statement evaluates to 1, there is only one element allocated to that dimension of the array. The statement:

```
reserve X(*) as 1, Y(*,*) as 1 by 3
```

allocates space to an array **X** with one element, **X(1)**, and a two-dimensional array **Y** with three elements, **Y(1,1)**, **Y(1,2)**, and **Y(1,3)**. For all practical purposes, these one- and two-dimensional arrays are equivalent to the unsubscripted variable **X** and a one-dimensional array **Y**.

When two or more arrays are to be allocated with the same dimensions, they may be combined in a list of array names. Thus, the following is acceptable:

```
reserve A (*,*), B(*,*), C(*,*) as 5 by 10
```

Any **reserve** statement can contain a sublist of this form among its list of arrays, as in:

```
reserve VECTOR(*) as 5,
      A(*), B(*) and C(*) as 15,
      LIST1(*) and LIST2(*) as N+M,
      TABLE(*,*) as 3 by Y,
      .
      .
```

## 2.6 Reading Subscripted Variables

Subscripted variable values can be assigned from input data by including each element of an array in the variable name list of a **read** statement. In the following examples, let **LIST** be a singly subscripted variable allocated by the statement **reserve LIST(\*) as 10**.

Individual elements of the array are read by listing their names (the array identifier followed by the appropriate subscript expression(s) enclosed in parentheses) in the list of a **read** statement. Values of **LIST(1)**, **LIST(5)**, and **LIST(9)** are read by the statement:

```
read LIST(1), LIST(5), LIST(9)
```

A variable name list can contain array elements whose subscript designators are expressions, such as **LIST(N\*M+2/J)** or **LIST(I)**, as long as the variables appearing in these expressions have had values assigned to them. Note that, as the variables named in a **read** statement are processed from left to right, variables to be used as subscripts may be assigned if they appear in a **read** statement before their subsequent use in the same statement as subscripts, as in:

```
read N, M, LIST(N), LIST(LIST(N) + M)
```

This example shows that both unsubscripted and subscripted variables can appear in the same **read** statement list.

This procedure is obviously tedious for large arrays, and so provision is also made for reading all the values of a subscripted array, in order, by including the unsubscripted array name in the list. **Read LIST** reads the 10 elements of **LIST**, as defined by the **reserve** statement. Numbers are read and assigned to the elements of **LIST** in increasing subscript order: the first data item is assigned to **LIST(1)**, the next to **LIST(2)**, and so on. If **LIST** were a multidimensional array, the data would be assigned to successive elements whose subscripts change in increasing order, with the last subscript position varying most rapidly. A two-dimensional array is read in row-by-row, as in **TABLE(1,1), TABLE(1,2), TABLE(1,3), ..., TABLE(1,N), TABLE (2,1), TABLE(2,2), ..., TABLE(2,N)**, etc.

Mixtures of unsubscripted variables, elements of arrays, and entire arrays can be read in one **read** statement. In the following example, if **LIST** and **VECTOR** are one-dimensional arrays and **x** and **y** unsubscripted variables, the statement:

```
read x, LIST(y), VECTOR
```

reads a data item and assigns its value to **x**, reads another data item and assigns its value to **LIST(y)**, and then reads as many values as there are elements reserved in **VECTOR**.

Clearly, the repetition provided by the use of a control phrase is useful when processing the elements of subscripted variables. Such a control phrase may be used to govern the reading of array values. The following statement reads **N** data values, assigning them to the first **N** elements of the array **LIST**:

```

for I = 1 to N
  read LIST(I)

```

If **N** were the reserved dimension of the array, this statement has the same effect as the statement **read LIST**.

A more complex example demonstrates the use of nested control phrases to govern the repetition of a **do** loop. The loop reads and assigns data values to only the lower triangular elements (i.e., those that lie below the diagonal) of a square two-dimensional array or matrix. For example:

```

reserve MATRIX(*,*) as N by N
for I = 1 to N
  for J = 1 to N
do
  if I gt J
    read MATRIX(I,J)
  always
loop

```

While the subscripts, in turn, take on the values to address each element, the **read** statement is executed only when the **if** condition is satisfied. The data values supplied would be the values for **MATRIX(2,1)**, **MATRIX(3,1)**, **MATRIX(3,2)**, **MATRIX(4,1)**, **MATRIX(4,2)**, **MATRIX(4,3)**, etc.

## 2.7 Using Subscripted Variables In Expressions

Recall that parentheses are also used to clarify the desired evaluation order in complex arithmetic expressions. Subscripted variables may appear in such expressions. In these cases, the evaluation of subscripts and the selection of the array elements may be considered to take precedence over other arithmetic evaluations. Note that subscripts may themselves involve expression evaluations. Thus, in the statement:

```
let Z = X(I + 1) * Y(J + 1)
```

the subscript expressions **I + 1** and **J + 1** are evaluated first, thus selecting the two elements of arrays **X** and **Y** that are to be multiplied. The subscript expressions may even involve subscripted variables. The same procedure, applied to these expressions, ensures that these are evaluated first:

```
let Z = X(Y(I + 1) + 1) * 2
```

The subscript **I + 1** is evaluated to select an element from **Y**; **1** is added to the value of this element to form the indexing value for the array **X**; and the selected element of **X** is then multiplied before assignment to **Z**. After conversion to **integer** mode (if necessary), the subscript expression should always evaluate in the range of 1 to the size given in the **reserve** statement. Out-of-range subscripts will produce execution errors that either terminate the program or introduce undesirable side-effects, depending on the implementation.

## 2.8 Nested DO Loops

As shown above, a number of **for** statements, for instance, may be nested to provide complex control over the repetition of a **do...loop**. **Do...loops** may also be nested within one another. This proves convenient when processing variables with multiple subscripts. Consider a program fragment that computes the row and column sums of a two-dimensional matrix. The sums are accumulated in the appropriate elements of two one-dimensional arrays:

```

for I = 1 to NROWS
do
    for J = 1 to NCOLS
    do
        add MATRIX(I,J) to ROWSUM(I)
        add MATRIX(I,J) to COLSUM(J)
    loop
loop

```

The **do...loop** controlled by the phrase **for I = 1 to NROWS** is termed the outer loop. Recall that all the statements between the bounds of the **do** and the matching **loop** statements are repeated for each value of the control variable. Thus, the inner **do** loop is repeated as each row of the matrix is indexed. Clearly, the inner loop indexes, for any one row, each matrix element within that row.

When **do...loops** are nested, each **do** should be paired with a matching **loop** as shown. Adopting a convention of indenting the controlled statements makes this clear. Where nested loops terminate on successive **loop** statements, however, a special construct, similar to the **then if** construct, may be used. When **also** is prefixed to a **for** phrase, SIMSCRIPT II.5 automatically pairs the **do** that follows with the **loop** that matches the **do** of the preceding **for** statement. Using this statement, the above example can be written as:

```

for I = 1 to NROWS
do
    also for J = 1 to NCOLS
    do
        add MATRIX(I,J) to ROWSUM(I)
        add MATRIX(I,J) to COLSUM(J)
    loop
loop

```

The **do** statements themselves need not be immediately adjacent, but they must terminate on adjacent **loop** statements. Statements to be repeated only under the control of the outer loop must appear after the first **do** and preceding the **also**. Care should be taken, when using the **also for** construct, not to obscure the logical intent of the repetition. To this end, the example above retains the indenting of the earlier example.

## 2.9 The Structure of a SIMSCRIPT II.5 Program

In the previous discussion, a program has been understood to contain a number of instruction statements, possibly preceded by some variable declaration statements in the **preamble** section of the

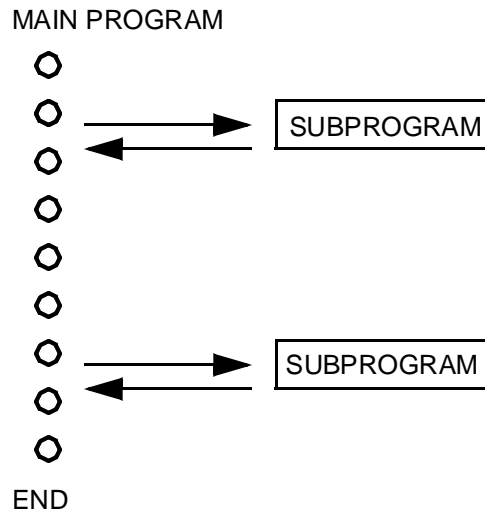
program. Program control structures have been described by which logical groups of statements may be executed conditionally, or repeated under some control.

There are two good reasons for developing a more elaborate program structure. First, problem solutions can require sequences of similar or identical statements to be executed at different places within a program. Although these statements can be rewritten in place each time they are needed, it is convenient to be able to combine them into groups and refer to them by symbolic names whenever required. Second, this grouping enables the separation of program elements that are logically distinct. Large programs can become too big to comprehend at a single level of complexity. Complex systems are better understood if treated in a hierarchical fashion. Dividing programs into logically related functional groups of statements allows these sections to be developed separately, and then combined at a conceptually higher level to form a whole program.

These program sections are commonly termed routines. Labeled routines that are referenced by a symbolic name are called subprograms. They are distinguished as programs because they perform some specific task. They are called subprograms because they are not executed independently, but rather perform functions within the execution of a program. When execution of a subprogram is requested by another routine, control passes from this calling routine to the subprogram, along with instructions for returning control, at completion of the subprogram, to the calling routine. This hierarchical structure is not limited to one level. A subprogram may itself call upon other subprograms.

Subprograms are not executed directly but are subordinate to a higher level routine. The routine at the highest level in the hierarchy is called the main routine. Every SIMSCRIPT II.5 program must have one main routine, and may contain one or more subprograms. When a program is submitted for execution, the control flow is directed to the first instruction in the main routine and proceeds from there, as the logic of the main routine-subprogram package directs. All of the example programs used thus far have contained only a main routine. In succeeding paragraphs, the structure and use of subprograms will be described.

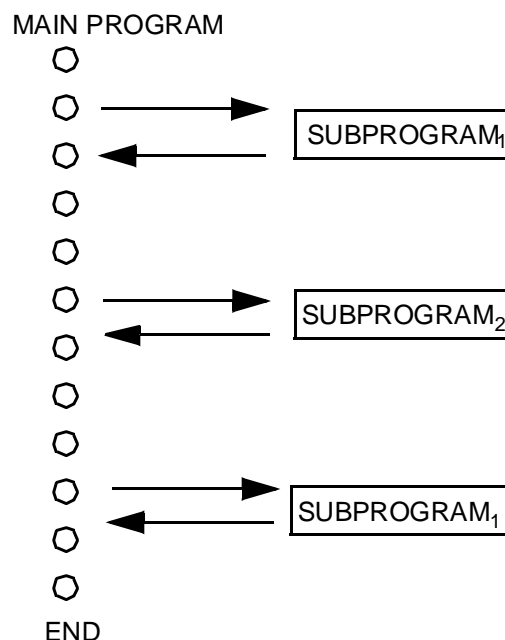
Figure 2-5 shows three examples of main routine-subprogram routine organizations. The examples in this figure consist of a main routine and one or more subprograms, with arrows indicating the direction of program flow. An arrow pointing to a subprogram indicates a call on that subprogram, and an arrow pointing in the opposite direction means a return to a calling routine.



**Figure 2-5a. Program Consisting of a Subprogram Called by a Main Routine**

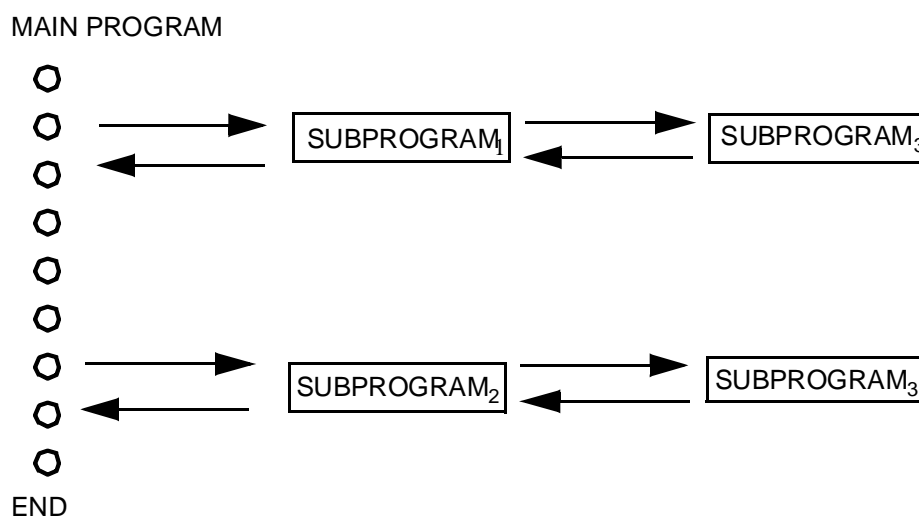
In Figure 2-5a, the main routine calls on the subprogram in two places. In each instance, after executing its statements, the subprogram returns control to the main routine at the statement following the one that called it.

Figure 2-5b shows a slightly more complicated program composed of a main routine and two subprograms. The main routine calls on each of the subprograms. They are independent of each other.



**Figure 2-5b. Program Consisting of Two Subprograms Called by a Main Routine**

Figure 2-5c illustrates a more complex situation in which a `main` routine and three subprograms interact. Subprograms 1 and 2 are both called and calling routines: They are called by the `main` routine and, in turn, they call on subprogram 3. The call of subprogram 1 or 2 by the `main` routine is the first level of calling. The call of subprogram 3 by subprograms 1 and 2 while under the control of the `main` routine is a second level. In general, there can be any level of calling in effect within a program at any time. The calling rules do not change from level to level. Control always passes from a calling to a called program and back again. Whether there are many intermediate calls and returns between an original call on a subprogram and a return to its calling program is insignificant. If A calls B and B calls C, then C must return control to B before B can return to A. A subprogram cannot return control to any routine other than the one that called it. For example, C cannot return control directly to A.



**Figure 2-5c. Program Consisting of Three Subprograms and a Main Routine**

## 2.10 Routine Definition

A SIMSCRIPT II.5 program may be composed of several program sections: a `preamble` (data declaration) section, a `main` routine, and a number of subprograms. Statements are needed to delimit these program components. As already noted, the variable declaration section is headed by the word `preamble` and terminated by the word `end`.

The statements that make up the `main` routine should be preceded by the one-word statement:

```
main
```

This is not strictly necessary. Since all other sections of a program must have a heading, it is possible to omit the `main` statement and assume that statements belong to the `main` routine if not otherwise labeled. Nevertheless, it is good programming practice to label program sections fully. Each



complete program may have only one `main` routine. The `main` routine, like all other program sections, should be terminated by the word **end**.

A subprogram definition statement precedes the statements belonging to each subprogram and:

1. Declares that the statements following are part of a subprogram
2. Names the subprogram
3. Sets up a communication mechanism for passing data to and from the subprogram.

Each subprogram has a name, which is declared in the subprogram definition statement that precedes the statements composing the body of the subprogram. Subprogram names follow the same naming conventions as variables (see paragraph 2.1). Each variable and subprogram name must be unique. A subprogram definition of the simplest form is:

```
routine name
```

The optional words **to** and **for** are allowed after the word **routine**. Thus, a program to calculate square roots might be named **SQUARE.ROOT** and could be defined by the statements:

```
routine SQUARE.ROOT
```

or

```
routine for SQUARE.ROOT
```

or it might be named **TAKE.SQUARE.ROOT** and be defined by the statement:

```
routine to TAKE.SQUARE.ROOT
```

As the words **to** and **for** are optional, there are obvious ambiguities in using the words **to** and **for** as subprogram names.

Execution of the statements within a subprogram may be requested from another routine by referencing the subprogram name. Such reference is known as calling the subprogram and commonly takes the form:

```
call name
```

This is the simplest form of the **call** statement. Additions to this statement and alternative routine references will be discussed in following paragraphs.

Each subprogram is defined with a **routine** statement. As for other program sections, an **end** statement indicates the physical end of the routine. The statements in between constitute the body of the subprogram. The logical end of a routine, rather than the physical end, is normally indicated by the special statement:

```
return
```

While the **stop** statement is used to terminate processing in a **main** routine, the **return** statement is used when processing in a subprogram is complete, indicating that the flow of control should return to the calling routine (note that there is no restriction to the use of the **stop** statement in a subprogram for abruptly halting all further execution within the program). Some of the examples may show a comment that includes the routine name following the **end** statement, which is done to make clear the separation between routines.

Routines used within a program are generally required to interact with program variables or data. The requirement to obtain the square root of a number, for example, may occur more than once in a program, and is also a logical subdivision of the program activity. If the statements to evaluate the square root of a number are to be grouped as a subprogram, the value of the number must somehow be transmitted to the subprogram, and the value of the square root must be communicated back to the calling routine. Values are passed from calling to called routines and back again in two ways: implicitly, as values of global variables, and explicitly, through arguments in an argument list.

## 2.11 Global and Local Variables

A global variable is a variable whose name has a common meaning throughout a program. Every use of the name of a global variable references the same data value, regardless of the routine in which the reference is made. A local variable, on the other hand, has a value defined only within a particular routine. A variable local to one routine cannot be directly referenced in any other routine. Consequently, if the same name is used for a local variable in more than one routine, the name used refers to a different value in each routine, as if a different variable name were being used in each place. Thus, local variable names that are not intended to reference the same variables may, for mnemonic reasons or even inadvertently, appear the same in different routines. In general, local variables do not maintain a permanent existence in computer memory, but rather pass in and out of existence as control passes to or from the routine to which they have been declared as local.

The preamble is used to define global variables. A variable is only defined as global when it appears in a statement of the preamble. Therefore, variable names that are desired to be globally known must appear in **define** statements, even though their properties may be fully described by the existing background conditions. Conversely, any variable not named in a program's preamble is local to those routines where it is used. A variable may be explicitly defined as local to a routine by specifying the name in a **define** statement within the routine. If it is not defined as a global name, nor explicitly defined within the routine, it is implicitly defined as local by its use within a routine.

It is commonly considered good practice, however, to explicitly define all local variables used by every routine. When a name is locally defined within a routine, it is unique to that routine and does not conflict with any other uses of the same name. Thus, it is possible to have many different uses of the same name — both variables and labels — in an entire program. Names declared as global can be temporarily redefined as local within a particular routine by declaring their names in local **define** statements within the routines. Local variables have the properties of the background

(**normally**) conditions in effect at the time they are first encountered, unless these properties are redefined in the **define** statements.

All variables that do not appear in a program preamble are local. Local variables can be used both in subprograms and in `main` routines. **Normally** statements can be used in routines to set background conditions for local variables, but these conditions do not carry over from one routine to another. Only the last defined **normally** conditions in the preamble carry over from routine to routine. Program 2-1 illustrates how **normally** and **define** statements are used to specify properties of local and global variables.

**Program 2-1.**


---

```

preamble
  normally, mode is integer
  define V1 and V2 as real, 1-dimensional arrays
  define V3, V4 and V5 as 2-dimensional arrays
  normally, mode is real
end

main
  read N
  reserve V1,V2 as N,  V3,V4,V5 as N by N
  read V1 and V2
  let V3(1,1) = V1(V2(1))
  :
  and other statements that make up a main routine,
  including calling references to the subprograms
  call PROCESS.DATA
  :
  call PRINTOUT
  :
end      ' ' of Main Routine

routine PROCESS.DATA
  normally dimension is 1, mode is real
  define Z as an integer array
  normally dimension is 0
  define L, M and N as integer variables
  reserve Z as 10
  'START'
  for X = 1 to 10
  do...
    other statements that make up a routine
  :
  return
end      ' ' of Routine PROCESS.DATA

routine PRINTOUT
  define Z as a 2-dimensional variable
  reserve Z as 10 by 5
  'START'
  let X = 1
  :
  return
end      ' ' of Routine PRINTOUT

```

---

Some points to observe from this example are:

1. A **preamble** can have more than one **normally** statement. Each successive **normally** statement sets background conditions that hold until they are overridden. The last **normally** conditions hold for all undefined local variables in routines. Local variables in routines can have their properties defined by **normally** and **define** statements in the routines.
2. The order of **normally** and **define** statements is important. In the above routine **PROCESS.DATA**, the variable **z** is defined as **1-dimensional** because the **normally** statement has set this background dimensionality. The **define** statement declares only that it is to be an **integer** array. If the order of these statements is reversed, the **normally** conditions of the program preamble will apply to **z**, and it will be defined as an unsubscripted variable, a definition that subsequently will be contradicted by the **reserve** statement. The possibility of error may be reduced by placing less reliance on background conditions and fully defining the mode and dimensionality of variables.
3. The name **x** appears in both subprograms, implicitly defining **x** as a local variable in both routines. The mode and dimensionality of **x** are derived from the background conditions in effect. In this case, the mode is **real** in both routines, as explicitly declared in the first **normally** statement in **PROCESS.DATA**. It is taken from the **preamble**-defined background condition for routine **PRINTOUT**, which does not set any background mode. For similar reasons, the dimensionality is also zero.
4. Unsubscripted local variables (**L**, **M**, and **N** in **PROCESS.DATA**, **x** in both routines) are automatically assigned storage locations and initialized to zero when control enters a routine. They are returned to "free storage" when control passes back to the calling routine. Subscripted local variables are not automatically assigned storage locations and must be **reserved** before they can be used. Recall that when an array is **reserved**, its elements are automatically initialized to zero.
5. The fact that two locally defined arrays share the same name is purely coincidental. **z** is a **1-dimensional, integer** local array in routine **PROCESS.DATA** and a **2-dimensional, real** array in routine **PRINTOUT**. If the name **z** were used in the main routine, it would be local to it, defined as unsubscripted and **real**. Confusion, however, may be reduced by avoiding duplicate names.
6. Unlike some block-structured languages, local variables used in inner (lower level) routines are not available to outer routines. Variables that are not global are accessible only in the routine in which they are declared.
7. Labels are always local. When a name is used as a label, it references a program statement in the routine containing the label. Label names can be duplicated in different routines without conflict. Labels appearing in one routine are not defined within other routines, and transfers cannot be made between routines by means of **go to** statements.

8. A subscripted local variable that does not appear in a **define** statement within a routine has its dimensionality defined by its first use. That is, even if a routine's **normally** condition is zero-dimensional, the statement **let x(1) = 0** implicitly defines **x** as one-dimensional. However, the array must still be **reserved** before its first use.
9. Definition statements for local variables placed at the head of a routine are not preceded by **preamble** and followed by **end**, as are similar statements in a program preamble. In fact, **normally** and **define** statements can be used anywhere within a routine, although it is good practice to place them before any instruction statements.

## 2.12 Routine Arguments

Global variables provide one mechanism by which values may be communicated between program routines. A preferred way is through routine arguments. Arguments are values that are explicitly transmitted between calling and called routines. By making the transmission of values between routines explicit, rather than using global variables, the logical interaction between these routines may be emphasized, reducing the risk of inadvertent interaction. Arguments represent variables that behave as local variables of a called routine, but which may either receive initial values each time the routine is called, termed *given arguments*, or may be used as *yielded arguments* to transmit result values back to the calling routine. In the case of **given** arguments, the initial values are supplied by the calling routine. Numeric **yielded** arguments are initialized to zero, as for normal local variables.

When a routine definition is written, those local variables that are to be arguments of the routine are listed in the routine definition statement. This definition list is termed the *formal argument list*. When a routine with arguments is called, the values that are to be used to initialize or receive values from the argument variables are listed in order corresponding to the formal argument list in the routine definition. The called routine may return values to a calling routine by assigning the values to those of its argument variables defined to be **yielded** arguments. Those **yielded** arguments not assigned a value in the routine retain the initialized values of zero. The general form of a routine definition is:

```
routine name given given argument list yielding yield argument list
```

Consider, for example, the common square-root calculation discussed above. A routine to evaluate the square root of a number might be written:

```

routine SQUARE.ROOT given NUMBER yielding SQRT
  let SQRT = NUMBER/2.0
  let DELTA = SQRT
  until DELTA < (0.00001 * SQRT)
  do
    let SQRT = (SQRT + NUMBER/SQRT)/2.0
    let DELTA = NUMBER/SQRT - SQRT
    if DELTA is not positive
      let DELTA = -DELTA
    always
  loop
  return
end

```

For simplicity, the problem of zero or negative given values is ignored. This routine may be referenced by any other routine in the program using the statement:

```
call SQUARE.ROOT given QUANTITY yielding RESULT
```

where **QUANTITY** and **RESULT** are variables, commonly local to the calling routine. When control enters the routine, the value assigned to **QUANTITY** in the calling routine is assigned to **NUMBER**. When control is returned to the calling routine, the value assigned to **SQRT** in **SQUARE.ROOT** is assigned to the variable **RESULT**.

Not all routines have both given and yielded arguments. Global variables may be used for communication, or perhaps only one-way communication of data is required. Either or both of the **given** and **yielding** clauses may be omitted from the routine definition and from the **call** statement. The word **given** may be replaced by **giving**, **the**, or **this** to improve readability. Alternatively, the given argument list may be enclosed in parentheses, using only the comma **,** as a separator. Hence, routine definition alternatives might be:

```

routine SQUARE.ROOT(NUMBER) yielding SQRT
routine to SQUARE.ROOT this NUMBER yielding RESULT

```

In a routine definition, the arguments are restricted to unsubscripted variable names. These arguments behave as defined local variables within the routine. This restriction does not apply to argument references in a **call** statement, which may be subscripted variables or even expressions. Synonyms for **call** are **perform** and **now**. Thus subprograms might be referenced by statements such as:

```

perform SQUARE.ROOT(QUANTITY(I)) yielding RESULT
call SQUARE.ROOT giving (B**2 - 4*A*C) yielding X
now SQUARE.ROOT this X yielding X
call SQUARE.ROOT given NUMBER yielding SQRT
now PRINTOUT

```

The same variable name may appear both as a given argument and as a yielded argument within a **call** statement, as in the third example above. There is no ambiguity, as the order in which the

arguments are transmitted and received is clear: at entry to the routine, the given value of **x** is used to initialize the local argument **NUMBER**; at return from the subprogram, the named variable, in this case **x**, is replaced by the resulting yielded argument, **SQRT**. Note that the same names may be used in both the **call** statement and the routine definition, as in the fourth example above. In the **call** statement, the given and yielding arguments refer either to variables local to the routine or to global variables. In the routine, however, these arguments are always taken as definitions of variables local to the routine, and thus, within the routine, do not directly reference the variables appearing in the **call** statement.

It is important to note that the variables listed as given or yielded arguments in a routine reference must match exactly, in number and mode, the arguments listed in the formal argument list in the routine definition. No automatic mode conversions, between **integer** and **real**, for example, may be assumed. Obviously, all references to a subprogram in different places in a program should include the same numbers of both given and yielding arguments. In order that any incorrect references may be diagnosed at program compilation, it is possible to define, in the program **preamble**, the "correct" numbers of arguments, using a statement of the form:

```
define name as a routine given i arguments yielding j arguments
```

More than one routine may be defined in the same statement; **a** is optional, and the word **routines** may be used. The word **values** is synonymous with **arguments**, and **with** and **giving** with **given**. Either or both of the **given** or **yielding** phrases may be omitted. If either is omitted the routine is assumed to have no such arguments. If neither **given** nor **yielding** phrases are included, compilation checks on argument numbers at each routine reference are omitted. Otherwise, inconsistent argument numbers will result in error messages. Some implementations provide for additional checks during program execution. Consult the relevant user's guide for options on such checking.

## 2.13 Routines Used as Functions

A function is a procedure that yields a single result value when applied to some given value. The value yielded is termed the result of the function, or the function value. Calculation of the square root of a given number could be considered to be a function evaluation, and a routine may be written to provide this service. The **call** statement, however, is a cumbersome way of referencing routines, which return only a single result value.

When a function is used in a mathematical expression, it indicates that the value that results from applying the function to the appropriate given values should be used in evaluating the expression. In programming, a function notation provides a convenient way to reference a subprogram that returns only a single result value. A subprogram that is to be referenced as a function is written in much the same way as subprograms discussed previously, requiring only minor changes in definition. The function symbol is the name of the function routine. If the routine **SQUARE.ROOT** were defined as a function, it could be referenced with a direct use of the name; as follows:



```
let X = SQUARE.ROOT(NUMBER)
```

The given argument or arguments, in this case **NUMBER**, are specified as before with the restriction that only the format of an argument list enclosed in parentheses be allowed. Instead of specifying a **yielded** argument, the function name is used. As a function reference is not apparently different from a reference to a subscripted variable, all functions must be defined in the program **preamble**. This may be done by a statement of the form:

```
define name as mode function
```

Recall that the modes of arguments are not automatically converted. As the function value replaces the single **yielded** argument, its mode must somehow be specified. If the mode word is omitted from the definition, the background mode in effect is assumed. The function value may be any of the modes associated with a variable. More than one function may be specified by including a list of function names. As the **yielded** argument can no longer be specified in the formal argument list of the routine definition, the **return** statement in the function routine is modified to indicate the value to be returned. This statement is written, within a function routine, as:

```
return with arithmetic expression
```

or

```
return (arithmetic expression)
```

More than one **return** statement may appear in any routine, including a function routine. A function may have several exit points, each returning different values. Consider providing a function routine to return the absolute value of a given argument:

```
function ABSOLUTE(NUMBER)
  if NUMBER is negative
    return with -NUMBER
  otherwise
    return with NUMBER
end
```

As the function mode has been declared, all returned values must be of the same mode.

To demonstrate the convenience of the function notation, the following example shows the square-root subprogram rewritten as a function routine, using, in turn, the **ABSOLUTE** function just defined:

```

function SQUARE.ROOT given NUMBER
  let SQRT = NUMBER/2.0
  let DELTA = SQRT
  until DELTA < 0.00001 * SQRT)
  do
    let SQRT = (SQRT + NUMBER/SQRT)/2.0
    let DELTA = ABSOLUTE(NUMBER/SQRT - SQRT)
  loop
  return with SQRT
end

```

By incorporating the function reference directly in the logical control phrase and eliminating the evaluation of the intermediate result, **DELTA**, this example reduces to:

```

function SQUARE.ROOT given NUMBER
  let SQRT = NUMBER/2.0
  until ABSOLUTE(NUMBER/SQRT - SQRT) < (0.00001 * SQRT)
    let SQRT = (SQRT + NUMBER/SQRT)/2.0
  return WITH SQRT
end

```

Function evaluation takes the same precedence as subscripted variable evaluation. The function is evaluated prior to evaluation of the expression in which the function appears. Obviously, expressions appearing as arguments to the function are independently evaluated before the function evaluation.

## 2.14 Global and Local Variables, Routines, Functions, and Side Effects

It has been suggested that communication of values between routines is best done through an explicit argument list. The interactions between a number of routines using many global variables can be hard to follow, and a single error may have widespread repercussions. The use of explicit arguments helps to logically separate the task of a single routine within the entire program. When global variables are used in routines that interact, care must be exercised to prevent unwanted side effects. Most rigorously, any change in the value of any nonlocal variable may be termed a side effect. More commonly, the term refers to an unexpected or unforeseen consequence of any statement, usually involving a routine or function call. The practice of explicitly declaring all local variables to a routine helps avoid the inadvertent modification of any global variables.

## 2.15 Library Functions

Some functions, such as the square root and absolute value, are used so frequently that they are incorporated in the SIMSCRIPT II.5 language. A list of these functions appears in [Appendix B](#). To help distinguish the use of these functions, the names are formed from mnemonic abbreviations suffixed with the two characters **.f**. For example, **abs.f** returns the absolute value of the given argument, **sqrt.f** returns the square root, and **log.e.f** returns the natural logarithm. Recall that

names defined by the SIMSCRIPT II.5 software are generally of the form letter-period-name or name-period-letter. Examples of the way these functions may be used are:

```
if abs.f(X-Y) > 1
let Z = log.e.f(Y)
let D = sqrt.f(A**2 + B**2)
for I = 1 to min.f(max.f(A,B), max.f(X,Y,Z))
```

Following from the earlier discussion of routine arguments, it might be expected that each library function would have a defined number of given arguments. This is true with the exception of two functions, **max.f** and **min.f**, which return the maximum or minimum value, respectively, from any number of given arguments. For uniformity, the function notation is used as described. However, not all of the library functions are implemented as routines. Depending on the implementation, they may be directly evaluated within the program statements.

Many of the library functions are implementations of widely used mathematical functions. Some others, however, have meanings specific to SIMSCRIPT II.5. These will be described further as the context requires.

The library functions can be used freely in all computations. Function arguments can be arithmetic expressions of any complexity (including function names) as long as they are of the correct mode and their values conform with the restrictions listed with the function descriptions.

## 2.16 Using Non-SIMSCRIPT Routines

With some restrictions, routines written in programming languages other than SIMSCRIPT II.5 may be used in a SIMSCRIPT II.5 routine. To do so, the routine must be specially defined within the program preamble as:

```
as a nonsimscript routine
as a fortran routine
```

By default, arguments to a **non-simscript** routine are passed by value, while arguments to a **fortran** routine are passed by reference. The appropriate SIMSCRIPT II.5 user manual should be consulted. **Yielded** arguments may not be specified for any non-SIMSCRIPT routine. Function values may be returned providing the function mode is correctly defined. In general, the interpretation of error conditions is not well defined when these occur within non-SIMSCRIPT routines called from SIMSCRIPT II.5.

## 2.17 Returning Reserved Arrays To Free Storage

When a **reserve** statement is executed, an amount of storage space determined from the dimensions is allocated to the array pointers named in the statement. If at any time the space associated with an array is no longer required, it may be returned to the free memory pool by executing a **release** statement naming the array. The total space requirement of a program may

often be reduced by structuring it so that not all arrays need be reserved concurrently. The **release** statement has the general form:

```
release array-pointer list
```

Examples are:

```
release A(*)
release COEFF (*,*), WIDTH (*), DIMENSIONS (J,*)
```

No access should be attempted to any element of a released array. The array cannot be distinguished from one that has not been reserved, and an error will result. The array may, of course, be re-reserved with the same dimensionality.

## 2.18 Array Pointers as Routine Arguments

Thus far, routine arguments have represented the values of variables, or, in the case of **given** arguments, the values of arithmetic expressions. These values are copied between the calling and called routine, as indicated by the ordering in the argument lists. Such arguments are said to be passed between routines by value. The value of a subscripted variable may be used in the same way as an unsubscripted variable. The transmission of an array of values is handled differently. To reserve and copy entire arrays of values would involve significant inefficiencies. For this reason, when arrays appear as routine arguments they are passed by reference, that is, a pointer value is passed.

When an array name appears in an argument list, the value of the array base pointer is transmitted, rather than the array element values. By using this pointer, the receiving routine can access the element values within the array structure. For an array pointer transmitted as an argument to be recognized as such, and to enable the correct accessing of its element values, both the mode and dimensionality of the array represented must be defined to the receiving routine. The following function routine illustrates the use of an array name as an argument. The function computes the trace of a square matrix, defined as the sum of the diagonal elements. As the matrix must be square, it is sufficient to pass one value indicating the number of rows and columns. For example:

```
function TRACE(MATRIX, SIZE)
  define MATRIX as a real, 1-dimensional array
  define SIZE as an integer variable
  define SUM as a real variable
  define I as an integer variable
  for I = 1 to SIZE
    add MATRIX(I,I) to SUM
  return with SUM
end
```

In this function routine, the argument **MATRIX** is locally defined as an array. A pointer value is assigned to it, not by a **reserve** statement, but by copying the transmitted value of the array base pointers passed from the calling routine. In this way, the function works with the actual element

values of the array passed to it. The function routine may be called as shown in the following statements:

```
define TABLE as a 2-dimensional array
.
.
reserve TABLE(*,*) as N by N
read TABLE
let VALUE = TRACE(TABLE(*),N)
```

It is possible to define an array as a local subscripted variable within a routine, allocating space to it with a **reserve** statement. However, local variables only have an existence while the routine is the subject of a call from a higher level routine, and that the local variables of a routine are reinitialized to zero values at every new call. If it is desired to subsequently access the elements of an array reserved within a called routine, the array pointer should be included in the list of **yielded** arguments, or returned as a function value. If subsequent access is not required, it is good practice to free the space occupied by the array elements using a **release** statement, before returning from the routine. Incidentally, although it might be thought desirable that SIMSCRIPT II.5 arrange to automatically release all such local arrays before a **return**, the facility to freely manipulate array pointers in programmer-defined structures precludes making general assumptions about the values of locally defined array pointers.

The SIMSCRIPT II.5 system function **dim.f** returns the dimension of an array pointer. In the case of a multidimensional array, given the array base pointer, **dim.f** returns the dimension of the array of row pointers at the first level. These row pointers may, in turn, be given to obtain the dimensions of lower levels of the structure. This function is useful in programs that work with arrays having varying dimensions by making it unnecessary to save array dimension values for later use, or to explicitly transmit the array bounds as arguments. For example, the following **for** loop uses the **dim.f** function to determine the current dimensions or bounds of the rectangular array **TABLE**:

```
for I = 1 to dim.f(TABLE(*,*)),
  for J = 1 to dim.f(TABLE(I,*)),
    let TABLE(I,J) = I**2 + J**2
```

Using the **dim.f** function rather than constants or expressions permits the above statement to process ragged tables as well as rectangular arrays. The first use of **dim.f** returns the number of array rows. The second reference returns the number of columns of each of these rows.

Two important features to remember about arrays used as arguments are (1) the pointer to an array is transmitted, rather than the individual element values, and (2) the mode and dimensionality of the array must be declared in the routine. Some examples illustrate these points.

1. A routine adds two two-dimensional arrays together and stores their sum in a third array. Note that the result array appears in the list of given arguments because only the array pointer value is passed. The called routine uses this pointer value to directly access the el-

ements in the prereserved array space. Responsibility for reserving this space rests with the calling routine.

Routine definition:

```

routine ADD.MATRICES given A, B, and C
define A, B, and C as real 2-dimensional arrays
normally mode is integer
for I = 1 to dim.f(A(*,*))
  for J = 1 to dim.f(A(I,*))
    let C(I,J) = A(I,J) + B(I,J)
  return
end

```

Routine called within a program:

```

define COST1, COST2, TOTAL.COST as 2-dimensional real arrays
.
.
reserve A(*,*), B(*,*) and C(*,*) as N by M
.
.
call ADD.MATRICES given COST1(*,*), COST2(*,*)
and TOTAL.COST(*,*)

```

2. As an alternative to the above example, the result array could have been reserved by the called routine and its pointer value returned as a yielded argument. This yielded argument must be defined at the calling program level to be an array. Note that each call to the routine reserves space for a new copy of the array. The calling program, therefore, is responsible for managing the release of these multiple space allocations.

Routine definition:

```

routine ADD.MATRICES given A and B yielding C
define A, B, and C as 2-dimensional real arrays
normally mode is integer
let NROWS = dim.f(A(*,*))
let NCOLS = dim.f(A(1,*))
reserve C as NROWS by NCOLS
for I = 1 to NROWS
  for J = 1 to NCOLS
    let C(I,J) = A(I,J) + B(I,J)
  return
end

```

Routine called within a program:

```

define COST1, COST2, TOTAL.COST
as 2-dimensional real arrays
reserve COST1, COST2 as N by M

```

```

.
.
call ADD.MATRICES given COST1(*,*), COST2(*,*)
yielding TOTAL.COST(*,*)
.
.
release TOTAL.COST(*,*)

```

## 2.19 Text Mode Variables

To this point, variables have been used to represent **integer** and **real** numeric data. The need can arise to work with text characters. SIMSCRIPT II.5 allows variables to be declared as **text** mode. Variables so defined may be used to represent strings of alphanumeric characters up to a maximum of 32,000 characters.

**Text** variables may be read from input data, be printed on an output device, or have their value assigned internally in a program. A variety of **text** manipulations are supported. Declaration of **text** mode is made in the same way as for other variable modes:

```
normally mode is text
```

or

```
define variable list as text variables
```

A **text** mode constant, or text literal, may appear in a program statement, and bears the same relation to **text** variables as do numeric constants to **integer** and **real** variables. A text literal is a character string enclosed between quotation marks ("). (Note that the single character " used to bracket a literal is different from the two characters " used to bracket a comment.) Thus a particular string of characters may be assigned to a **text** variable as follows:

```
let text variable = "character string"
```

Any character included in the complete character set representation supported on a particular machine, including the blank character, may be included in a **text** string. The relevant SIMSCRIPT II.5 user manual may be consulted for a list of character representations. If the quotation mark is to appear within a string, it must be specified as two successive quotation marks.

The character string **LEWIS CARROLL** may be assigned to the **text** variable **AUTHOR** by the statement:

```
let AUTHOR = "LEWIS CARROLL"
```

This string may be copied to the **text** variable **NAME** by the statement:

```
let NAME = AUTHOR
```

This second assignment creates a second copy of the of the character string "**LEWIS CARROLL**", assigning it to the variable **NAME**. Each **text** variable represents a unique copy of a character string. Thus, subsequent assignment of another string to the variable **AUTHOR** does not affect the value of **NAME**.

A character string that contains no characters is termed a null string and is represented by the literal "" in **text** assignments. Character strings may be erased using the **erase** statement:

```
erase variable list
```

where each variable in the list is a **text** variable. Alternatively, a **text** variable may be directly assigned a null value. Thus, the statements:

```
erase AUTHOR
let AUTHOR = ""
```

have the same effect. Note that the value of **NAME** is still "**LEWIS CARROLL**".

Only **text** variables or literals may be assigned to another **text** variable. No automatic conversions takes place between **text** and any other variable mode .

## 2.20 Reading and Displaying Text Variables

**Text** variable names may appear in the variable name list of the **read** statement:

```
read variable list
```

The variables are assigned values from fields in the input data, delimited on either side by blank characters or by the beginning of a new input record. Such strings cannot contain blanks, as these would delimit new data fields. This restriction will be discussed more fully later. For example, if **TVAR1** and **TVAR2** are **text** variables, the statement:

```
read TVAR1, TVAR2
```

will assign the characters **ANTIDISESTABLISHMENTARIANISM** to **TVAR1** and the characters **IS** to **TVAR2** after reading the following data record:

```
column number
          0          1          2          3  ...
12345678901234567890123456789012...
ANTIDISESTABLISHMENTARIANISM IS
```

Both numeric and **text** variables may appear in the variable name list of the same **read** statement.

As **text** data may not always be delimited by blank characters, a second more general **text** variable **read** statement is supported. The statement takes the form:

```
read text variable as T *
```



which reads a variable length text string enclosed by matched delimiters. This form of the **read** statement skips to the next nonblank character in the input data, treating this character as a leading delimiter, and then reads until the next occurrence of this same character. The character string may begin in any record column position and extend over any number of input records. Any nonblank character may serve as a delimiter for any individual **read**. For example, the statement:

```
read TVAR1, TVAR2 as 2 T *
```

when reading the following data record:

```
column number
```

```
0          1          2          3          4...
1234567890123456789012345678901234567890...
      /A simple phrase/      'Two words'
```

is equivalent to:

```
let TVAR1 = "A simple phrase"
```

and

```
let TVAR2 = "Two words"
```

A **text** variable may be included in the variable list of a **print** statement. The print format information should contain a field of asterisks denoting the positions to be occupied in the printed line. If the text string to be printed contains more characters than there are allocated print positions, only the indicated number of characters will appear in the output. Conversely, if more positions are allocated than there are characters, the unfilled positions will appear as blanks. Thus, the statement:

```
print 1 line with TVAR1, TVAR2 thus
*****
```

produces the result:

```
ANTIDISESTABLISH      IS
```

A technique for producing variable-length string output is described in [Chapter 3](#).

## 2.21 Operations With Text Variables

Although arithmetic operators cannot operate on text mode variables, certain logical expressions can use **text** variables. The most usual of these is comparison for equality; thus:

```
if NAME = "LEWIS CARROLL"
```

Such comparisons between **text** variables or literals are treated on a character-by-character basis, starting from the first character position and proceeding left to right. If two text strings differ in

length, the shorter string is considered to be extended with blanks for comparison purposes. Comparisons are not limited to equality or inequality. However, the result of "less than" or "greater than" comparisons depends on the collating sequence of the internal character sequence used. This is based on the implementation and the *SIMSCRIPT II.5 User Guide* should be consulted. On all implementations, however, the null string compares less than all other strings.

### 2.21.1 Concatenation: **CONCAT.F(text1, text2...textn)**

The **concat.f** function returns a **text** variable by concatenating the **text** variables or **text** expressions given as arguments. To illustrate the effect, let the **text** variables **STRING1** and **STRING2** be assigned the characters "**PIANO**" and "**FORTE**", respectively. The effect of the statement:

```
let LONGNAME = concat.f(STRING1, STRING2)
```

is to assign the characters "**PIANOFORTE**" to **LONGNAME**. Similarly,

```
let LUNCH = concat.f("HAM", "AND", "EGGS")
```

assigns "**HAMANDEGGS**" to **LUNCH**. The concatenation is in the order of the given arguments. If any argument has a null value, the remaining strings are concatenated normally.

### 2.21.2 Substring: **SUBSTR.F(text, index, length)**

The **substr.f** function provides access to a substring within a **text** variable. The substring is specified by two **integer** values, a start position within the source string, and the substring length. The first character of the string is referenced by an index of 1. If **A** and **B** are text variables, then the statement:

```
let B = substr.f(A,I,J)
```

copies **J** characters, starting from the **I**<sup>th</sup> character position in **A** to the character string **B**. **A** remains unchanged. For example, if **A** = "**SIMSCRIPT II.5**", then:

```
let B = substr.f(A,4,6)
```

assigns the characters "**SCRIPT**" to **B**.

Unlike most functions, **substr.f** may be used on the left-hand side of an assignment statement to replace a substring within a **text** variable. If string **A** has the value "**FOOTBALL**", then the effect of the statement:

```
let substr.f(A,1,4) = "GOLF"
```

is to replace the first four characters in **A**, giving it the value "**GOLFBALL**". For either use, the start position specified must be 1 or greater. The **substr.f** function may not be used to extract or replace characters beyond the length of the string, **A**. If the substring is so specified, only the remain-

ing characters in the string are used. Thus, `substr.f(A, I, INF.C)` refers to all remaining characters in the string starting from the  $I^{\text{th}}$  position.

### 2.21.3 Pattern Matching: `MATCH.F(text, pattern, skip)`

The function `match.f(A, B, I)` searches from left to right for the character pattern defined by `text` variable `B`, within the `text` variable `A`, after skipping the first `I` characters of `A`. If the pattern is matched, the location of the pattern string within `A` is returned. If no matching string is found, zero is returned. Both `A` and `B` are unchanged. If either `A` or `B` is the null string, zero is returned. For example, if `NAME` is the string `"JOHN JOHNSON"`:

```
let I = match.f(NAME, "JOHN", 1)
```

will return 6, as the first character position is skipped in the search.

### 2.21.4 Length Function: `LENGTH.F(text)`

A `text` variable may represent a character string of any length, from zero to a maximum of 32,000 characters. The `LENGTH.L` function returns the length of the `text` variable or `text` expression given as an argument. The length of a null or unassigned string is zero.

### 2.21.5 Case Conversion: `UPPER.F(text)` and `LOWER.F(text)`

These functions convert the alphabetic characters of the given `text` argument to upper case or lower case, respectively. Other characters are not changed.

### 2.21.6 String Repetition: `REPEAT.F(string, count)`

This `REPEAT.F` function repeats `string` (a `text` variable) `count` times (where `count` is an integer), returning a text variable. For example:

```
repeat.f ("CAMEL", 2)
```

returns the string `"CAMELCAMEL"`.

### 2.21.7 Truncation and Expansion: `FIXED.F(string, length)`

This `FIXED.F` function expands a `text` string to `length`, where `length` is an integer, by truncating or space-padding on the right. The new `text` string is returned. For example:

```
fixed.f("CAMEL", 3)
```

returns the string `"CAM"`, while:

```
fixed.f("DOG", 5)
```

returns the string `"DOG "`.

### 2.21.8 Blank Character Elimination: TRIM.F(*string*, *flag*)

This function trims leading and/or trailing blanks from text *string*, according to the value of *flag* (an integer variable). Thus:

Flag	Action
-1	Remove leading blanks only
0	Remove leading and trailing blanks
+1	Remove trailing blanks only

Thus, for example:

```
trim.f (" CAT ", 1)yields the string " CAT"
```

```
trim.f (" DOG ", -1)yields the string "DOG "
```

```
trim.f (" CAT AND DOG ", 0)yields the string "CAT AND DOG"
```

### 2.21.9 INTEGER to TEXT Conversion ITOT.F(*integer*)

This function returns a **text** string representation of its single integer argument. The length of the returned string is determined by the number of digits required to represent the integer value. Strings representing negative integers are prefixed with a "-". Thus, for example, if **INT** = 26 and **TVAR** is a **text** variable:

```
let TVAR = itot.f(INT)
```

assigns "26" to **TVAR**.

## 2.22 Alpha Variables

As **text** variables may not be used in arithmetic expressions, SIMSCRIPT II.5 provides for an **alpha** mode. An example of such a requirement might be the indexing of an array using a character subscript. An **alpha** variable provides for the representation of alphanumeric data which may be manipulated in a way similar to numeric data.

Earlier implementations of SIMSCRIPT did not support a **text** mode, and hence did all character processing in **alpha** mode. The number of characters represented by each **alpha** variable was machine dependent. Although this interpretation of the **alpha** mode may still be supported for compatibility reasons, **alpha** variables should now be assumed to be restricted to a single character. Usage that requires multiple-character representation is provided by the **text** mode, and it is recommended that **text** mode be used for character processing where possible. Variables are defined to be **alpha** in the usual ways:

```
normally, mode is alpha
```

or

```
define variable list as alpha variables
```

An **alpha** variable may contain any character from the character set, including the blank character. A character value is assigned to an **alpha** variable by delimiting the character literal with quotes ("). If the literal comprises more than one character, the first character is assigned. (When an **alpha** variable contains more than one character, the number of characters equivalent to the alpha variable size will be extracted.) For example:

```
let ALPHAVAR = "A"
```

The quotation mark is assigned by writing four successive quotation marks (""). **Alpha** variables may be assigned and compared. They may also be used in arithmetic operations, but care must be taken that such use is meaningful. It must also be noted that the effect of such use may differ with various implementations, as various internal character representations have different numeric values. An example of the use of an **alpha** variable might be the use of alphabetic item codes in the inventory program mentioned earlier:

```
define ITEM.CODE as an alpha variable
define STOCK as a 1-dimensional integer array
.
.
read ITEM.CODE and QUANTITY
if ITEM.CODE <> "X"
    subtract QUANTITY from STOCK(ITEM.CODE)
always
.
.
```

However, a similar effect may be achieved without resorting to such implementation-dependent code.

### 2.22.1 TEXT to ALPHA Conversion: TTOA.F(text)

The system function **ttoa.f** returns the first character(s) of the given **text** variable as an **alpha** variable. Although typically only one character is returned, more may be given depending on the implementation and computer option selected. If the null string is given, a blank character(s) is returned.

### 2.22.2 ALPHA to TEXT Conversion: ATOT.F(alpha)

A complementary function, **atot.f**, generates a **text** representation of the given **alpha** variable. In general, this is a single character string, but **alpha** representation may vary on some systems. Consult the user's manual.

## 2.23 Recursive Routines

All SIMSCRIPT II.5 routines are recursive, meaning that they can call upon themselves. The concept of recursion is commonly exemplified using a procedure evaluating the factorial of a number. The factorial of a number is defined by:

$$\text{Factorial}(n) = n * (n-1) * (n-2) * \dots * (2) * (1)$$

This recursive function routine may be used to compute the factorial of its given argument:

```

routine FACTORIAL(N)
  if N eq 1
    return with 1
  otherwise
    return with N * FACTORIAL(N-1)
end

```

The routine calls on itself repeatedly until it has reduced its argument to 1. If this function were called with **N = 4**, the factorial would be evaluated in the following steps:

```

FACTORIAL(4) = 4 * FACTORIAL(3)
              = 4 * ( 3 * FACTORIAL(2) )
              = 4 * ( 3 * ( 2 * FACTORIAL(1) ) )
              = 4 * ( 3 * ( 2 * ( 1 ) ) )
              = 24

```

This may not be an efficient way to compute a factorial, but it does illustrate the concept of a recursive call.

An important consequence of recursion is that local variables are unique to each routine call. Each call has a separate "memory" that shares nothing with previous calls except their common routine structure. Recall that local variables are reinitialized at every entry to a routine. Global variables are defined across all levels of recursion, as their names represent the same values at all points in a program. Using global variables and passing values in argument lists are two ways that separate invocations of a recursive routine can communicate across different levels of recursion.

Program efficiency and inter-routine communication are two reasons why it might be desired to have some routines behave nonrecursively. The mechanism for isolating variables and making them local, not just to a routine but to each call of a routine, involves some computational overhead. Isolating local variables of routines between routine calls also makes it impossible for a routine to transmit information from one call to another through a local variable, or to "remember" values across successive calls. In recursive routines, this can only be accomplished by using global variables or explicitly passing values as arguments.

All the local variables of a program, or selected local variables in individual routines, can be defined as **saved** or **recursive**. If a variable is **saved**, it is stored in a memory location associated with a routine it is local to, but accessible by all references to it from any invocation of this routine. Unlike a **recursive** variable, a **saved** variable is not released when control returns to a calling program, and is not reinitialized at each new call, but retains any value assigned to it when the routine was last executed. **Saved** variables are initialized to zero before their first use.

There are three different kinds of routine variables: arguments, **saved** variables, and **recursive** variables. Arguments are implicitly treated as **recursive** variables initialized from transmitted values. They may not be defined as **saved**.

All local variables in a program, except for routine arguments, may be declared as either **saved** or **recursive**, by using the phrases:

```
type is saved
```

or

```
type is recursive
```

in the last **normally** statement of a program preamble, as in:

```
normally, mode is real, type is saved
```

Because the last **normally** statement in the program preamble applies to all local variables unless they are otherwise qualified, this statement sets a background condition that is binding on all unqualified variables. If a **type** phrase is not used, all local variables are treated as **recursive**.

Within routines, local variables can be declared as **saved** or **recursive** in a **normally** statement or in **define** statements. In **define** statements, use of the words **saved** or **recursive** is similar to use of the property words that define the mode. Examples are:

```
define VALUE as a real, recursive variable
define QUANTITY as a saved variable
define X,Y and Z as recursive, integer variables
```

Local arrays may be treated as **saved** or **recursive** by making their base pointers **saved** or **recursive**. Thus, write:

```
define TABLE as a real, saved, 2-dimensional array
```

Recursion can best be understood with an example. The program below uses Horner's method for evaluation of polynomials. This method has the computational advantage of requiring only  $2(K-1)$  arithmetic operations to evaluate a polynomial of order  $(K-1)$ , which is fewer than are required by straight-forward evaluation. A polynomial of the form:

$$A(K) + A(K-1)*X \dots + A(1)*X^{(K-1)}$$

may be expressed in the recursive form:

$$A(K) + X*( A(K-1) + \dots + A(1)*X^{(K-2)} )$$

The following brief SIMSCRIPT II.5 routine demonstrates a program for evaluating this form.

In the program preamble:

```
define POLYN as a real function
```

Routine definition:

```
function POLYN given A, XVAL and K
  define A as a 1-dimensional real array
  define XVAL as a real variable
  define K as an integer variable
  if K eq 0
    return with 0
  otherwise
    return with A(K) + XVAL * POLYN(A(*), X, K-1)
end
```

Notice that the interior call to **POLYN** uses **K-1** as an argument instead of **K**. To illustrate how the routine works, the evaluation of the polynomial is described:

$$3.3x^2 + 2.1x + 9.2$$

Assume that the coefficients **3.3**, **2.1**, and **9.2** are stored in an array **COEF**, in the order **COEF(1)**, **COEF(2)**, and **COEF(3)**, respectively. The polynomial is to be evaluated for the value **x = 0.5**. The function is called by the statement:

```
let VALUE=POLYN(COEF(*), 0.5, 3)
```

The polynomial is evaluated as:

```
POLYN(COEF(*), 0.5, 3)
= 9.2 + 0.5 * POLYN(COEF(*), 0.5, 2)
= 9.2 + 0.5 * ( 2.1 + 0.5 * POLYN(COEF(*), 0.5, 1) )
= 9.2 + 0.5 * ( 2.1 + 0.5 * ( 3.3 + 0.5 * POLYN(COEF(*), 0.5, 0) ) )
= 9.2 + 0.5 * ( 2.1 + 0.5 * ( 3.3 + 0.5 * 0.0 ) )
```

which evaluates to **11.075**.

A commonly used data structure in computing is the "tree" structure. One form of such a structure is a "binary tree," where each node within the tree may have a "left branch" and a "right branch" that represents links to other nodes in the tree. One node is chosen to represent the root. No node is directly linked to/from more than one other node. Any node may be reached by starting from the root and taking successive links at each node encountered. At the end of each possible path are "leaf" nodes that have no successor links. Binary trees are well suited to processing with recursive routines, since each node in such a tree may be considered as a "root" for a tree at a lower level within the hierarchy of nodes.

An example of a recursive routine for destroying all the nodes of binary tree is shown below. The tree is constructed of two-element, one-dimensional arrays that point to each other. Data storage at the nodes may be disregarded for this example. To illustrate the tree-building process, the following program segment forms the root of a binary tree named **TREE**:

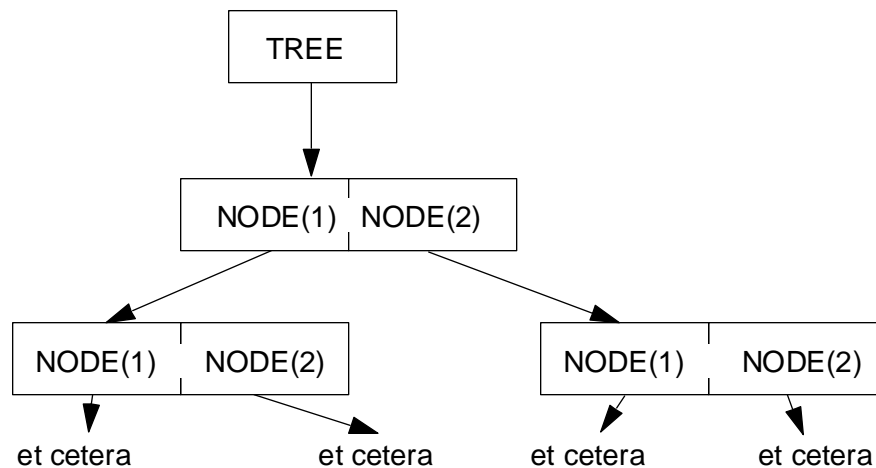


```

normally mode is integer
define NOD and NODE as 1-dimensional arrays
reserve NODE(*) as 2
let TREE = NODE(*)
let NODE(*) = 0
reserve NODE(*) as 2
let NOD(*) = TREE
let NOD(1) = NODE(*)
let NODE(*) = 0
reserve NODE(*) as 2
let NOD(2) = NODE(*)
let NODE(*) = 0
:
end

```

**NOD** is used as a dummy array name to which a previous **NODE** pointer is assigned to allow nodes to connect to the nodes above them in the tree. This is not the most efficient way to process such trees. The tree constructed by the program above is illustrated in figure 2-6.



**Figure 2-6. Tree Construction**

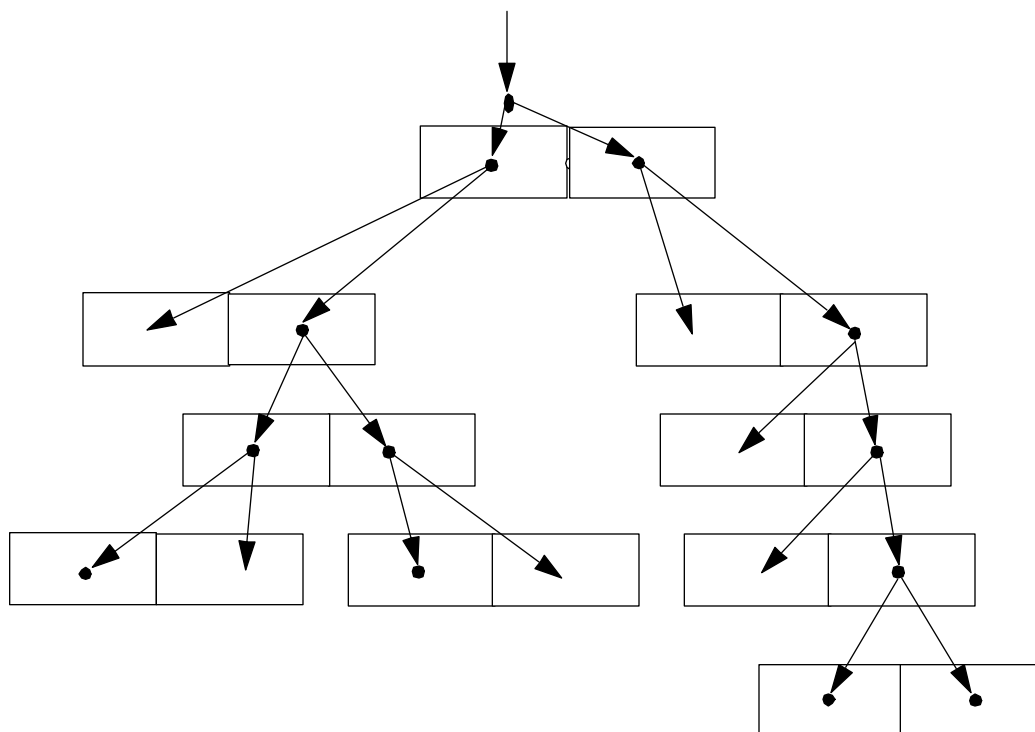
A recursive routine to destroy such a tree is shown below. Given the pointer to the root of the tree, the routine follows all paths in the tree and destroys the nodes on them:

```

routine DESTROY(NODE)
  normally mode is integer
  define NODE as a 1-dimensional array
  if NODE(*) is not zero,
    for BRANCH = 1 to 2
      call DESTROY(NODE(BRANCH))
    release NODE(*)
  always
  return
end

```

This routine, when called by a statement such as `call DESTROY(TREE)`, calls upon itself as each node destroys the nodes below it. Because each node either points to a successor node or is zero, the routine can tell whether it has to follow a downward path to destroy successor nodes, or whether it can destroy the node it is working on by releasing it. Perhaps the easiest way to understand this routine is to construct a typical tree, such as that shown in figure 2-7, and follow the logic through.



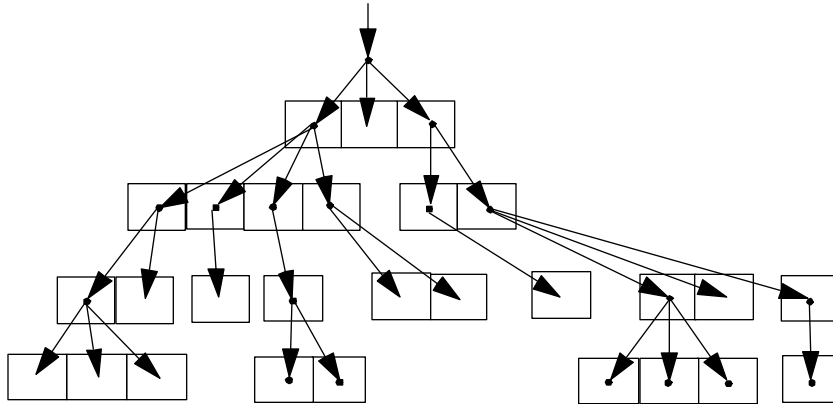
### Figure 2-7. A Binary Tree

By changing one statement, as shown below, the routine can easily be expanded to destroy not only binary trees, but those containing limitless branches as well:

```

routine DESTROY(NODE)
    normally mode is integer
    define NODE as a 1-dimensional array
    if NODE(*) is not zero,
        for BRANCH = 1 to dim.f(NODE(*))
            call DESTROY(NODE(BRANCH))
        release NODE(*)
    always
    return
end

```



**Figure 2-8. A Complex Tree**

The ability to use the `dim.f` function makes it easy to allow each node to have several branches, rather than only two. Such a tree might look like figure 2-8.

## 2.24 Pre-Processing Program Text

In the interests of readability, SIMSCRIPT II.5 provides two program text substitution facilities. The first allows a defined sequence of words to be substituted for a single word. The statement:

```
word to mean sequence of words
```

means that each occurrence of word in the program text is replaced, before interpretation, by a sequence of characters. The word to be replaced may be any name, single character, or sequence of characters not containing a blank. However, only clearly identifiable occurrences are replaced. Embedded occurrences in other strings are not extracted for replacement. The string to be substituted may be any sequence of characters or words, delimited by the end of a statement line. It may contain embedded blanks. Comment text is not affected. This feature provides, for instance, the ability to represent the constants that frequently appear in programs as meaningful names. Including such definitions, for example, as:

```
define .IDLE.STATUS to mean 0
define .BUSY.STATUS to mean 1
define .DOWNSTREAM to mean 2
```

allows statements to be written as:

```
if STATUS.CODE = .BUSY.STATUS
or DIRECTION = .DOWNSTREAM
let STATUS = .IDLE.STATUS
```

while being interpreted as:

```

if STATUS.CODE = 1
or DIRECTION = 2
  let STATUS = 0

```

Defining constants in this symbolic way greatly eases the task of program modification, should some of these constant values have to be adjusted. Of course, variables could be assigned to these constant values with similar effect. However, it is possible for variables to be inadvertently modified with consequent effect on the meaning. In order to clearly distinguish constants defined in this manner from program variables, it is suggested that a unique name construction be reserved for those names that are to be substituted. The form used above, which does not detract from readability, is to prefix all such names with a period.

Another potential use is in the redefinition of keywords in a program. For instance, the words **procedure**, **execute**, and **finish** may be preferred to the SIMSCRIPT II.5 terms **routine**, **call**, and **end**. Preceding a program with the statements:

```

define PROCEDURE to mean routine
define EXECUTE to mean call
define FINISH to mean end

```

allows the program to be written with this redefined vocabulary and then be translated into SIMSCRIPT II.5 vocabulary before compilation.

The scope of the **define to mean** statement is similar to that of the **normally** statement. When used in a program preamble, it extends throughout an entire program unless overridden. When used in a routine, it holds (until overridden) for that routine only.

Entire sequences of statements can be generated directly into a program by an extended form of the **define to mean** statement. The extended form allows more than one line of statements to be substituted for a particular word, and it offers greater possibilities for macro-instruction generation. The statement can be written in two ways:

```

substitute this line for word

```

and

```

substitute these i lines for word

```

In the first statement, the contents of the line following the statement are substituted for the word wherever it appears. In the second statement, the contents of the following *i* lines are substituted. As with the **define to mean** statement, totally blank cards and comments cannot be substituted.

**Define to mean** and **substitute** statements can be used freely in a program with few restrictions. They can "call on" one another at different levels of substitution. The following statements show how a series of **define to mean** and **substitute** statements can be applied to a program statement and used to translate the words of the statement into legal SIMSCRIPT II.5 code.

```

substitute these 2 lines for ZZ
    set VALUE = B
    go to START
define SET to mean let
define B to mean X(1)*Y(1)+1

```

Program statement:

```

if VALUE is greater than 0 ZZ

```

Translation:

**ZZ** is translated to:

```

set VALUE = B
go to START

```

set VALUE = B is translated to

```

let VALUE = B and then to

```

```

let VALUE = X(1)*Y(1)+1

```

Compiled as:

```

if VALUE is greater than 0
    let VALUE=X(1)*Y(1)+1
    go to START

```

Certain words, such as statement key words, should be redefined with extreme caution. If, for example, the word **A** is defined, as in the statement:

```

define A to mean X

```

and a **define** statement such as **define LIST as a real array** is processed, **X** will be substituted for **A**, and will create the incorrect statement **define LIST as X real array**.

The effect of **define to mean** statements can be withdrawn by the statement:

```

suppress substitution

```

and reinstated by the statement:

```

resume substitution

```

These statements should be placed alone on program statement lines, because substitution takes place for an entire line as it is read, and before the contents are interpreted. If other statements appear on the same record as a **suppress substitution** statement, substitutions are made for such statements (if called for) before the **suppress** command is recognized. To suppress substitution for a particular word, the word itself is defined, as in the following example:

```

suppress substitution
define X to mean X
resume substitution

```

If the **suppress** statement is not used, the current substitution will be made for **x** before the **define** statement is recognized, and **x** will never be redefined.

Thoughtfully used, these substitution capabilities can add to the readability of a program and simplify the modification of program constants or parameters. Conversely, careless or excessive use can render a program almost unreadable, greatly obscuring the logical intent and adding to the difficulties of program maintenance.

## 2.25 More On Changing The Flow of Computation

Although the control structures described in Chapter 1 are sufficient to express any desired direction of the flow of control, they do not readily suit the case where there are many possible paths from which to choose.

An additional control structure which is very useful in these more complex situations is the **select ...endselect** control block, commonly referred to as the **case** statement. This construct allows transfer of control to any one of an arbitrary number of alternatives. The **select** statement transfers control to the first **case** statement with a value corresponding to the value of the expression. If a matching value is not found, execution begins following the **default** statement, if specified. A run-time error occurs if there is no match and **default** is omitted. The general form of the **select** structure is:

```

select case expression

case constant list
    statement group
.
.
.
case constant list
    statement group
default
    statement group
endselect

```

where:

**expression** is a valid expression of any mode.

**constant list** is a list of the form:

```
value1 [ , value 2 , ... , value n ]
```

in which each **value i** is of the form:

**constant**

or

**constant to constant**

the mode of **expression** and each **constant** must agree, in accordance with the following rules:

1. If **expression** is numeric (integer, real or double), then each **constant** must be numeric.
2. If **expression** is alpha or text, then **constant** must be a literal string delimited by quotation marks,

e.g., **"string"**.

3. If **expression** is a subprogram variable, **constant** must be a subprogram literal (see paragraph 2.30) delimited by single apostrophes, e.g., **'sin.f'**.

Each statement group is a sequence of 0 or more SIMSCRIPT statements.

The following example emulates a simple calculator:

```
define OPERATION as a text variable
define OPERAND1, OPERAND2 and RESULT as real variables
until OPERATION = "halt"
do
    read OPERATION, OPERAND1 AND OPERAND2
    select case OPERATION
        case "+"
            let RESULT = OPERAND1 + OPERAND2
        case "-"
            let RESULT = OPERAND1 - OPERAND2
        case "*"
            let RESULT = OPERAND1 * OPERAND2
        case "/"
            let RESULT = OPERAND1 / OPERAND2
        case "halt"
        default
            print 1 line with OPERATION thus
            ***** is not a valid operation.
    endselect
loop
```

The cases may be overlapping, in which case the first matching case will be selected for execution. For example:

```

define LETTER as an alpha variable

.
.
.
select case LETTER
  case "A", "E", "I", "O", "U"
    print 1 line with LETTER thus
    * is a vowel.
  case "Y"
    print 1 line with LETTER thus
    * is strange.
  case "A" to "Z"
    print 1 line with LETTER thus
    * is a consonant.
endselect

```

Unlike comparable constructs in other languages, it is not necessary to explicitly exit a **select...endselect** block. Where a **case** statement begins a group of statements, the group is automatically terminated by the next **case**, **default**, or **endselect** statement. Control is transferred to the statements following the **endselect** statement. Thus:

```

case 1
case 2
  print 1 line thus
  this is a small number

```

would cause absolutely nothing to happen if the value of the expression is **1**. The programmer probably intended to write:

```

case 1,2
  print 1 line thus
  this is a small number

```

which will print the message for values of both one and two.

The use of the **default** statement is optional. If included, it must come after all of the corresponding **case** statements. If omitted, a run-time error will result if **expression** does not match one of the specified cases.

**Select...endselect** blocks may be nested within each other, or with **if...else...always** and **do...loop** structures. Care must be taken to ensure that the blocks do not overlap.

## 2.26 Some Data-Related Logical Values

Two of the system-defined functions supplied in SIMSCRIPT II.5, **efield.f** and **sfield.f**, have no given arguments. These functions together with some system defined logical values are provided in SIMSCRIPT II.5 to allow a number of properties of input data to be examined or tested



during program execution, before the data are read using a free-form **read** statement. These functions and logical values, sometimes called "look-ahead functions," are shown in table 2-4.

**Table 2-4. Look-Ahead Functions**

<u>Name</u>	<u>Value</u>
<b>data</b>	End of data indicator: <b>ended</b> or <b>not ended</b>
<b>sfield.f</b>	Starting column number of the next data field
<b>efield.f</b>	Ending column number of the next data field
<b>mode</b>	Mode of the next data field: <b>integer</b> , <b>real</b> , or <b>alpha</b>
<b>card</b>	First data field on card indicator: <b>new</b> or <b>not new</b>

Some examples illustrate the use of these system variables:

1. Frequently, the logical condition for terminating processing is reaching the end of the input data. This condition may be tested for with logical comparisons of the form:

```
if data is ended
until data is ended
while data is not ended
```

2. **sfield.f** can be used to distinguish input data records that appear in two formats. Some of the records contain data beginning in column 1, while in others the data fields start in column 25. These two record types are to be processed differently. A value for **sfield.f** is determined before each new value is read, but the data item itself is not read until a **read** statement is executed.

```
if sfield.f eq 1
  read DATA1
else
  if sfield.f eq 25
    read DATA25
  else
    skip 1 record
  always
always
```

3. **efield.f** may be used in the same way to determine the last column position of the next data field. Using both functions, the number of characters in a data field may be determined before the field is read and processed.
4. The **mode** property of a data field may be tested to discriminate between **integer** and **real** numeric data, or any non-numeric data, identified as **alpha**. A succession of name

fields, each followed by a varying number of numeric values, might be processed by statements such as:

```
while data is not ended
until mode is alpha
do
    read NUMBER
.
.
loop
stop
```

The property **double** is treated as synonymous with **real**, while **text** may be used as a synonym for **alpha**.

5. Although free-form input in SIMSCRIPT II.5 ignores record columns or record boundaries, it is possible to test whether the next data field is positioned at the beginning of a data record. Perhaps this condition might indicate the start of a new batch of data items. The condition may be tested for by such logical comparisons as:

```
if card is not new
until card is new
```

When there are no further data fields (either none exists or all data have been read and look-ahead is impossible), the system variables have the values shown in table 2-5.

**Note:** The term **card** is used for historical reasons . It stands for record.

**Table 2-5. Values for System Variables When Data Are Ended**

<u>Name</u>	<u>Value</u>
<b>data</b>	<b>ENDED</b>
<b>sfield.f</b>	<b>0</b>
<b>efield.f</b>	<b>0</b>
<b>mode</b>	<b>ALPHA</b>
<b>card</b>	<b>NEW</b>

## 2.27 More Sample SIMSCRIPT II.5 Level 1 Programs

### 2.27.1 A Data Analysis Program: 1

This example illustrates a use of subscripted variables, with **reserve** and **read** statements, and the use of **for** loops to control the indexing of subscripted variables.

The program reads a list of **N** data items into an array. It then goes through the list, computing for each index value the averages of successive overlapping sequences of values, with sequence lengths varying from 2 to a maximum of **N-1**. These moving averages are compared with an arbitrary tolerance value. If they are less than this value, the values of the index, the sequence length, and the average are printed.

#### Program 2-2.

---

```

main
define LIST as a 1-dimensional array
define I, J, SEQ.LEN and N as integer variables
define TOLERANCE.VALUE, SUM and AVERAGE as real variables
read N
reserve LIST(*) as N
read LIST, TOLERANCE.VALUE
for SEQ.LEN = 1 to N-1
    for I = 1 to N-SEQ.LEN
do
let SUM = 0
    for J = 0 to SEQ.LEN
        add LIST(I+J) to SUM
let AVERAGE = SUM/(SEQ.LEN+1)
if AVERAGE is less than TOLERANCE.VALUE
    print 1 line with I, I + SEQ.LEN and AVERAGE thus
ITEMS *** THROUGH *** HAVE AN AVERAGE OF **.*
always
loop
release LIST(*)
stop
end

```

---

### 2.27.2 A Data Analysis Program: 2

To illustrate the way in which the logical elements of a program may be separated into routines, this example repeats the computations of the previous problem, but instead of computing the averages of the data values, computes the average of a function of the values. As the function to be used may conceivably vary for different sets of data, or under different circumstances, the function evaluation is logically partitioned from the main body of the program, and written as a function routine. It may then be both separately tested and altered without having to modify the main routine. Note that the function routine must now be declared within the program preamble.

#### Program 2-3.

---

```

preamble
    define VALUE as a real function
end
main
    define LIST as a 1-dimensional array
    define I,J, SEQ.LEN and N as integer variables
    define TOLERANCE.VALUE, SUM and AVERAGE as real variables
    read N
    reserve LIST(*) as N
    read LIST
    read TOLERANCE.VALUE
    for SEQ.LEN = 1 to N-1,
        for I = 1 to N-SEQ.LEN
            do
                let SUM = 0
                for J = 0 to SEQ.LEN
                    add VALUE(LIST(I+J)) to SUM
                let AVERAGE = SUM/(SEQ.LEN+1)
                if AVERAGE is less than TOLERANCE.VALUE
                    print 1 line with I, I + SEQ.LEN and AVERAGE thus
ITEMS *** THROUGH *** HAVE AN AVERAGE OF **.*
                always
            loop
        release LIST(*)
    stop
end
routine VALUE given VARIABLE
    if VARIABLE is less than -1000
        return with -1
    otherwise
    if VARIABLE is greater than 1000
        return with 1
    otherwise
    return with VARIABLE/1000
end

```

---

### 2.27.3 A Matrix Multiplication Program

Two matrices (double-subscripted variables) are to be read from data records. Matrix **A** is input row by row. That is, the values appear in the order **A(1,1)**, **A(1,2)**, ..., **A(1,M)**, **A(2,1)**, ..., **A(2,M)**, **A(3,1)**, ..., **A(N,M)**. Matrix **B** appears column by column in the order **B(1,1)**, **B(2,1)** ..., **B(S,1)**, **B(1,2)**, ..., **B(S,2)**, **B(1,3)**, ..., **B(R,S)**.

The values of the matrix dimensions **N**, **M**, **R**, and **S** precede the element data. This program reads the data, checks that multiplication is possible and, if so, multiplies the matrices **A** and **B** together placing the values in matrix **C**.

For matrix multiplication to be possible, **M** must equal **R**. The rules for computation are:

```

if A has dimensions N, M and
  B has dimensions M, S then
    C has dimensions N, S and the elements of C are computed as:

```

$$C(I,K) = \sum_{j=1}^M A(I,J) * B(J,K)$$

The program below illustrates the use of the **reserve** statement with variable dimensions executed in the body of a program, two forms of **read** statement formats for inputting subscripted variables, nested **for** loops, and the use of the **list** statement.

**Program 2-4.**


---

```

main
  define A,B and C as real 1-dimensional arrays
  define I,J,K,M,N,R and S as integer variables
  read N, M, R and S
  if M is not equal to R,
    print 2 lines thus
MATRIX DIMENSIONS ARE NOT EQUAL,
MULTIPLICATION IMPOSSIBLE
    stop
  otherwise
  reserve A(*,*) as N by M,  B(*,*) as R by S,  C(*,*) as N by S
  read A
  for J = 1 to S,
    for I = 1 to R,
      read B(I,J)
  for I = 1 to N,
    for K = 1 to S,
      for J = 1 to M
        add A(I,J) * B(J,K) to C(I,K)
  list A,B and C
  stop
end

```

---

**2.27.4 A Matrix Multiplication Routine**

This program presents the previous program written as a routine. It returns a coded value if multiplication is not possible. Unlike the foregoing program, this routine does not assume that the matrix **C** is initialized to zero by the calling routine, and an initialization statement is included in the routine.

**Program 2-5.**


---

```

routine MATRIX.MULTIPLY given A,B and C
    yielding CODE
    define A, B and C as 2-dimensional real arrays
    define CODE as an integer variable
    define N, M, R, S, I, J, K as integer variables
    let N = dim.f(A(*,*))
    let M = dim.f(A(1,*))
    if M is not equal to dim.f(B(*,*))
        let CODE = 1
        return
    otherwise
    let S = dim.f(B(1,*))
    for I = 1 to N,
        for K=1 to S
        do
            let C(I,K) = 0
            for J = 1 to M
                add A(I,J) * B(J,K) to C(I,K)
            loop
        return
end

```

---

This routine might be used in a program by calling on it as:

```

call MATRIX.MULTIPLY(TABLE1(*,*), TABLE2(*,*), TABLE3(*,*))
    yielding FLAG
if FLAG ne 0
    print 1 line thus
MATRIX DIMENSIONS INCOMPATIBLE
else
:

```

**2.28 More on Program Format**

In general, SIMSCRIPT II.5 program statements may occupy up to 80 character positions on each of the source input records. By convention, some systems use a number of positions at the end of each program source record for sequence numbering. These sequence numbers do not constitute valid SIMSCRIPT II.5 program content, and, should they appear within the first 80 positions, would give rise to syntax errors during compilation. The compiler may be instructed to ignore such sequence numbering using a statement of the form:

```

last column is integer constant

```

This specifies that columns to the right of the indicated column do not contain program statements. These columns appear on all program listings produced during compilation, but are not treated as part of the program text. Each time a **last column** card is used in a preamble, the number of program statement columns may change. The last **last column** statement used in a preamble applies to all subprograms that follow. This statement may not appear in individual routines within a program. The simplest preamble, used to specify sequence number columns, is:

```
preamble
  last column is 72
end
```

This specifies that in all succeeding cards only columns 1 through 72 contain program statements. Columns 73 through 80 are listed but ignored during compilation.

## 2.29 A Useful Output Statement

There are occasions when it is useful to generate clearly labeled values of selected variables with no attempt at explicit formatting. This is particularly helpful when checking for programming errors, for example.

The **list** statement prints labeled values of expressions and variables. The form of the statement is:

```
list variable name or expression list
```

Explicitly subscripted variables and entire array names may be included in the list. Expression and array values are printed in standard formats. These formats vary somewhat on different implementations.

In general, expression values are printed in rows across a page with the "name" of each expression beside its value. Thus a request to:

```
list A, B(1), A*B(1)
```

might produce the output:

```
A = 2.000000          B(1) = 3.500000          A*B(1) = 7.000000
```

If unsubscripted array names appear in the list, all elements of the array are listed in the output with each element value labeled with its corresponding subscripted array name. As many values are placed on each line as will fit, according to spacing conventions. Such conventions usually allow the name of the variable justified on the left in a field aligned to a column multiple of 16, followed by the value of the variable. A minimum of two character positions is allowed between successive variable fields across a line. **Text** and **alpha** variables values are enclosed in double quotation marks.



Multiple-subscripted variables, both rectangular and ragged, may be printed using the **list** statement. Any row in an array that has not yet been reserved by a **reserve** statement, produces an output of the form:

```
array name(i,j,...*) = ***unreserved***
```

If more than one array is mentioned in a **list** statement, they are printed successively in the order in which they appear in the list.

As the spacing conventions must constrain the number of character positions allocated to a noninteger number, those having very large or very small values are output in exponent or scaled scientific notation. In this format, the value is represented as a normalized value between 1.0 and 0.1 scaled by a power of 10, which may be positive or negative. This exponent is usually indicated as **E+xx** or **E-xx**, where **xx** represents the power of 10, immediately suffixed to the normalized value.

As a word of caution, the **list** statement can be misleading in respect of numeric precision. The number of significant figures printed by a **list** statement cannot be chosen, as in a **print** statement, to limit the apparent accuracy and thus reflect the true significance, but rather is selected to allow a wide range of values to be output. Thus, some interpretation of the printed values may be required.

## 2.30 Subprogram Variables

Thus far, all references to subprograms have used the defined subprogram name to identify the subprogram to be executed. It is possible, however, to reference a subprogram indirectly, through the use of a **subprogram** mode variable. Such a variable, like any other variable type, may be assigned various values during execution of a program. The values that may be assigned are the referencing values of routines within the program. As the only valid use of a **subprogram** variable is as a reference within an indirect call, the only operations permitted are assignment and comparison operations, and the only values that may be assigned or compared are other **subprogram** variables or **subprogram** literal values, or a zero, indicating a null value. A variable is declared as a **subprogram** mode in the usual way:

```
define variable list as a subprogram variable
```

A subprogram literal is formed by enclosing in single quotes the name of any routine used within the program, or any defined library routine, with some exceptions mentioned later. A **subprogram** variable, which has been assigned a value, may then be used in place of a routine name in a normal **call** statement. The example below demonstrates the assignment and use of a **subprogram** variable:

```
define RVAR as a subprogram variable
let RVAR = 'DATA.TRANSFORM'
.
.
call RVAR giving DATA(*) yielding VALUE
```

As seen in this example, a **subprogram** variable can be used instead of an actual routine name in a **call** statement. When a **subprogram** variable appears in a **call** statement, the effect is the same as a direct **call** on the routine named in the assignment to the **subprogram** variable. This provides a powerful mechanism for directing the selection of routines to be called during program execution.

**Subprogram** variables can be global or local, **saved** or **recursive**, and subscripted or unsubscripted. They are initialized to zero in the normal way, and should not be used in a **call** until a value has been assigned. Obviously, the numbers of arguments passed through a **subprogram** variable cannot be checked against any one routine definition in the preamble. Execution time checking, however, may still be carried out.

While **subprogram** arrays can be defined and values assigned to the subscripted elements, subscripted elements cannot be used directly to reference a routine. This is because of the ambiguity in the notation used for both subscripts and routine arguments. Any parenthesized variables or expressions following the **subprogram** variable are interpreted as **given** arguments to the routine being referenced.

**Subprogram** variables can also be used to call functions. The mode of the **subprogram** variable must be declared in a statement of the form:

```
define variable list as a mode subprogram variable
```

All functions called indirectly through this variable must be of the declared mode. If no mode is declared, the current background mode is assumed.

An indirect function call must be indicated by putting a dollar sign (\$) before the **subprogram** variable name. This is required to distinguish between assignment of values between **subprogram** variables and actual function references. If **FVAR1** and **FVAR2** are declared as **subprogram** variables, the statement:

```
let FVAR2 = FVAR1
```

assigns to **FVAR2** a copy of the value in **FVAR1**, while:

```
let VAR = $FVAR1
```

assigns to **VAR** a value computed by the function referenced by **FVAR1**.

Program 2-6 illustrates several of the permissible usages of variables defined as **subprogram**. The first example shows a number of routine name literals passed as arguments to a subprogram, which in turn calls the selected routine indirectly. The second example is similar, but illustrates the use of a **subprogram** variable array, comparison operations, and the function notation used with **subprogram** variables.

**Program 2-6.**


---

```

main
    normally mode is integer
    define DATA as a 1-dimensional real array
    read N
    reserve DATA(*) as N
    read DATA
    call PROCESS.DATA given 'EXP.F' and DATA(*)
    call PROCESS.DATA given 'SQRT.F' and DATA(*)
    call PROCESS.DATA given 'LOG.10.F' and DATA(*)
    stop
end

routine PROCESS.DATA given FVAR and ARR
    define FVAR as a real subprogram variable
    define ARR as a 1-dimensional real array
    for I = 1 to N,
        compute S as the sum, M as the mean and V as the variance
            of $FVAR(ARR(I))
        print 1 line with S, M and V thus
SUM= *.*      MEAN= *.*  VARIANCE= *.*
        return
end

define FVARR as a 1-dimensional real subprogram array
define FUNCV as a real subprogram variable
.
.
let FVARR(1) = 'DATA.READ.FN'
let FVARR(2) = 'DATA.TRANSFORM.FN'
let FVARR(3) = 'DATA.INVERT.FN'
.
.
for I = 1 to N
    with FVARR(I) ne 0
do
    let FUNCV = FVARR(I)
    let DATA(*) = $FUNCV(DATA(*))
.
.
loop
.
.
call PROGVAR giving 'DATA.PLOT' yielding NULL
.
.
end

```

```
routine PROGVAR given RVAR yielding VALUE
  define RVAR as a subprogram variable
  define VALUE as an integer variable
  if RVAR ne 'DATA.PLOT'
    and RVAR ne 'DATA.PRINT'
    call RVAR giving DATA(*) yielding VALUE
  else
    call RVAR giving DATA(*)
    let VALUE = 0
  always
  return
end
```

---

### 2.31 The Store Statement

Previous implementations of SIMSCRIPT II.5 offered a **store** statement which provided for assignment of variables without any attempt at variable mode conversion. This proved to be a common source of error. The **store** statement is still provided, but it is restricted to use only with variables of compatible mode. Its effect is identical with that of the **let** statement, which is recommended as preferred usage. The **store** statement is not intended for use with values in the **text** mode. All other nonconversion assignments may be achieved by variable equivalencing, described in Chapter 6.

## 3. Input/Output Concepts

---

### 3.1 Introduction

This chapter introduces some additional control structures provided by SIMSCRIPT II.5, and then describes in detail the full input and output formatting facilities available in the language.

### 3.2 A Search Capability

It is often necessary to search among a number of variable values for one satisfying some stated condition. The **find** statement provides a means of specifying some such condition and is used, in conjunction with a **for** control phrase, to search a group of values for the first value meeting the specification. The statement:

```
for I = 1 to N,  
  with X(I) * Y(I) greater than LIMIT,  
  find BIG = the first I
```

is a compound statement composed of a qualified **for** phrase and a **find** statement. The **for** phrase steps the variable **I** through the sequence of values **1 ,2, ..., N**; the **with** phrase specifies that only those values of **I** for which **X(I) \* Y(I)** is greater than **LIMIT** are eligible for consideration; the **find** statement specifies that the repetition is to terminate as soon as such a value is found, assigning this value to the designated variable, **BIG**. The words **the** and **first** are optional after the equal sign. The statements:

```
find BIG = the first I  
find BIG = first I  
find BIG = I
```

are equivalent, and illustrate alternate forms of the basic **find** statement:

```
find variable = arithmetic expression
```

Any variable, subscripted or otherwise, may be designated. When the first index value is found for which the logical expression in the **for** phrase is true, the arithmetic expression is evaluated and assigned to the variable. Thus, in the above example the value of the expression **I** is assigned to the variable **BIG** when a value of **I** is found for which **X(I) \* Y(I)** is greater than **LIMIT**. As the search is always terminated at the first suitable value encountered, a backward-iterating **for** phrase may be used to find the last such value in a group.

A special form of the **if** statement may be used in conjunction with the **find** statement. This provides for alternative actions to be selected based on the outcome of the search. An **if** statement appended to a **find** statement may test for success or otherwise using the logical conditions:

```
if found
```

or

```
if none
```

These logical conditions obviously have no meaning outside the immediate context of a **find** statement. The following statements search a number of elements of array **A** for one that matches the value **B**, assigning a new element value if no match is found:

```
for I = 1 to N
  with A(I) = B
  find the first case
  if none
    let N = N+1
    let A(N) = B
  always
```

More than one **for** phrase can be used to control a **find** statement. Also more than one **find** variable may be assigned in one **find** statement. This is done by including a list of variable assignment phrases. The following example illustrates both features:

```
for I = 1 to N,
  for J = 1 to M,
    with FN(I) less than FN(J)
  find FS(1) = the first I and FS(2) = the first J
```

In cases where there is no expression to compute, a special form of the **find** statement can be used. The words **the first case** replace the variable assignment phrase. The search terminates, as before, with the first matching value. The terminating value of the **for** index variable is available for subsequent use. Both of the following statements terminate with the same value of **I**:

```
for I = 1 to MAX,
  with V(I) less than QQ(I),
  find the first case

for I = 1 to MAX,
  with V(I) less than QQ(I),
  find I = the first I
```

### 3.3 A Statement for Computing Some Standard Functions of Variables

Rather than selecting a single value satisfying some criterion, it may be desirable to summarize some statistics of a group of values. When these values are stored in arrays, or can be computed by some regular iteration, the **compute** statement facilitates compilation of descriptive statistics. An example of the use of a **compute** statement is:

```

for I = 1 to N,
  compute
    MEANX as the mean,
    MAXIMUMX as the maximum of X(I)

```

Like the **find** statement, the **compute** statement contains a list of variables that are set to a computed value after iteration. In this case, the values are specified by statistical names, such as **mean** and **maximum**. A **compute** statement has the general form:

```

compute compute list of arithmetic expression

```

where **compute list** is a list of variable and statistical names of the form **variable = statistic name**. The optional word **the** may be omitted before each statistic name, and the word **as** may be replaced by the equal sign. A **compute** statement can be controlled by more than one **for** phrase, and these may use logical control phrases to qualify the iteration sequence or the selection of individual variables. For example:

```

for I = 1 to N,
  for J = 1 to M,
    with LIST(J) greater than zero
    compute
      MN as the mean of TABLE(I,J) * LIST(J)

```

When a **compute** statement appears within a **do** loop with other statements, calculation of computed statistics, such as **mean**, takes place at the **loop** statement. If, for some reason, control is transferred out of the loop, the statistics are undefined. In the following example, computation of the indicated statistics is executed at termination of the inner **do** loop. Within this loop, the values **X(J)** are summed, and a count accumulated of the number of elements that form this sum. Before statement 4 is executed, these two values are used to compute the mean.

```

for I = 1 to N,
do
  statement1
  for J = 1 to M,
do
  statement2
  compute
    MEANX as the mean of X(J)
  statement3
  loop
  statement4
loop

```

Within the inner loop, the value of **MEANX** is undefined.

To have a **compute** statement controlled by several control phrases, a program is written with **also** phrases, as:

```

for I = 1 to N,
do
    statement1
also
    for J = 1 to M,
    do
        statement2
    compute
        SUMX as the sum and
        MAXX as the maximum of X(I,J)
loop

```

The names that may appear in the statistical list, and their computations, are shown in table 3-1.

**Table 3-1. Statistical Names Used In The Compute Statement**

<u>Statistic</u>	<u>Alternative or Abbreviation</u>	<u>Computation</u>
NUMBER	NUM	Number of items selected in the iteration.
SUM		Sum of the selected values of the expression.
MEAN	AVERAGE,AVG	SUM/NUMBER
SUM.OF.SQUARES	SQ	Sum of squares of the selected values of the expression.
MEAN.SQUARE	MSQ	SUM.OF.SQUARES/NUMBER
VARIANCE	VAR	MEAN.SQUARE - MEAN**2
STD.DEV	STD	SQRT.F(VARIANCE)
MAXIMUM	MAX	Largest of the selected values of the expression.
MINIMUM	MIN	Smallest of the selected values of the expression.
MAXIMUM(e)	MAX(e)	Value of the index variable (e) where the maximum was found.
MINIMUM(e)	MIN(e)	Same as MAX(e) but for minimum.

The following example illustrates the use of each of these statistics. Assume that an array **x** in a program has element values as shown:

```

X(1) = 4.0   X(2) = 7.3   X(3) = 12.8
X(4) = 0.5   X(5) = 2.2   X(6) = 7.3

```

and that **N** has the value 5. Let the program contain the statement:



```

for I = 1 to 6,
  with (I < N and X(I) < X(I+1)) or I = N,
    compute
      NX as the number, SUMX as the sum, NM as the mean,
      SSQX as the sum.of.squares, MSQX as the mean.square,
      VARX as the variance, SDVX as the std.dev,
      MINX as the minimum,
      MAXX as the maximum,  MINI as the min(I) of X(I)

```

The above statement iterates the control variable **I** over the values **1, 2, 3, 4, 5**, and **6**, and selects only those values for inclusion in the **compute** statement computations for which **I < 5** and **x(I) < x(I+1)**, or for which **I** equals **5**. Thus, it selects **x(2)**, and **x(4)** under condition 1 and **x(5)** under condition 2. For these index numbers, the statistical quantities are computed for the expression **x(I)**. The computed statistics are:

<u>Computed Variable</u>	<u>Statistic</u>	<u>Computation</u>
NX	NUMBER	4
SUMX	SUM	$4.0 + 7.3 + 0.5 + 2.2 = 14.0$
NM	MEAN	$14.0 / 4 = 3.5$
SSQX	SUM.OF.SQUARES	$(4.0)^2 + (7.3)^2 + (0.5)^2 + (2.2)^2 = 74.38$
MSQX	MEAN.SQUARE	$74.38 / 4 = 18.595$
VARX	VARIANCE	$18.595 - 3.5^2 = 6.345$
SDVX	STD.DEV	$\text{SQRT.F}(6.345) = 2.52$
MINX	MINIMUM	0.5
MAXX	MAXIMUM	7.3
MINI	MIN(I)	4

### 3.4 Input/Output Statements

The **read**, **write**, and **list** statements as described so far provide facilities to:

1. Read data in free form from an input data stream
2. Display messages and computational results in picture like formats
3. Generate labeled output data in a standard predefined format. No mention has been made of any selection capability for the source of input data or the destination of output data.

In practice, you may desire to associate an input or output data stream with any one of the variety of input and output devices, such as terminals, tape drives, or line printers, which may be connected

to a computer. A mechanism is also required to specify in detail the formats in which data should be read and written, and a facility to transmit data in internal machine representation.

Although the input/output programming statements provided are similar from one SIMSCRIPT II.5 compiler implementation to another, the exact interpretation and additional parameters required by these statements may vary from machine to machine. This variation is due to the differences in operating system requirements and device characteristics of different computer systems. Individual SIMSCRIPT II.5 user manuals describe the nature of these differences.

In general, three pieces of information must be specified when an input/output operation takes place:

1. A physical device
2. A data or information list
3. The desired data format.

In the statements **read**, **print**, and **list**, a physical device is implied (some default input and output device), the data list is stated explicitly, and the format is, in the first instance, "free," in the second, a "picture," and in the third, standardized. The statements described here provide a more flexible means of specifying this information.

### 3.4.1 Physical Device Specification

SIMSCRIPT II.5 programs may reference specific data streams using a logical unit number in certain input and output (I/O) statements. Each SIMSCRIPT II.5 logical unit number may then be associated with a specific device or data file through the computer system job control or command language. This allows each SIMSCRIPT II.5 program to refer to a file or I/O device in a common logical manner, postponing the detailed specification of individual file or data characteristics for definition in the appropriate system command language. Each logical unit number, therefore, is linked to an individual file or specific I/O device through the operating system.

Each file or I/O device that is to be referenced within a program is assigned a logical unit number. Logical unit numbers in SIMSCRIPT II.5 are integer numbers within the range 1 to 99 inclusive, units 98 and 99 being reserved for SIMSCRIPT II.5 system use. Some implementations may not support 99 distinct units. Consult the appropriate user's manual for details. A specific I/O device or file may be selected as the current input or output unit by executing a statement of the form:

```
device for input or          use unit device for input
```

and

```
use device for output or    use unit device for output
```

The word **unit** may be omitted. The value **device** may be any arithmetic expression that evaluates to a logical unit number. The SIMSCRIPT II.5 logical unit number referenced will be

associated with a particular I/O device through a logical filename, on operating systems that support such names. This logical filename will take the form **simunn**, where **nn** is the logical unit number. This logical filename may be used to associate the logical unit with some physical file or device, using the execution control commands specific to the operating system used.

By convention, most implementations designate **unit 5** as the default input device, usually the terminal or a card reader, and **unit 6** as the default output device, usually the terminal or a system printer. If a program does not contain **use** statements as in level 1 and 2 programs, SIMSCRIPT II.5 assumes the default input and output units are to be used for all **read**, **print**, and **list** operations. Note that the assignment of devices to these default logical unit numbers is installation-dependent, and may be altered through system control commands.

Any of the **read**, **print**, and **list** statements may be directed to use units other than the default input/output units, by executing a **use** statement before their execution. Each time a **use** statement is executed, a global variable named **read.v** or **write.v** is assigned the logical unit number of the designated unit. These two global variables can be used freely in all SIMSCRIPT II.5 statements:

```
if read.v = 5
    call SWITCH.UNIT
always
```

When a **use** statement is executed, the unit specified becomes the current input or output unit, as appropriate. This condition remains in effect until altered by a subsequent **use** statement, specifying that some other unit is now to become the current unit. It is possible to specify that a particular unit be treated as the current unit for the duration of a single input or output statement by appending to the statement a **using device** phrase. This phrase sets the current input or output unit to the indicated unit during the statement's execution, and returns it to its previous value on completion. Such a facility may be used to direct the flow of exception messages. For example:

```
use 5 for input
use 6 for output
while data is not ended
do
    read A,B,C
    call action A,B,C yielding FLAG, RESULT
    if FLAG ne 0
        print 1 line with A,B,C thus using unit 1
        ERROR WITH VALUES ** ** **
    else
        print 1 line with A,B,C, RESULT thus
        RESULT FOR VALUES ** ** ** IS **.*
    always
loop
```

Here data are accepted from **unit 5**, and results of some processing are printed on **unit 6**. Any error conditions, signified by a nonzero flag value returned from the processing routine, produce an exception message on **unit 1**.

### 3.4.2 The Formatted I/O Statements READ and Write

As described in Chapter 1, input and output data streams consist of a sequence of records, corresponding to lines of printed output or lines of data accepted from a terminal. Each record, in turn, is composed of a sequence of fields. A field is a logically defined group of consecutive symbols. In free-form data, a field is delimited by blank characters. In **print** output statements, an output field position within a printed line may be defined by asterisks. This latter facility may be extended to provide greater program-directed control over the structuring of both input and output records. A **read** statement that accepts formatted data has the form:

```
read variable list as format list
```

in which each variable value to be read has its input data format field described by a corresponding field descriptor character in a format list. These formats, which are codes describing how the fields in the input data stream are composed, are described in the next subsection.

The **write** statement transfers values from within the computer to specified external media. Every **write** statement is formatted. With the sole exception of the **list** statement, the programmer is always required to indicate the arrangement of output data. The **write** statement looks like the **read** statement. Its form is:

```
write expression list as format list
```

The indicated expressions, which may simply be variables, are evaluated and printed in the form described by their matching format descriptors. Before illustrating these **read** and **write** statements with examples, the format descriptors are defined.

#### 3.4.2.1 I (Integer) Descriptor

A descriptor of the form **n I w** is used for converting numbers from their internal integer computer storage representation to an external format, and vice versa. The character **I** is always followed by an expression (**w**), specifying the maximum number of digits in the integer field, including the sign. The **I** can be preceded by a number (**n**), declaring that the descriptor defines **n** consecutive identical data fields. Such formats as **2 I 6** and **14 I 3** define **2** fields of **6** positions and **14** fields of **3** positions, respectively. There must be at least one blank between the fields **n**, **I**, **w**.

When an **I** format is used for input, it specifies that the full contents of a field **w** digits wide are to be stored as the value of a corresponding variable in a **read** statement. Blank field positions — leading, embedded, or trailing — are treated as zeros. If a field is unsigned, it is interpreted as positive, although a plus sign can be typed. Except for the sign character, only numbers can be typed in a **I** data field. If **w** is larger than the maximum number of digits that can be stored in a computer word, only the rightmost, storable digits are used.

On output, an **I** format places a right-justified integer value in a field of specified width. Numbers larger than the field width are converted to scientific notation (see paragraph 3.4.2.3). Positive

numbers are printed unsigned, while negative numbers have the sign printed to the left of the highest-order digit. Leading zeros are suppressed.

### 3.4.2.2 D (Decimal) Descriptor

A descriptor of the form **n D(a,b)** is used for converting numbers from internal to external decimal representation, and vice versa. The **a** field specifies the number of characters in the data field, including the sign and decimal points. The **b** field specifies the number of digits to the right of the decimal point; and the optional **n** field specifies the number of consecutive values of the format.

When used for input, the **D** format accepts numbers typed with or without decimal points. If a decimal point is omitted, one is implied before the first digit in the **b** field. When a decimal point is present, it overrides the location specified by **b**. Very large and very small numbers can be input in scientific notation, for when used for input the **D** and **E** formats are equivalent.

Used in output statements, **D** formats describe the precision in which decimal numbers are displayed. Numbers that cannot be printed exactly in the specified format are rounded. Every number output by a **D** format is printed in a field of **a** columns: the first column is used for the sign, the next **a-b-2** columns are for digits, the next column is for the decimal point, and the remaining **b** columns are for digits. The sign is printed if a number is negative; otherwise it remains blank. If the integer part of a negative decimal number does not require all the **a-b-2** positions allotted to it, the sign is shifted to the right, next to the high-order digit. Leading zeros are suppressed. If a number has trailing zeros, as in the number 10.0, the trailing zeros are printed. Trailing zeros are not printed for a value of exactly zero.

### 3.4.2.3 E (Scientific) Descriptor

Extremely large and extremely small numbers, and numbers that vary widely in scale, can be read and written in a constant field width by using an **E** format. This format is similar to the **D** format in that it specifies a field width and a decimal point position by the numbers **a** and **b** in the form **n E(a,b)**, but it differs from the **D** format in having a scale factor field. The scale factor field appears to the right of a decimal number and indicates the necessary number of places right or left that the decimal point must be moved to convert the scaled number to its proper form.

The **E** format is thus equivalent to the **D** format, plus a scale factor. Numbers read under **E** format control are of the general form:

$$\pm XXX.XXXE\pm XX$$

although some latitude is allowed in writing the scale factor. A positive scale factor, such as **E+02** or **E 7**, raises the value of a printed number; **24.795E-04** represents an internally stored value of **.0024795**.

The **E** format can be used for both input and output. When used for output, it aligns numbers according to the format specification and prints a scale factor indicating the true value of the printed number. All **E** formatted numbers are **a** print positions wide, with the first **a-4** positions used for

the number, including its sign and decimal point, and the last four positions used for the scale factor  $E\pm xx$ .

**E**-formatted input data can be written in a variety of ways, as the scale factor may or may not contain a sign or the letter **E**. The numbers **1.00E+05**, **1.0E05**, **+1.0E 5**, and **1.0E+5** are equivalent input data representations of the number 100,000 under the input format **E(7,1)**. As shown below, either a sign or the letter **E** must be present to separate the number and scale factor fields.

It must be emphasized again that when values are too large to be printed in their indicated formats, data should be displayed in scientific notation, as governed by the following rules:

Field Width	Characters Printed	Example: Number=247.538
1	{"E"}	E
2	{sign of number} {"E"}	+E
3	{sign of number} {"E"} {sign of exponent}	+E+
4	{sign of number} {"E"} {sign of exponent} {d}	+E+2
	d = digit if $0 \leq \text{exponent} \leq 9$ , or = * if $\text{exponent} \geq 10$	
5	{sign of number} {"E"} {sign of exponent} {exponent}	+E+02
6	{sign of number} {digit} {"E"} {sign of exponent} {exponent}	+2E+02
7	{sign of number} {digit} {"."} {"E"} {sign of exponent} {exponent}	+2.E+02
8	{sign of number} {digit} {"."} {digit} {"E"} {sign of exponent} {exponent}	+2.4E+02
9	{sign of number} {digit} {"."} or {additional digits} {"E"} more {sign of exponent} {exponent}	+2.47E+02 +2.475E+02 +2.47538E+02

Numbers can be written in scientific notation for free form as well as for format-directed input. A field of the form: {number} {exponent} is interpreted as a scientific notation input field in free-form input statements. No blanks are allowed between the number and exponent parts of the field. The forms of these parts are:

{number}:     a **real** or **integer** constant

{exponent}:   **E±xx**   **E** is optional  
                  + is not needed if exponent is positive

Examples:

1.0067E+10	1.0067+10
9.46755+04	9.46755E4
4.0E1	4.0+1
9.999-6	9.999E-06
5E6	5+6

#### 3.4.2.4 T (Text) Descriptor

A descriptor of the form **n T w** is used to read and write formatted **text** from and to an external medium. The descriptor is similar in form and action to the **I** descriptor. The variable to be read or printed must have been declared as a **text** variable. **Text** literals appearing in a **write** list must be output using a **T** format descriptor.

When used for input, the statement reads as a text string the next **w** characters from the current input record. Any printable character that can be typed on a terminal or input record, including blanks, will be accepted as part of the string. The input record column position indicator is advanced by the field width.

When used in output statements, the **T** format displays successive characters, starting from the leftmost position of a string, and displaying from the leftmost column position within the field. Each character of the string is printed until either the string is exhausted or the end of field is reached. In either case, the output record column position indicator is advanced to the end of the field.

In cases where the length of a **text** variable is not known, or may vary, the entire **text** variable may be simply output using the format:

```
write text variable as t *
```

which begins writing at the current output column and continues writing until the entire **text** string is printed. If the output string will not fit on the remaining space on the output record, the string may overflow to one or more subsequent records. The output record column is positioned after the last character written.

#### 3.4.2.5 A (Alphanumeric) Descriptor

Any printable character that can be typed on a terminal or input record, including a blank character, may be read under an **alpha** format. The alphanumeric descriptor **n A w** is similar to the **I** descriptor in form and action. On input, the content of a specific field is assigned as the value of a corresponding variable in the **read** list. This variable must have been declared as **alpha**. The manner in which characters read are placed within the **alpha** variable may vary, depending on machine and **alpha** implementation. In general, where only one character is represented in each **alpha** vari-

able, the first character of the input field will be read. In some earlier implementations, and where an **alpha** variable may represent more than one character, a number of characters up to the maximum representation size will be read. The column position pointer is advanced by the specified field width.

When used in output statements, the **A** format will normally print the single character represented by the **alpha** variable in the first column of the output field, padding any further positions with blank spaces. When more than one character **alpha** representation is supported, a number of characters, up to either the maximum representation, or the field width, may be printed.

### 3.4.2.6 C (Computer Representation) Descriptor

Few computers use decimal notation internally. Most use binary coding schemes that represent decimal numbers as sequences of zeros and ones. Generally, a group of binary bits constituting a character in a number system other than binary or decimal is used as an input/output character. Because strings of such numbers are short, they are easy to interpret. Commonly used representations are octal and hexadecimal, for groups of 3 and 4 binary bits, respectively.

The format **n C e** interprets characters read or written in the unit of the computer on which a particular SIMSCRIPT II.5 system is implemented. The field width, **e**, specifies the number of character positions occupied. Each position corresponds to a single octal or hexadecimal symbol, depending on the particular machine implementation.

### 3.4.3 Format Lists

Format lists are composed of sequences of format descriptors separated by commas. During the execution of **read** and **write** statements, format lists are scanned from left to right and individual format descriptors are used as needed to match the variables named in the variable list. With few exceptions, variables being read or expressions being written must agree in mode with their format descriptors. The exceptions are **integer** and **alpha** modes that can be used interchangeably. When they are interchanged, the mode of the format descriptor governs. When a format descriptor is preceded by a repetition character **n**, **n** consecutive **read** and **write** statements that use formatted data follow. Some examples of format lists are given below.

1. `read X, ANSWER and Y as I 3, I 2, I 2`

If one assumes they have data in an input data file, and the above statement — the first in a program — starts reading at column 1 of the first input record, the value appearing in columns 1-3 is assigned to **X**, that in columns 4-5 is assigned to **ANSWER**, and the value in columns 6-7 is assigned to **Y**. The data might appear as:

```
column  0          1    ...
number 12345678901234

      160 3 8
```



in which case **X** = 160, **ANSWER** = 3, and **Y** = 8; should it appear as:

```
column  0          1      ...
number  12345678901234
        -336-9
```

the result will be **X** = -3, **ANSWER** = 36, and **Y** = -9. The data are read sequentially. The information needed to locate a number and determine its form is contained in the format descriptors.

2. read **X**, **ANSWER** and **Y** as I 3, 2 I 2

Here, the format list is the same as example 1 except that the second and third format descriptors have been combined.

3. write **X**, **ANSWER** and **Y** as I 3, 2 I 2

In this example, the values of the expressions **X**, **ANSWER**, and **Y**, are output in the indicated format. It will be assumed that the output has been specified to appear on the standard line printer and that this statement is the first to be executed. If the values of **X**, **ANSWER**, and **Y** are 9, -3, and 0, respectively, the printed line appears as:

```
column  0          1      ...
number  12345678901234
        9-3 0
```

Notice that leading zeros are left blank, but that the rightmost zero in a zero-valued integer is printed.

4. read **X**, **Y**, **Z** as 3 D(10,3)

Three decimal fields are specified, the first in columns 1-10, the second in columns 11-20, and the third in columns 21-30. Assume that the data are written as:

```
column  0          1          2          3      ...
number  12345678901234567890123456789012...
        126.345  -18.62    768954346
```

The first data field is assigned to **X** and the decimal point is, as expected, in column 7. The second data field is assigned to **Y**. Here the decimal point is not where expected, in column 17. Instead, the written number overrides the stated format, and so the value -18.62 is assigned to **Y**. A characteristic of the **D** format is that it may be so overridden if a decimal point appears explicitly within a field. If no decimal point is written, as occurs in the third data field, its location is assumed from the format. In the above example, the value 768954.346 is assigned to **Z**.

5. read X as D(8,2)

Such a data item might be written as:

column	0	1	...
number	12345678901234		
	16.5E 2		

The written decimal point overrides the format. The scale factor multiplies the resulting number by  $10^{**2}$  so that the value **1650** is assigned to **X**. The flexibility of the decimal format is shown in the following statement that defines a data record so that a large range of numbers can be accommodated:

6. read X(1), X(2), X(3), X(4), X(5) as 5 D(10,2)

A data record may appear as:

column	0	1	2	3	4	5...
number	12345678901234567890123456789012345678901234567890...					
	41.25	19.22E-03	4537992		-167.1	

in which case **X(1) = 41.25**, **X(2) = 0.01922**, **X(3) = 45379.92**, **X(4) = 0.00**, and **X(5) = -167.1**.

7. write A,B,C,D,E as 2 I 4, D(10,3), E(9,1), I 6

This statement defines output formats for five expressions, **A** to **E**. Assume that **A** and **B** are **integer** variables, both having the value **9**, **C** is a **real** variable having the value **19.2**, **D** is a **real** variable with the current value **8.25**, and **E** is an **integer** variable with the value **-1863976**. The output will be:

column	0	1	2	3	4
number	1234567890123456789012345678901234567890123456789				
	9	9	19.200	8.3E+00-2E+06	

The output of **E** illustrates the action taken when a value is too large for its field. In this instance, a seven-digit integer could not be printed in a six-digit field, and was converted to a six-character scientific representation. The actual value **-1.86397x10<sup>6</sup>** was rounded to a value that could be printed (**-2x10<sup>6</sup>**) and would retain the most significance.

8. read NAMES(1), NAMES(2), NAMES(3) as 3 T 10

Assuming that the array **NAMES** has been declared as **text**, the above statement will read three successive 10-character fields assigning 10-character **text** strings to the variables **NAMES(1)**, **NAMES(2)**, and **NAMES(3)**. Thus:

```

column  0          1          2          3
number  1234567890123456789012345678901234567
        JOHNSON  EDWARD    JOE

```

9. These character strings may now be printed under different formats:

```
write NAMES(3), NAMES(1), NAMES(2) as T *, T 10, T 2
```

will produce the output:

```

column  0          1          2          3
number  123456789012345678901234567890
        JOEJOHNSON  ED

```

10. Assuming **MACHINE** and **TCODE** have been defined as **text** variables and **TEMP** and **TOLERANCE** as **integer** variables:

```
read MACHINE, TEMP, TCODE, TOLERANCE as T 10, I 5, T 1, I 9
```

will read:

```

column  0          1          2          3
number  123456789012345678901234567890
        FORGE      3K      05

```

and assign "**FORGE**" to **MACHINE**, 3 to **TEMP**, "**K**" to **TCODE**, and 5 to **TOLERANCE**.

11. Let **ALPHA.VAR1**, **ALPHA.VAR2** and **ALPHA.VAR3** be **alpha** variables. The statement:

```
read ALPHA.VAR1, ALPHA.VAR2, ALPHA.VAR3 as 3 A 1
```

after reading the following input data, will assign the values **a**, **b**, **c** to the three variables, respectively:

```

column  0          1
number  1234567890123456
        abc

```

The output statement:

```
write ALPHA.VAR1, ALPHA.VAR2, ALPHA.VAR3 as B 1, 3 A 4
```

will now produce:

```

column  0          1          2
number  12345678901234567890
        a    b    c

```

The above examples have assumed that each new **read** or **write** statement starts at the beginning of a new data record or line. This need not always occur. All **read** and **write** statements operate on a continuous string of characters and only skip to a new data record or output line when so instructed. Thus, the two statements:

```
read X as I 5
```

and

```
read Y as D(10,2)
```

read successive fields from the same data record. Often, of course, data are split between data records, or must be read from noncontiguous parts of the same data record. The current input pointer and current output pointer are variables that point to the last referenced columns in the input and output data streams. They can be advanced by the statements:

```
input record
```

or

```
start new output record
```

and

```
start new page
```

as previously described, and also by five non-numeric formats. These formats can be interspersed among data formats, or they can appear alone in **read** and **write** statements. Examples of the use of these formats are given following their description.

### 3.4.3.1 B (Beginning Column) Descriptor

This format is used to specify the position in which the first character of an item of input or output data is found or displayed. The format **B n** positions the current input/output device at column n. When several **B** format descriptors are used within a format list, they do not have to appear in ascending numeric order. For instance, the format:

```
B 47, I 10, B 5, D(6,3), B 57, D(7,3), B 20, I 4
```

prints a line of the following form:

col 5	col 20	col 47	col 57
D(6,3)	I4	I10	D(7,3)
_____XX.XXX_____	..._____XXXX_____	..._XXXXXXXXXX_____	..._XXX.XXX_____

### 3.4.3.2 S (Skip Column) Descriptor

Spaces may be skipped between output items, or columns may be skipped on input data records by specifying, through the **s n** format, that *n* spaces are to be skipped before reading or printing the next item of data. Skipped positions are left blank on output, while data in skipped positions are ignored on input.

### 3.4.3.3 / (Skip to New Record) Descriptor

Format descriptors described above have presented conventions for locating and laying out data within input/output records. There is an implicit understanding that each format list refers to a single input data record or printed line of output. Input/output records change only when a **start new input record** or **start new output line** statement is executed. Unless this occurs, statements continue to read from the same record or to print on the same line. A record can be changed within a format list, however, by using a **/** format descriptor. This descriptor may be used repeatedly within a format list. Each time it is encountered, it skips a record on the current input/output unit.

### 3.4.3.4 + (Transmit Buffer) Descriptor

This format descriptor is analogous to the **/** format, with the exception that the record is transmitted to the device without being followed by a hardware new line or end of record indicator. For devices that support it, this allows construction of same-line interactive dialogues and use of hardware escape sequences. When used with devices that do not have necessary capabilities, the **+** descriptor is handled as **/**.

### 3.4.3.5 \* (Skip to a New Page) Descriptor

This format descriptor is analogous to the **/** format. It ejects a page on a line printer.

### 3.4.3.6 " " (Character String) Descriptor

Literal alphanumeric data can be included in output formats using a character string format descriptor. All characters included between quotation marks are printed as they appear, with one exception. Each pair of quotation marks inside the quotation marks is mapped to a single quotation, as is the case with other string constants. The spacing of the character string can be specified by other format descriptors such as **B**, **S**, and **/**, as well as by blanks within the character string. The character string, however, cannot exceed the length of a program text line. If a long string is required, it must be split into two strings.

### 3.4.3.7 Examples

Some examples of formatted **read** and **write** statements are shown below.

1. read IVAR and JVAR as I 5, /, I 5

A value for **IVAR** is read from the first five columns following the present location of the current input pointer for the current input unit. A value for **JVAR** is read from columns 1-5 of the record following.

2. read IVAR and JVAR as B 1, I 5, /, I 5

The current input pointer is returned to the first column of the current record. If the pointer is greater than 1, a new record is not selected; instead, the pointer is moved back. Values for **IVAR** and **JVAR** are then read from the first five columns of this record and the one following.

3. read IVAR, JVAR, KVAR, as 3 D(10,2), /

The above statement establishes a "record-oriented" input format. Each group of 3 variable values is contained on a different record. After one group is read, a new record is read in preparation for the next group.

4. write A,B,C,D,E,F as I 5, S 50, I 5, /,/,/,/, 4 D(10,4)

This statement writes two integer variables spaced 50 columns apart in an integer format, concludes this record, bringing the current output pointer to the head of the output buffer, skips three records, and writes four decimal values on a second record.

5. write N and AVERAGE as "Of", I 3, " To Date, The Average Is ",D(6,2)

Two values embedded in character strings are written from the above statement. If writing occurs on a line printer and the current output pointer is at the beginning of a line, the output looks as follows for **N=97** and **AVERAGE = 53.287**:

Of 97 To Date, The Average Is 53.29

6. read A(1),B(2),A(3),A(4),A(5) as B 5, I 10, D(7,3), /, B 20, 3 I 5

This statement begins in column 5 of the current input unit, reads two values in integer and decimal formats, respectively, and then starts a new record and reads three integer values starting in column 20.

7. write as \*,/,/,/,/

The statement starts a new output page and skips four lines. No output values are written.

### 3.4.4 Controlled READ and WRITE Statements

It is commonly required to read a number of subscripted variable values under the control of a **for** statement, as in:

```
for I = 1 to N, read A(I)
```

Here, a free-form **read** reads a sequence of values across the current input record. If the values are packed, however, with no blanks between them, the individual data fields cannot be identified by the free-form **read**. An alternative might be to write:

```
for I = 1 to N, read A(I) as I 4
```

This form may be used if the values of **A(I)** are spaced across entire records. If, however, the data are arranged so that values are contained only in columns 1 through 60 of successive 80-byte data records, the above statement will read through column 60 and attempt to take values from columns 61 through 80. The **read** must be directed to skip to a new input record upon reaching column 61. An expression enclosed in parentheses, placed before a format list, repeats that format list the indicated number of times and then skips to a new record. The statement above should be written as:

```
for I = 1 to N, read A(I) as (15)I 4
```

If **N = 12** and four numbers are to be read per record from columns 1 through 24, the following statements read 12 values from 3 records:

```
start new record
for I = 1 to N, read A(I) as (4)I 6
```

This form may also be used if groups of variables with different formats are in a record. The following statement reads four pairs of data fields in the format **I 6,D(6,2)** from each data record until **2\*N** values have been read:

```
for I = 1 to N, read A(I), B(I) as (4) I 6, D(6,2)
```

Such a repetition facility can be used with both **read** and **write** statements, but it can only be used in statements controlled by **for** phrases. This particular form of the **read** statement assumes that input starts at the beginning of a data (record), which explains the **start new record** statement in the foregoing example. The statement can terminate, of course, with the current input pointer positioned in the middle of a record, depending on the format used.

Similar rules apply to the **print** and **list** statements, as well as to all input/output operations performed by the SIMSCRIPT II.5 system. Output is printed wherever the current pointer points, assuming it is at the head of a record. After output, the system positions the pointer at the head of the next record.

### 3.4.5 Variable Formats

The use of format descriptors containing expressions as well as constants is one feature available in **read** and **write** statements that has not been discussed. Arithmetic expressions can be used to control field widths in formats for data-layout purposes. For instance, a curve of the natural log function, using \* as a graphical character, is generated by the statement:

```
for I = I to 100, write as B LOG.E.F(I), "*", /
```

Table 3-2 indicates where expressions can be used in format descriptors and states their form — a feature that allows formats to be constructed during program execution, freeing programs from particular data forms. Constants defining a format can be read in, perhaps in free form, before a file of data records to specify the form in which the data appear. If a program reads in sets of data records that are grouped three items to a record with the first item being **integer** and the balance **real**, the initialization routine of the program could contain the free-form **read** statement:

```
read C1, C2, C3, C4, C5
```

and the program could contain the formatted **read** statement:

```
read ALPHA, BETA, GAMMA as B C1, I C2, S C3, 2 D(C4,C5)
```

and the input data stream might look like:

```
column0      1      2      3      ...
number12345678901234567890123456789012345678...

      6  4  10      5  2
      342      16.25  1.5
      -10      0.5  73.4
```

**Table 3-2. Format Descriptor Forms**

<u>Format Descriptor</u>	<u>General Form</u>
Integer field	<b>i I e</b>
Decimal field	<b>i D(e,e)</b>
Scientific field	<b>i E(e,e)</b>
Starting column	<b>B e</b>
Space skip	<b>S e</b>
Text field	<b>i T e</b> or <b>i T *</b>
Alpha field	<b>i A e</b>
Computer representation field	<b>i C e</b>

**NOTE:** **i** is an **integer** constant which defaults to 1 if omitted. **e** is an arithmetic expression.



### 3.5 Miscellaneous Input/Output Statements and Facilities

#### 3.5.1 Logical File Assignment: The OPEN Statement

Physical device or data characteristics, specified by execution control commands to the operating system, are associated with SIMSCRIPT II.5 logical unit numbers through a logical file name. As mentioned previously, this is usually constructed from the logical unit number to give a name of the form **SIMUnn**.

To allow the specification of device or file characteristics within a program, the SIMSCRIPT II.5 language supports an **open** statement. The **open** statement provides a means of explicitly specifying a logical filename and some of the associated data characteristics at program level rather than at execution command level. Consult the SIMSCRIPT II.5 user manual for specific details of the parameters.

The general form of the statement is:

```
open unit device for input (or output), data characteristics
```

where **device** is an arithmetic expression evaluating to the logical unit number. The clause **for input** or **for output** designates whether the device is to be used as an input or output device. The word **for** is optional. The data characteristics may describe required characteristics of the data stream. An example of the use is:

```
open unit 2 for output, file name is "OUTFILE"
use 2 for output
```

which will open a file, referred to in the future as **unit 2**, using the logical name **"OUTFILE"**. This logical file name must be a **text** variable. If the file name is not specified, the default logical file name, **simu02**, is created as described above.

Many file and I/O device data characteristics may be specified at program level in the **open** statement. Some of these are common across machines, while some are particular to one machine or language implementation. In general, however, the characteristics consist of logical filename assignment and file format and file-type description.

File format parameters contain information on how the file is structured internally. The basic physical unit of the data file is the record, which usually corresponds to a line of input or output. File format parameters that may usually be specified are the **recordsize**, or length of each record, and whether this size is **fixed** or indicates the maximum of variable length records. For example:

```
open unit 2 for output,
file name is "OUTFILE", recordsize = 80, fixed
```

assigns **unit 2**, in the **output** mode, to a file or device whose logical filename is **"OUTFILE"**, which is composed of 80-character fixed length records.

After all input or output to a unit has been completed and the unit is no longer required, the link between the SIMSCRIPT II.5 logical unit and the physical device, as controlled by the operating system, may be removed by closing the unit. This is achieved by a statement of the form:

```
close unit device
```

If the device is the current input or output unit, then that unit (**read.v** or **write.v**) is reset to its default value. Note that at the completion of a SIMSCRIPT II.5 program, all files used or opened during the course of the program run will be closed automatically by SIMSCRIPT II.5.

### 3.5.2 End-of-File Conditions

Whenever a **read** statement is executed, there is the possibility of reading data from an "empty" file or reaching the end of the data file, which is referred to as an end-of-file condition. The free-form **read** statement, as previously noted, provides a check for an end-of-file condition through the statement **if data is ended**. A similar check is needed for formatted I/O.

A SIMSCRIPT II.5 system-defined variable, **eof.v**, is maintained for each logical input unit. A reference to **eof.v** applies always to the value of the current logical unit, set by **use**. This variable is initialized to zero when a unit is first referenced. When an end-of-file condition is encountered by a **read** statement, the SIMSCRIPT II.5 system refers to the **eof.v** variable for direction. If **eof.v** is still equal to zero, encountering the end-of-file condition is considered an error, and the program terminates with an error message. If, however, under program control, the **eof.v** variable has previously been assigned the value 1, the variables in the **read** list are assigned values of zero, the **eof.v** variable is set to 2, and control returns to the statement following the **read**. In other words, setting the value of **eof.v** to 1 is considered a message to the SIMSCRIPT II.5 system to the effect, "Do not terminate the program; return zero values and indicate that the end-of-file marker has been encountered." By testing **eof.v** after a **read** statement, the program logic can determine whether the statement read true data or encountered an end-of-file marker. This facility can be used in the following ways:

1. As an end of data signal:

```
use unit 1 for input
let eof.v = 1

.
while eof.v ne 2,
do
    read Z as I 2
    add Z to SUM
    add 1 to COUNTER
loop
write COUNTER, SUM/COUNTER as "The Average of", I 4,
"Items Processed Is", D(6,2)
stop
end
```

2. To transfer control to an error-diagnostic routine rather than terminate:

```

use unit 1 for input
let eof.v = 1
.
.
read X,Y,Z
if eof.v = 2
    call ERROR.PRINTOUT
else
.
.
always

```

### 3.5.3 Repositioning Files

A disk or tape file may be repositioned to its starting position by the statement:

```
rewind d
```

The words **unit** is optional after **rewind**. After a unit has been rewound, it must be mentioned in a **use** statement before it can be read from or written on again, as is the case with the **close** statement. A **rewind** command before a unit has been "used" is ignored.

### 3.5.4 Input/Output of Nondecimal Information

When an external file or I/O device is used with normal SIMSCRIPT II.5 **read** and **write** free-form or formatted I/O statements, the file will usually be a "character"-type file.

All data written or read from the file are converted from their internal computer representation, called **binary**, to an external media form, usually one of the character representations, ASCII or EBCDIC. The normal **read** free-form, **print**, and **list** statements perform this conversion automatically on all I/O operations. When data are used only for transmission between computers or are saved for subsequent reuse in a program, they may be saved directly in their internal representation to improve efficiency. Variables are transferred in this binary format by the statements:

```
read variable list
```

and

```
write variable list
```

where a current unit is implied, or through the statements:

```
read variable list as binary using d
```

and

```
write variable list as binary using d
```

where a unit **d** is specified.

Any variable name may be included in the variable list. Only the **real** equivalent of **double** precision variables, however, will be transmitted. **Double** variables may be transferred with full precision using the statements:

```
read variable list as double binary
```

and

```
write variable list as double binary
```

**Binary** input and output statements may not be mixed with, or used on the same input/output unit, as any free-form and formatted-type statements, with the exception of record boundary formatting. The **start new** statements and the formats **write** or **read as /** are permitted with **binary** I/O on most implementations. In all other cases, a SIMSCRIPT II.5 file usage error results if **binary** is mixed with other I/O types.

If the language implementation supports an **open** statement, it may be indicated, that the file is to be used only for **binary** data by appending the word **binary** to the list of file characteristics. For example:

```
open unit 20 for output, binary, name is "BINDATA"
```

Correspondingly, declaring the parameter **formatted** indicates non-**binary** mode data transfer. If the I/O mode is not defined while being opened, the mode is defined by the first usage.

### 3.6 Internal Editing of Data

The SIMSCRIPT II.5 system maintains separate data buffers for each logical unit. The size of each buffer depends on the associated I/O device characteristics, and is usually set by job control commands or by default, but may also be determined by **open** statement parameters. All data, read or written, are transferred through these buffers. Both an input pointer (**rcolumn.v**) and an output pointer (**wcolumn.v**) associated with the current input and output units, point, within these buffers, to the last accessed character, being reset when a / format is encountered or when a physical data transfer is forced by reaching the end of the buffer.

Individual character positions in the current output buffer may be accessed using the **alpha** function **out.f**. **out.f(1)** refers to the first character and **out.f(10)** to the tenth character. The **out.f** function normally returns a single character **alpha** variable.

It is possible to edit output data by inserting alphanumeric or numeric data directly into the buffer. When a new record is begun, by either a **start new** statement or a / format descriptor, the buffer is emptied and filled as the ensuing formats dictate. Thus, the statement:

```
write X as /, "The Buffer Contains", I 3, " Characters"
```

empties the buffer and inserts the characters "**The Buffer Contains**" in character positions 1 through 19, the value of **x** in positions 20 through 22, and the characters "**Characters**" in positions 23 through 33. Assuming a buffer length of 132, the buffer could be edited, for example, so that blank positions in the text, indicated here by underscores, are replaced by periods, by the statements:

```
for I = 1 to 131,
  until out.f(I)="_" and out.f(I+1)="_"
do
  if out.f(I) = "_"
    let out.f(I) = "."
  always
loop
```

**wcolumn.v** points to the last character written into the buffer, so the loop condition could be written:

```
for I = 1 to wcolumn.v,
do
```

If numbers representing dollar amounts are written, dollar signs (\$) can be put before the first digit of each number in a similar way:

```
for I = 1 to wcolumn.v,
do
  if out.f(I) = "_" and out.f(I+1) ne "_"
    let out.f(I) = "$"
  always
loop
```

A special internal buffer called **the buffer** may be used for data editing using **read** and **write** statements. The length of this special buffer is specified by setting a system global variable, **buffer.v**, before its first use. If **buffer.v** is not set, it is assigned a default value of 132. Input or output operations are directed to use **the buffer** in the usual way:

```
use the buffer for input
and
use the buffer for output
```

or the statements:

```
write variable list as format list using the buffer
and
read variable list as format list using the buffer
```

The examples below illustrate how **the buffer** may be used for variable mode conversion.

1. In this example, a **text** string containing numeric character fields is written to **the buffer** and then read in free form to assign values a list of **integer** variables.

```
write as /, "11 12 13 14 15" using the buffer
read V1,V2,V3,V4,V5 using the buffer
```

Note that / clears **the buffer** and sets the current output column pointer to its first position.

The buffer column pointer is arranged to be dynamically reset on read/write transitions. On the transition from a **write** to a **read** using the buffer, the column pointer is reset before the variables are read so the first free-form read starts at the beginning of the buffer. A similar transition from a **read** to a **write** using the buffer blanks the entire buffer and resets the column pointer.

2. **Alpha** variables, **ACODE(1)**, **ACODE(2)**, **ACODE(3)**, for example, might be written and then reread as a **text** variable as below:

```
write ACODE(1), ACODE(2), ACODE(1), ACODE(3) as 4 A 1
using the buffer
read NEW.TEXT as T 4 using the buffer
```

If **ACODE(1) = "C"**, **ACODE(2) = "A"**, and **ACODE(3) = "I"**, then **NEW.TEXT** will be assigned the text string **"CACT"**.

### 3.7 Writing Formatted Reports

The **print** and **write** statements may be used to display messages and variable values as desired. Using these statements to produce lengthy reports, however, can involve much tedious programming. This section adds two phrases to the **print** statement and introduces two control statements that provide a report-generator capability.

These features permit a programmer to specify the layout of printed results, to control the printing of headings and titles, to eject pages between various report sections, and to arrange "wide reports" on standard-width paper. Figure 3-1 below illustrates the kind of complex reports that can be generated.

The statement **begin report** marks the start of a report section, within which various kinds of control can be exercised. A report section, like a routine, is terminated by an **end** statement. The statements:

```
begin report
  for I = 1 to N,
    print 1 line with I, X(I) as follows
    **      **.*
end
```

illustrate a simple report section that merely marks off a controlled output statement. That report section prints  $N$  lines containing two values each. If the output report is to be labeled, the program can be written as:

```
begin report
  print 1 line as follows
    I      X(I)
  for I = 1 to N,
    print 1 line with I, X(I) as follows
      **      **.***
end
```

<div> <div>PAGE 1</div> <div>1 2 3 4 .....50</div> <div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>5</div> <div>6</div> <div>7</div> </div>	<div> <div>PAGE 3</div> <div>51 52 .....100</div> <div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>5</div> <div>6</div> <div>7</div> </div>
<div> <div>PAGE 2</div> <div>1 2 3 4 .....50</div> <div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>5</div> <div>6</div> <div>7</div> </div>	<div> <div>PAGE 4</div> <div>51 52 .....100</div> <div>8</div> <div>9</div> <div>10</div> <div>11</div> <div>12</div> </div>

**Figure 3-1. Report Using Row and Column Repetition**

A heading is printed above the  $N$  lines of output that identify the displayed values. If  $N$  is large and the output continues on more than one page, only the results on the first page are labeled. All other pages are untitled.

A heading section may be defined within a report section so that titles are printed and any necessary computation performed whenever a page is ejected. A heading section is started by the statement **begin heading** and ended by the statement **end**. All statements between a **begin heading** and its matching **end** are executed whenever a page is ejected by an output statement within an enclosing report section, but after the heading section itself.

To title all pages of output on the foregoing example, the program can be written as:

```
begin report
  begin heading
    print 1 line as follows
      I      X(I)
  end  '' HEADING SECTION
  for I = 1 TO N,
    print 1 line with I, X(I) as follows
      **      **.***
  end  '' REPORT SECTION
```

The statements in a heading section are executed the first time they are encountered and thereafter every time a page is changed. Pages are changed whenever the current line count exceeds the number of printed lines a page can contain. Two system-defined variables **line.v** and **lines.v**, maintained for each logical output unit, hold the values of the current line count and the permitted number of lines per page, respectively. **line.v** is initialized to 1 when an output device is first used. It is stepped from 1 to the current maximum value, specified by **lines.v**, each time a new line is printed. You may change **lines.v** at any time to vary the number of lines that may appear on each output page. The SIMSCRIPT II.5 system usually sets **lines.v = 55** for the default output unit, and for units selected for print output, at the start of program execution. This may vary on different SIMSCRIPT II.5 implementations.

Pages are numbered sequentially, starting from 1, with the number of the page currently being written contained in a system variable **page.v**. As with **line.v**, a separate count of **page.v** is kept for each output device. **Page.v** may be reset at any time. When this is done, numbering continues in sequence from the new value. **Page.v** and **line.v** always refer to the current output unit. A unit should be selected with a **use** statement before any explicit reference to these variables.

Page changing can be disabled at any time by setting **lines.v = 0**.

Within a heading section, the statement:

```
if page is first
```

may be used to select statements to be executed only on the first page of a report section's output. The following program illustrates one way of using the report facilities described thus far.



**Program 3-1.**


---

```

'' Generate a Table of Mathematical Functions on a Separate Output Unit.
'' Program Reads Number of Lines per Page, Number of Table
'' Entries and Output Unit on which Results to be Displayed.
preamble
    normally mode is integer
end

main
    read PAGE.SIZE, TABLE.SIZE, REPORT.UNIT
    call DISPLAY(PAGE.SIZE, TABLE.SIZE, REPORT.UNIT)
    stop
end

routine DISPLAY( NO.LINES, TSIZE, UNIT.NO)
    use UNIT.NO for output
    let page.v = 1
    let lines.v = NO.LINES
    begin report
        begin heading
            if page is first
                print 1 line as follows
                Tabulation of Mathematical Functions
                skip 3 output lines
            always
                print 1 line with page.v as follows
                Page No. **
                skip 2 output lines
                print 1 line as follows
                I      SQRT(I)      I SQ      LOG(I)
                skip 1 output line
            end
            '' HEADING SECTION
        for J = 1 to TSIZE,
            print 1 line with J, SQRT.F(REAL.F(J)), J**2, LOG.10.F(REAL.F(J))
            as follows
            **          **.**      ****          *.***
        end
        '' REPORT SECTION
    return
end
'' ROUTINE DISPLAY

```

---

In its **MAIN** routine, this program reads in control data and passes these data to the **DISPLAY** routine that uses them in its **REPORT** section. **PAGE.SIZE** is used to indicate the number of lines per page, **TABLE.SIZE** the number of entries in the Mathematical Table, and **REPORT.UNIT** the output unit on which the report is to be produced.

Within the routine **DISPLAY**, an output unit is selected, the first page of the report is set to 1 by setting **page.v** to 1, and its **lines.v** are set to the number of lines per page required. Within the report section, **skip** statements are used to separate heading information.

If the sequence of values read by this program is **50 100 7**, a report will be printed on **unit 7**, which will display the values  $j$ ,  $\sqrt{j}$ ,  $j^2$ , and  $\log(j)$  for  $j = 1, 2, \dots, 100$  on three pages. Assuming that printing starts at the top of the first page, this page will start with the heading "**Tabulation of Mathematical Functions**," the page number, the heading **I SQRT(I) I SQ LOG(I)**, and values for  $j = 1, 2, \dots, 41$ . The second page will contain the page number, the heading **I SQRT(I) I SQ LOG(I)**, and values for  $j = 42, 43, \dots, 86$ . The third page will resemble the second, except that it will include values for  $j = 87, 88, \dots, 100$ .

The sequence of input values **20 40 8** will produce a report similar to the first, except that it will display the values for  $j = 1, 2, \dots, 40$  on pages that contain only 20 lines. The heading "**Tabulation of Mathematical Functions**" will be printed on the current page, renumbered 1, of output **unit 8**.

Whenever it is necessary to begin each report section on a new page, as might be done in this example, the **begin report** statement can be written as:

```
begin report on a new page
```

which ejects a page on the current output device unless the current page has no text (**line.v** = 1, **wcolumn.v** = 0). This prevents blank pages from being ejected between report sections.

The structure of a "typical" report-generating program, using the statements described thus far, is illustrated below. The **end** statements are inserted for clarity.

```
begin report on a new page
.
program statements
.
begin heading
.
if page is first
.
always
.
skip N lines
.
end          ' ' HEADING
.
more program statements
.
end          ' ' REPORT
```

**Print** statements appear in heading and report sections, and usually are controlled by **for** or **while** statements in the part of the report section labeled "program statements." The flow of control in a report section like the one which appears on this page is as follows:

1. Execute statements between **begin report** and **begin heading**, if any
2. Execute statements in the heading section, if any
3. Execute statements between **end ' 'HEADING** and **end ' 'REPORT** if any, executing statements in the heading section every time a page is changed.

These statements are adequate for many reports. A report for which they are not suited is one that must print more than 80 columns of information per line. Adding the word **double** to a **print** statement in the following way:

```
print I double lines with expression list as follows
```

specifies that **2i**, rather than **i**, format lines follow that are to be read in pairs and interpreted as one format line 160 columns long. To fill an entire line on a printer 132 columns wide, write a statement such as:

```
print 1 double line as follows
AAAAAAAAAAAAAAAA.....AAAAAA
AAAAAAAA.....AAAAAAAAA
```

The first format record has an **A** typed in each of its 80 columns. The second format record has an **A** typed in its first 52 columns. "Double width" **print** statements are not restricted to report sections. Any **print** statement can be expanded to double width. If the **last column** statement is used, the first format record is scanned up to the specified column, instead of column 80.

The inclusion of an optional clause in the **begin report** and **print** statements adds one more important report-generation feature. Figure 3-1 shows the kind of report the clauses handle—reports that have rows of data with more items in each row than a single page can contain.

In preparing this type of report, a series of pages is printed with different column indices. In Figure 3-1, pages 1 and 2 are printed with column indices ranging from 1 to 50, and pages 3 and 4 are printed with column indices ranging from 51 to 100. This feature, specifying an iteration sequence for column indices and having pages printed on a wide page, is known as column repetition, and is specified by an optional clause in the **begin report** statement:

```
begin report printing for, in groups of e per page
```

The word **for** represents a **for**, **while**, or **until** statement, perhaps qualified, that generates column indices. The arithmetic expression **e** specifies the number of indices in this iteration sequence to be used on each page. Thus, the statement:

```
begin report printing
for I = 1 to 50, in groups of 10 per page
```

specifies that five sets of column indices will be used for five executions of a report section. The report section will be executed first with  $I = 1, 2, 3, 4, 5, 6, 7, 8, 9$ , and  $10$ ; second with  $I = 11, 12, \dots, 20; \dots$ ; and fifth with  $I = 41, 42, \dots, 50$ .

The groups of iteration values are used in a **print** statement by a clause specifying that a group of values are to be printed using the indices generated by a preceding **begin report** statement. The following example illustrates one such use:

```
begin report printing
  for J = 1 to 25, in groups of 5 per page
    begin heading
      print 1 line with a group of J fields as follows
      *   *   *   *   *
      skip 1 output line
    end
    ' ' OF HEADING
  for I = 1 to 6,
    print 1 line with a group of X(I,J) fields as follows
    **  **  **  **  **
  end
  ' ' OF REPORT
```

This program generates five pages of output. Page 1 uses the first five values of  $J$ . A heading displays the values of  $J$ , and a row repetition statement prints the values of  $X(I,J)$  for those values of  $J$  and  $I = 1, 2, 3, 4, 5, 6$ . Figure 3-2 illustrates how such a page might appear.

1	2	3	4	5
**	**	**	**	**
**	**	**	**	**
**	**	**	**	**
**	**	**	**	**
**	**	**	**	**

**Figure 3-2. Column Repetition, Page 1**

Figure 3-3, page 2 looks exactly like page 1 in form, but uses the second five values of  $J$  to select values for display.

6	7	8	9	10
**	**	**	**	**
**	**	**	**	**
**	**	**	**	**
**	**	**	**	**
**	**	**	**	**

**Figure 3-3. Column Repetition, Page 2**

Pages 3, 4, and 5 are similar, with page 3 using  $J = 11, \dots, 15$ , and page 4 using  $J = 16, \dots, 20$ , etc.

The index values are computed entirely within this version of the **print** statement. They are not individually accessible in any other statement and should not be referenced outside this context.

The phrase **a group of .. fields** in a **print** statement notifies the compiler that a sequence of index values generated for the enclosing column repetition block is to be used in computing the output fields. As shown above, one format must be provided for each of the fields in the column repetition group. If the **begin report** statement specifies groups of six, then six formats must be provided in each **print** statement containing a **a group of ... fields** clause. For example, the previous displays can be better labeled by using the statement:

```
for I = 1 to 6,
  print 1 line with I,
    and a group of X(I,J) fields as follows
      *  **  **  **  **  **
```

Several values can be alternated within a **a group of ... fields** clause, each using the index values. For example, the previous program might want to display both  $X(I,J)$  and  $Y(I,J)$  as follows:

```
for I = 1 to 6,
  print 1 line with I,
    and a group of X(I,J), Y(I,J) fields as follows
      *  **  *.*  **  *.*  **  *.*  **  *.*  **  *.*
```

A format must be given for each output value, of course. All repeated formats must agree in mode. It is not possible to write:

```
print 1 line with a group of I fields thus
```

and have the format line be:

```
*  *. *  *. *
```

All repeated formats need not be identical (e.g., \* and \*\*), but they must be of the same mode.

If a controlling **for** phrase in a **begin report** statement is empty (produces no values), for example:

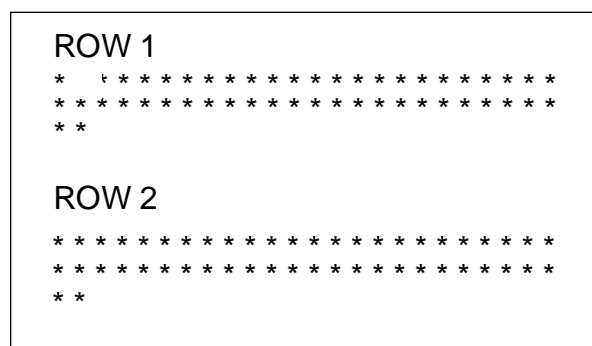
```
for I = 1 to 4, with X(I) > 0,
```

when no **X(I)** is greater than 0, the entire report section headed by this statement is skipped.

If it is not necessary that each set of column repetition groups start on a new page, the **per page** clause may be omitted from the **begin report** statement. The following report section uses this feature to display a matrix containing more columns than can be put on one line:

```
for I = 1 to N,
do
  print 1 line with I as follows
  ROW **
  begin report printing
    for J = 1 to M, in groups of 24
      print 1 line with a group of X(I,J) fields as follows
      * * * * * * * * * * * * * * * * * * * * * * * * * * * *
    end          ' ' OF REPORT
  skip 2 lines
loop
```

Such a program produces a report that, for **M = 50**, looks like figure 3-4.



```
ROW 1
*  *****
*  *****
*  *

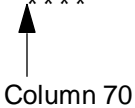
ROW 2
*****
*****
*  *
```

**Figure 3-4. An Example of Column Repetition**

**Note:** The total number of column indices generated need not be an even multiple of the group size (e.g., 50 and 24 above).

A final feature makes it possible to include row, as well as column, summarizations, in reports using the column repetition feature. This is done by adding a clause to the **print** statement that suppresses a part of the output for each line, until all column repetition data have been printed. A typical use of this feature is illustrated as follows:

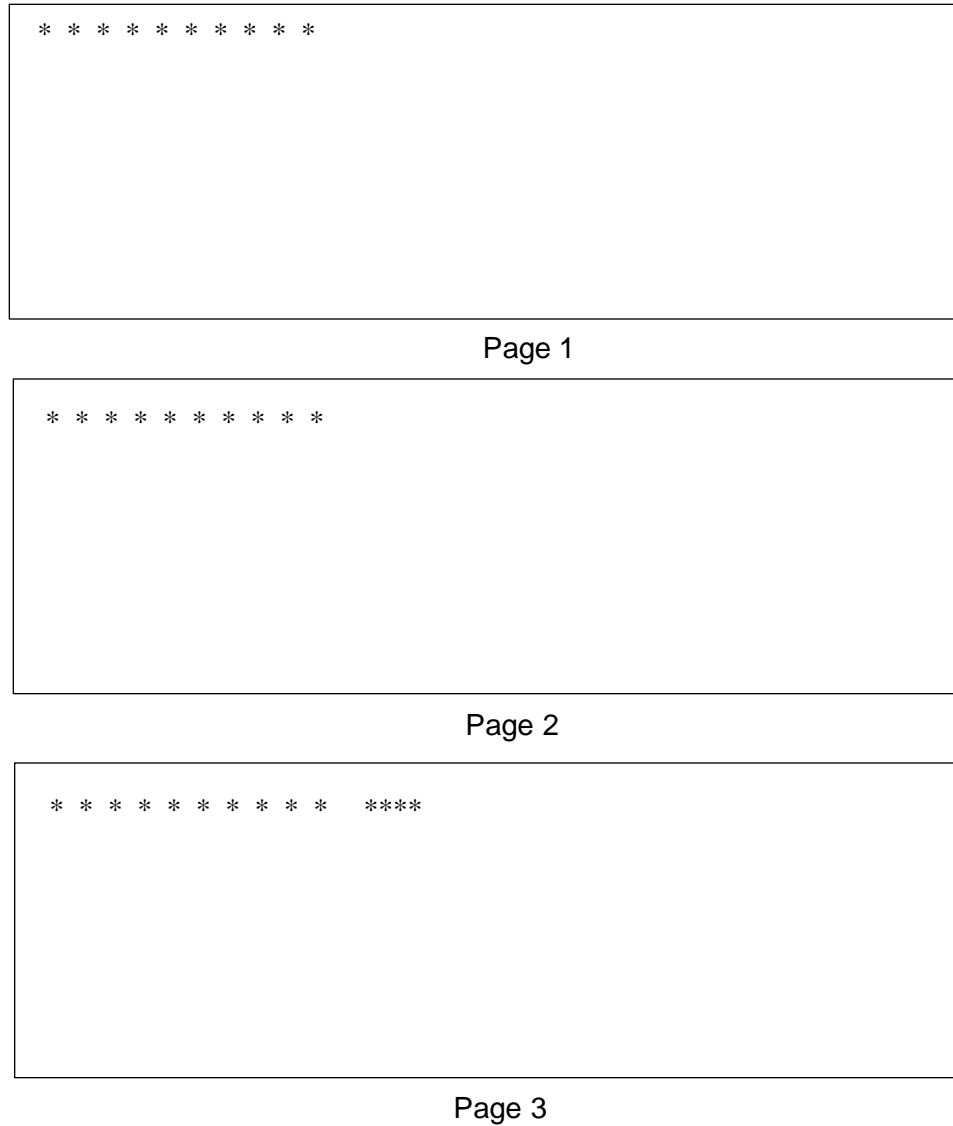
```
begin report printing
  for J = 1 to M, in groups of 10 per page
    print 1 line with a group of X(I,J) fields, SUMX(I)
      suppressing from column 70 as follows
        *   *   *   *   *   *   *   *   *   *   ****
end      ' ' OF REPORT
```



Column 70

If **M = 30**, three sets of column indices will be generated; the above format line will be repeated three times, on three separate pages. Only on the last page, however, will the last format be used, and the value **SUMX(I)** printed. The **suppressing** clause specifies that the printing of any data formatted to appear from column 70 onward is to be inhibited until all the column index values have been used. This applies both to data and to any text literals appearing in the format specification. The three pages printed by the above statements are shown in figure 3-5.

The following program segment illustrates the skeleton of the report section of a program that generates the report shown in figure 3-5. The report produces a table of shipment amounts from **120 BASES** to **60 DEPOTS**, together with totals for each **BASE** and **DEPOT** and a grand total of all shipments, to produce an output report on double-width paper.



**Figure 3-5. An Example of Format Suppression**



**Program 3-2.**


---

```

preamble
    normally mode is integer
    define SHIPMENT as a 2-dimensional array
    define BTOTAL, DTOTAL as 1-dimensional arrays
        .
        .
end

main
    .
    .
    reserve SHIPMENT(*,*) as 120 by 60
    reserve BTOTAL(*) as 120
    reserve DTOTAL(*) as 60
        .
        .
    use 6 for output
    let page.v = 1
    begin report on a new page
        printing for DEPOT = 1 to 60
            in groups of 24 per page
            begin heading
                print 1 double line with page.v as follows
                Page *
                print 1 line as follows
                Depot to Base Shipments
                skip 1 output line
                print 1 double line
                    with a group of DEPOT fields
                    suppressing from column 91 thus
DEPOT  ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
** ****          TOTAL
                print 1 line as follows
BASE

                end '' HEADING SECTION
                for BASE=1 to 120
                print 1 double line
                with BASE, a group of SHIPMENT(BASE,DEPOT) fields,    BTOTAL(BASE)
                suppressing from column 92 as follows
                **      *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
                *      ***
                skip 1 output line
                print 1 double line
                with a group of DTOTAL(DEPOT) fields, GRAND.TOTAL
                suppressing from column 92 as follows

```

```

TOTAL      ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **^
**          ***
          end ' ' REPORT SECTION
stop
end

```

---

### 3.7.1 Page Heading Control

Two further variables, maintained for each output unit, allow page heading control to be exercised throughout a program, rather than just within report sections. One of these variables, **heading.v**, is an example of the use of a **subprogram** variable. If the name of a user-written page titling routine is assigned to the **heading.v** variable for any unit, control will be automatically passed to this routine as every new page is begun. This is done by statements such as:

```

use 2 for output
let heading.v = 'TITLE.ROUTINE'

```

A routine of the name **TITLE.ROUTINE** must, of course, be included in the program. This routine may contain any desired **print** or **write** statements. Routine names may be assigned to **heading.v** at any time. Different units may each have their own titling routines. Titling may be suppressed by assigning a value of zero to the appropriate **heading.v** variable. A second variable, also maintained for each output unit, is **pagecol.v**. If this has a nonzero value, for any unit, it is taken to specify the starting column on the first line of each page where the value of the current page count, **page.v**, is to be printed in the format **PAGE \*\*\*\***.

## 4. Modelling Concepts

---

### 4.1 Introduction

In Chapter 1, a programming language was presented as a means of describing both instructions and the data on which they operate. The description of data items has been limited to naming the data items, specifying modes, and, in the case of arrays, describing some simple data structuring. This chapter describes the additional data-structuring facilities and commands provided by SIMSCRIPT II.5 and illustrates their potential use. These data structures are designed to aid in problem definition, particularly in the areas of simulation and modelling.

The provision of enhanced data-structuring facilities is necessary for two reasons: (1) the need for more organizational structure than simple arrays afford, and (2) the lack of clarity of programs written within the descriptive limits of variable name and subscript expression conventions. SIMSCRIPT II.5 provides needed structure and narrative clarity through statements that define and manipulate entities, attributes, and sets.

This chapter is organized into three parts: definition, organization, and manipulation. First, definitions are provided for the three constituents of the SIMSCRIPT II.5 world view: entities, attributes, and sets. Next the relationships between these constituents are discussed, with special attention to how they are organized. Finally, statements that use these constituents to perform useful functions are presented.

### 4.2 Entities and Attributes

An entity is a structured data item that represents some element of a modelled system. Similar to a subscripted variable. It may have more than a single value to define a particular configuration or state of the entity. Unlike subscripted variables, the attributes of entities are referenced by name rather than by a subscript number, enhancing readability and model description. Using subscripted variables, a collection of ten workers having the attributes of age, number of dependents, and social security number might be represented in SIMSCRIPT II.5 by a two-dimensional array reserved as follows:

```
reserve WORKER as 3 by 10
```

with the understanding that **WORKER(1,4)** represents the age of the fourth worker, **WORKER(3,6)** the social security number of the sixth worker, etc., according to the layout shown in figure 4-1.

	1	2	3	4	5	6	7	8	9	10
AGE	1									
DEPENDENTS	2									
SOC.SEC.NO.	3									

**Figure 4-1. Storage of Attributes in a Two-dimensional Array**

The entity and attribute structuring permits an entity type, **WORKER**, to be defined by the statement:

```
every WORKER has an AGE, a NUMBER.OF.DEPENDENTS
and a SOCIAL.SECURITY.NUMBER
```

A particular entity of this type may be specified by the value of an implicitly declared global variable called **WORKER**, associated with this entity type, and the attribute values associated with this particular instance of a **WORKER** may be accessed by references such as:

```
AGE ( WORKER )
```

and

```
SOCIAL.SECURITY.NUMBER ( WORKER )
```

Thus, the **every** statement may define a class of entities, each having similar properties. Every **WORKER** entity, of which there may be many, has the same attributes; the actual values of these attributes may differ for each.

Entities and their attributes are declared in a program preamble by statements of the general form:

```
every entity name has an attribute name list
```

Entity and attribute names follow the same naming convention as variables and routines, and each variable, entity, attribute, and routine name must be unique. To assist in the creation of readable programs, the words **a**, **the**, and **some** can be used in place of **an**, as in:

```
every WORKER has an AGE, some DEPENDENTS and a
SOCIAL.SECURITY.NUMBER
```

In general, these entity declarations implicitly state the ordering of the attributes within the entity structure. The data structure associated with each instance of a **WORKER** entity may be pictured as shown in figure 4-2.

WORKER	
	value of AGE
	value of DEPENDENTS
	value of SOCIAL.SECURITY.NUMBER

**Figure 4-2. Order of Storage of the Attributes of an Entity**

### 4.3 Sets

Entities and their attributes allow some structuring of related data. Sets, in turn, provide a higher level of structuring of these data. Sets are organized collections of entities. Sets are like arrays in that each of the entity elements of which they are composed may be identified and manipulated, but in contrast with the static structuring imposed on array elements, the organization of entities in sets may be dynamic and changeable. The set concept and the underlying mechanism are introduced here by way of an example.

Consider the following situation: Over the years, residents of a community join various clubs and societies. As residents are born, grow up, remain in or move out of the community, and die, the club memberships change. To model the relationships that exist between the members of the community, both over time and at particular instants of time, requires some way of grouping the individual society and club members together. Such groupings might be defined by the statements:

```
every COMMUNITY owns a MASONS,
    and a BOY.SCOUTS
every MAN may belong to the MASONS,
    and the BOY.SCOUTS
```

The first statement declares that each entity of the class **COMMUNITY** owns a set called **MASONS** and a set called **BOY.SCOUTS**. Each of these sets corresponds to a logical grouping of residents in the community. This statement does not specify which residents belong to the particular sets; rather, it establishes a system of set pointers and set attributes for the owner entities that enable set memberships to be constructed. For each **COMMUNITY** entity, the attributes shown in figure 4-3 are automatically defined to exist.

COMMUNITY	
F.	MASONS
L.	MASONS
N.	MASONS
F.	BOY.SCOOTS
L.	BOY.SCOOTS
N.	BOY.SCOOTS

**Figure 4-3. Automatically-defined Attributes of COMMUNITY Entities**

The attributes starting with **F.** are set pointers that point to the first member of the respective sets. The attributes starting with **L.** are set pointers that point to the last member of the respective sets. The set members, as we shall see, point to one another, defining their interrelationships and making the connection between the set owner and the set members complete. The attributes starting with **N.** maintain the number of entities in each set.

The second statement declares that each entity of the class **MAN** may belong to sets called **MASONS** and **BOY.SCOOTS**. It is important to note that membership is declared as possible in this statement, but not mandatory. This statement automatically defines the set attributes shown in figure 4-4 for member entities.

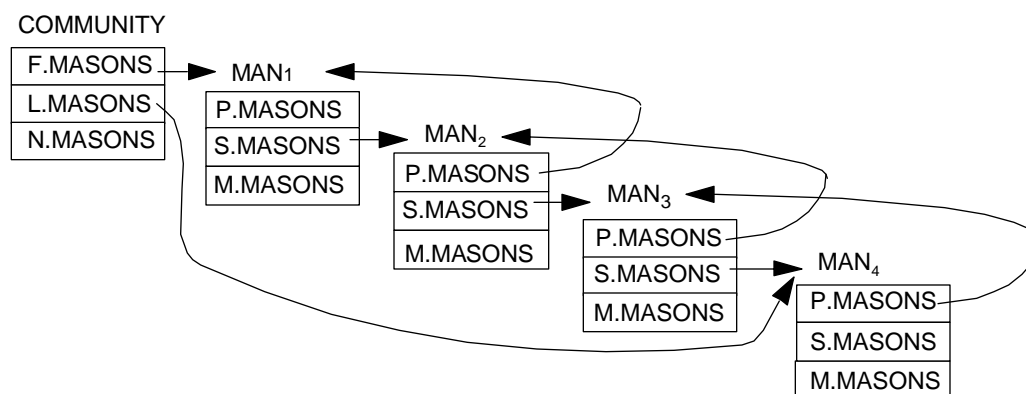
MAN	
P.	MASONS
S.	MASONS
M.	MASONS
P.	BOY.SCOOTS
S.	BOY.SCOOTS
M.	BOY.SCOOTS

**Figure 4-4. Automatically-defined Attributes for Members of the Class MAN**

The attributes starting with **P.** are set pointers pointing to the predecessor entity in the indicated set. Those starting with **S.** are set pointers pointing to the successor entity in the indicated set, and those starting with **M.** indicate whether an entity is currently a member of the set. The concepts of predecessor and successor, as well as first and last, can be best explained by an illustration. In figure 4-5 the entity **COMMUNITY** owns one set called **MASONS**. The members of the set are entities of the class **MAN**. The entity-set relationships are defined by the statements:

every COMMUNITY owns some MASONS  
 every MAN may belong to the MASONS

The entity structures shown contain the automatically-generated ownership and membership pointers **F.MASONS**, **L.MASONS**, **N.MASONS**, **P.MASONS**, **S.MASONS**, and **M.MASONS**.



**Figure 4-5. Owner-member Set Relationships**

The set owner, the entity named **COMMUNITY**, has two attributes that point to the member entities that are logically first and last in the set **MASONS**. It also has an **N.MASONS** attribute, which in this case is 4. The member entities, here called **MAN1**, **MAN2**, **MAN3**, and **MAN4**, have two attributes that point to the members of the set that logically precede and succeed them. Thus, **F.MASONS** in **COMMUNITY** points to the entity structure of **MAN1**, indicating that it is the first entity (logically) in the set **MASONS**. The pointer **P.MASONS** of **MAN1**, points nowhere (has a zero value), as **MAN1** has no predecessor in **MASONS**. Its **S.MASONS** pointer, however, points to **MAN2**, which logically follows it in **MASONS**. As shown, **P.MASONS** of **MAN2** points back to its predecessor, **MAN1**. The same is true of **MAN3**. **MAN4**, as the last member of **MASONS**, differs somewhat. It has no successor (**S.MASON** = 0), and is pointed to directly by **L.MASONS**, the last-in-set pointer of **COMMUNITY**. Each **MAN** also has an **M.MASONS** attribute which is non-zero since each **MAN** is a member of the set **MASONS**.

The items to note from this example are:

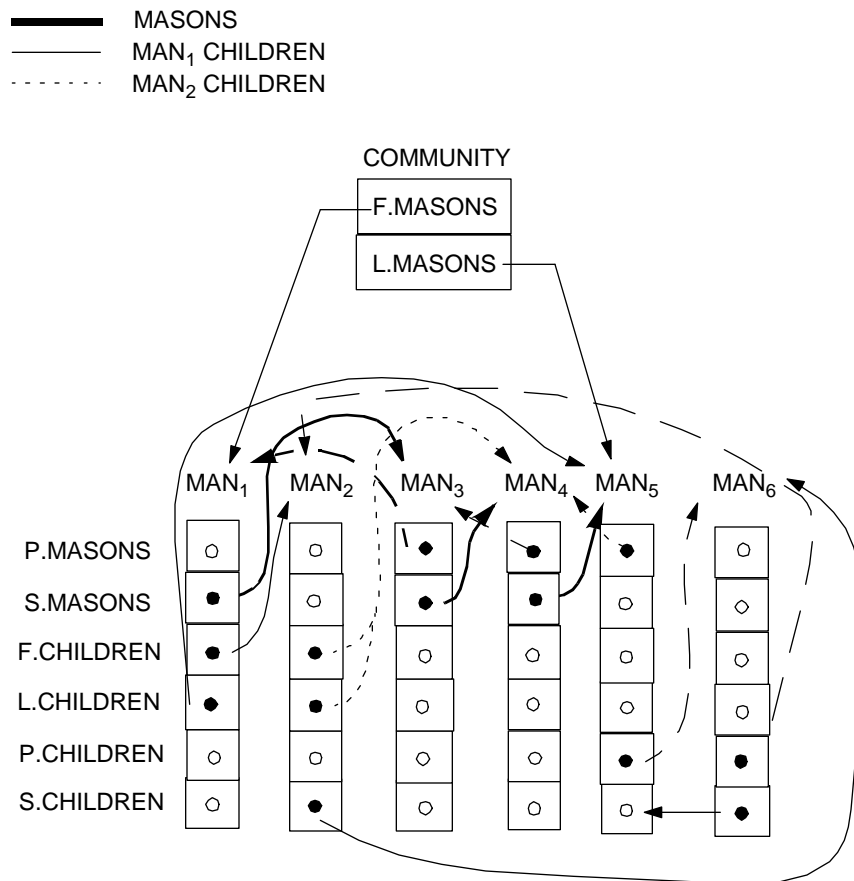
1. A set is made up of entities that point to one another, thereby expressing their member relationships.
2. First-in-set and last-in-set pointers connect a set's owner to its member entities.
3. A specific entity can own or belong to any number of sets as long as it has the required pointer attributes. For example, the entity **MAN** might own the set **CHILDREN** whose members are also entities of the type **MAN**. These relationships might be defined by the statement:

every MAN may belong to the MASONS,  
 own some CHILDREN, and belong to the CHILDREN

Figure 4-6 illustrates a collection of **MAN** entities having one possible relationship to each other. The relationships expressed in figure 4-6 are:

1. **COMMUNITY** owns the set **MASONS** whose members are **MAN1**, **MAN3**, **MAN4**, and **MAN5**.
2. **MAN1** owns a set **CHILDREN** whose members are **MAN2**, **MAN6**, and **MAN5**.
3. **MAN2** owns a set **CHILDREN** whose single member is **MAN4**.

These relationships are depicted in figure 4-7.



**Figure 4-6. Set Relationships**

An entity's attributes and set relationships can be declared in one or more **every** statements using attribute name clauses, set ownership clauses, and set-membership clauses. The clauses have the form:

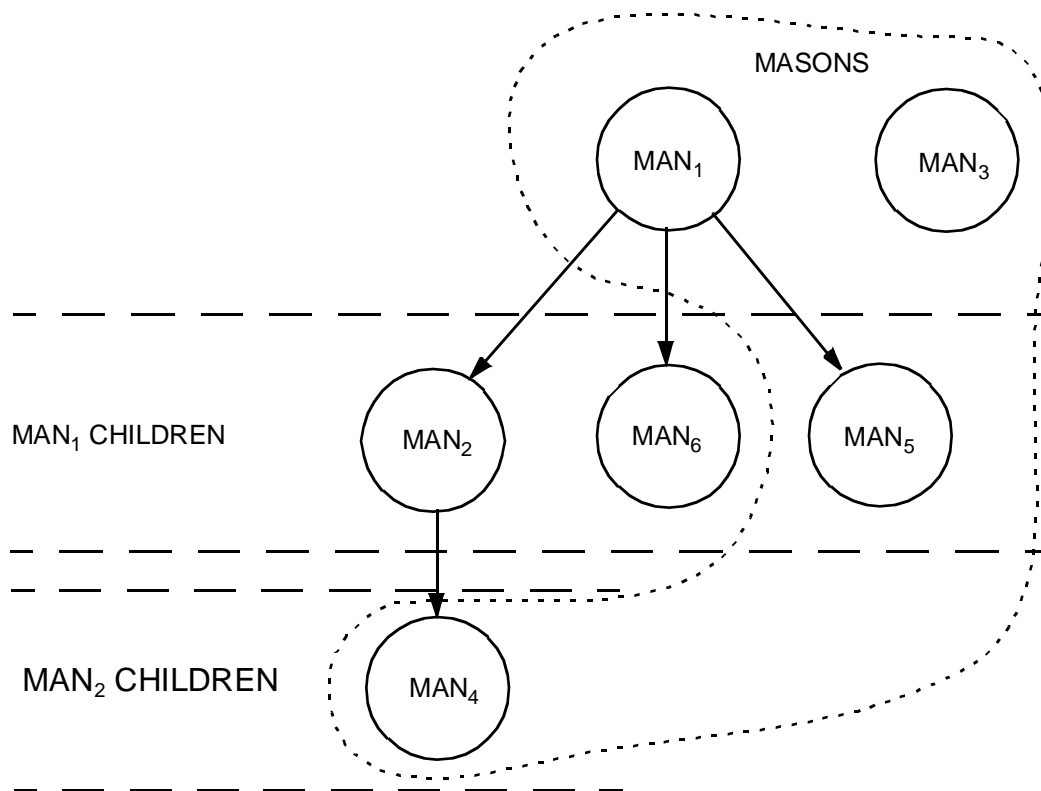
```

attribute clause           has attribute name list
                           or have attribute name list

```



set-ownership clause	owns set name list or own set name list
set-membership clause	belongs to set name list or belong to set name list



**Figure 4-7. Set Relationships**

When more than one clause is used in an **every** statement, adjacent clauses are separated by commas. If desired, a clause can be preceded by the words **may** or **can**. Some examples are:

every PERSON has list, owns list and may belong to list  
 every CITY owns list and has list  
 every CAR has list, and may own list

The items in an attribute name or set name list must be separated by both a comma and one of the words **a**, **an**, **the**, or **some**. For example:

```

every PERSON has a NAME, and an ADDRESS,
    owns some CHILDREN
    and may belong to the MASONS, a CHURCH, and a FAMILY
every X has a P, a Q, a R and an A

```

Set names should follow the same naming conventions as entities and attributes and must be unique. Recall the guidelines on variable naming given in Chapter 1. It may now be apparent why care should be taken in assigning names of the form letter-dot-name, as the declaration of set names implicitly defines a number of attribute names, made up from the set name by just this form of prefixing.

An **every** statement defines a data structure. The next several paragraphs explain how these data structures are created and used, and the items within them are given further definition.

## 4.4 Temporary Entities

An **every** statement defines the structure of a class of entities. Entity classes can be temporary or permanent. This paragraph describes temporary entities. Paragraph 4.5 discusses permanent entities.

When the statement:

```
temporary entities
```

appears before a collection of **every** statements in a preamble, it declares that all following entities are temporary. This means that storage is allocated to entities individually as they are created during the course of program execution. Individual entity records are provided for each temporary entity when a **create** statement is encountered. The form is:

```
create entity name called variable
```

A **create** statement allocates space in memory for the entity representation and assigns a pointer to this space to the indicated variable. Each entity is a unique and distinct individual that is identified by its pointer. As long as the variables into which these pointer values are placed are distinct, the identity of individual entities is preserved. For example:

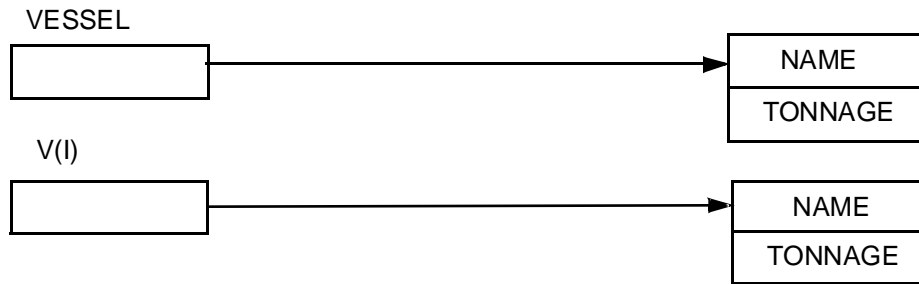
Entity definition in a preamble:

```
temporary entities
    every SHIP has a NAME and a TONNAGE
```

**Create** statements in a program:

```
create SHIP called VESSEL
create SHIP called V(I)
```

These two **create** statements assign pointers to distinct copies of the **SHIP** entity structure to the variables **VESSEL** and **V(I)**. Figure 4-8 provides an illustration.



**Figure 4-8. Entity Creation**

If desired, the words **a** or **an** can be used after **create** to improve readability, as in:

```
create a SHIP called QUEEN.MARY
create an EVENT called BIRTH
```

If no variable is specified in a **called** clause, the entity identification number is assigned to the global variable with the same name as the entity class. Recall that the **every** statement implicitly declares a global pointer variable with the same name as the entity class. The statement:

```
create a SHIP
```

allocates space for a **SHIP** entity, and assigns the pointer value to the automatically defined global variable named **SHIP**. It is interpreted as if written:

```
create a SHIP called SHIP
```

The attributes of a particular instance of a temporary entity are referenced using the notation:

```
attribute name(identification number)
```

as in:

```
NAME (VESSEL)
```

and:

```
TONNAGE (QUEEN.MARY)
```

Because attribute references refer to locations in memory, like variable names, they can be used in the same way that variables are used — in input/output lists and in logical and arithmetic expressions. For example:

```

preamble
  normally,mode is integer
  temporary entities
    every SHIP has an AGE and a TONNAGE
  define V as 1-dimensional array
end

main
  read N
  reserve V as N
  for I = 1 to N
  do
    create a SHIP called V(I)
    read AGE (V(I)), TONNAGE (V(I))
  loop
  read YEARS
  for I = 1 to N
    with AGE(V(I)) less than YEARS
      add TONNAGE(V(I)) to SUM.TONS
  print 1 line with YEARS, SUM.TONS  thus
  Total tonnage of ships less than ** years old is *****
end

```

In this program, **N** temporary entities of the class **SHIP** are created and their identifying pointers stored in the subscripted variables **V(1)**, **V(2)**, ..., **V(N)**. The attributes of these entities are then accessed in **read**, **with**, and **add** statements.

The assignment of memory space to entity structures is much like the assignment of pointer and data words to arrays as they are reserved. Similarly, entities can be released when they are no longer needed. The statement:

```
destroy entity name called variable
```

uses the value of the identifying pointer stored in the indicated variable to indicate the space that is to be released. When destroyed, the space is returned to the pool of unused memory for possible reuse. The words **the** or **this** can be used before the entity name, if desired, as in:

```
destroy the SHIP called VESSEL
```

and

```
destroy this SHIP called V(I)
```

If the pointer variable name is omitted as in:

```
destroy entity name
```

the statement uses the pointer value in the global variable that has the name of the entity class. The statement is interpreted as if written:

```
destroy entity name called entity name
```

## 4.5 Permanent Entities

Permanent entities are defined in much the same way as temporary entities, but these declarations must be preceded by the statement:

```
permanent entities
```

Entities declared as permanent are stored collectively rather than in individually identifiable records. The entire group of permanent entities of a given class is created by a single statement. The attributes of the entities in the group are stored as indexed arrays. The attributes for a particular entity are accessed by effectively selecting a common index for all the associated attribute arrays. The number of entities in a particular entity group is maintained in an implicitly declared global variable called **N.entity**. The attribute arrays are allocated by a **create** statement of a different form than that used for temporary entities. Given the preamble declaration:

```
permanent entities
    every HOME has an ADDRESS and an AREA
```

the number of **HOME** entities to exist may be set by assigning a value to **N.HOME** by a **read** or **let** statement. The statement:

```
create each HOME
```

allocates arrays for all the attributes of the **N.HOME** entities of the class by executing the statement **reserve ADDRESS and AREA as N.HOME**. The words **every** and **all** can be used in place of **each**. Several permanent entities can be created together by naming a list of entity names, as in:

```
create every HOME, HOTEL and RESTAURANT
```

which is of the general form:

```
create permanent entity name list
```

As an alternative to assigning a value to **N.entity** before permanent entity creation, an arithmetic expression can be used in the **create** statement to indicate the size of the attribute arrays. For example, the following statements are equivalent:

```
let N.HOME = 5
create every HOME

create every HOME(5)
```

When the second form is used, **N.entity** is thereafter set to the value of the parenthesized expression.

Permanent entities are not referred to by a pointer value, but by an index value that varies between 1 and **N.entity**. Thus we speak of the attributes of each **HOME** as **ADDRESS(1)**, **ADDRESS(2)**, ..., **ADDRESS(5)**, **AREA(1)**, **AREA(2)**, ..., **AREA(5)**. The layout of these attributes is shown in figure 4-9.



**Figure 4-9. Attribute Storage of Permanent Entities**

The program of paragraph 4.4 is repeated here, using permanent rather than temporary entities, to illustrate the difference in how they are defined and used:

```
preamble
  normally, mode is integer
  permanent entities
    every SHIP has an AGE and a TONNAGE
end

main
  read N.SHIP
  create every SHIP
  for I = 1 to N.SHIP
    read AGE(I), TONNAGE(I)
  read YEARS
  for I = 1 to N.SHIP
    with AGE(I) less than YEARS
      add TONNAGE(I) to SUM.TONS
    print 1 line with YEARS, SUM.TONS  thus
    Total tonnage of ships less than ** years old is *****
  end
```

Unlike temporary entities, permanent entities cannot be destroyed individually. They can be destroyed collectively, as in:

```
destroy each SHIP

or

destroy every HOME
```

All attributes of permanent entities are thus released at the same time.

Like temporary entities, permanent entities have global variables defined for them. Each statement of the form:

```
every entity name has...
```

implicitly includes the effect of a statement:

```
define entity name as an integer variable
```

## 4.6 System Attributes

To provide consistency in usage, it is convenient to be able to declare attributes as belonging to **the system**, rather than to a particular entity. These attributes appear much like global variables, but with some differences. Attributes of **the system** are declared by statements of the form:

```
the system has attribute name list
```

For most purposes, the statements:

```
the system has an X and a Y
```

and:

```
define X and Y as variables
```

are equivalent. Because there is only one "system," references to system attributes are not indexed or subscripted, as are references to attributes of permanent and temporary entities. A value of 1 is assigned to the variable **x** by the statement **let x = 1**, whether **x** is defined as in the first or second example above. System attributes will be subscripted if the background dimensionality condition at the time of their declaration is greater than zero. **x** is declared to be a two-dimensional system attribute by the statements:

```
normally, dimension is 2
the system has an X
```

The convenience of system attributes derives mainly from their use as pointers that enable a program as a whole to own sets. The statement:

```
the system owns a QUEUE
```

specifies that a program contains two system attributes named **F.QUEUE** and **L.QUEUE** that point to the first and last entities belonging to a set named **QUEUE**. Several system-owned sets can be defined at one time by the statement:

```
the system owns set name list
```

If a background dimensionality, other than zero, is declared, the effect is to define any system-defined attributes, including any set pointers, as arrays rather than as unsubscripted variables, as in:

```
normally dimension is 2
the system owns a TABLE and has a MATRIX
```

Subscripted system attributes, both explicitly declared and any implicitly defined set pointers, must be **reserved** before they can be used. To use the system set **TABLE** and the system array **MATRIX**, defined above, a statement such as:

```
reserve F.TABLE, L.TABLE, N.TABLE and MATRIX as N by M
```

must be executed.

## 4.7 Attribute Definitions: Mode and Dimensionality

Attributes of the system, and of permanent and temporary entities, may be declared to have any of the modes associated with variables. As with any global or local variables, modes can be declared by default, using **normally** statements, and explicitly, using **define** statements. Set pointers are automatically declared to be of **integer** mode.

Permanent and temporary entity declarations define the dimensionality of their attributes implicitly, making additional definitions unnecessary. The statement:

```
every PERSON has an AGE
```

declares that **AGE** has a single subscript, a pointer value if **PERSON** is declared as temporary, or an index value if **PERSON** is permanent. The notation **AGE(PERSON)**, meaning **AGE** of **PERSON**, provides for this subscript. System attributes, on the other hand, must be declared and reserved as explained in paragraph 4.6.

The rules for assigning modes and dimensionalities to attributes are straight forward.

Mode:

1. The current "background mode" is assigned to all attributes specified in **every** and **the system** statements except for automatically-generated set pointers.
2. **Define** statements following **every** and **the system** statements can redefine attribute modes.

Dimensionality:

1. The current "background dimensionality" is assigned to all attributes and sets specified in **the system** statements.
2. **Every** statements specify the dimensionality of the attributes and sets listed in them.

The following preamble illustrates each of these rules.



```

preamble
  normally dimension is 2
    the system has an EXCESS
    define EXCESS as an integer array
  normally dimension is 0, mode is real
    the system has a VALUE and owns a COLLECTION
  permanent entities
    every SAMPLE belongs to the COLLECTION
    and has a PRICE and a NAME
  temporary entities
    every POINT has an IDENTITY and a
      COLLECT.TIME
  define NAME and IDENTITY as text variables

```

This preamble defines five system attributes, one of which is **real**-valued (**VALUE**), one of which is a base pointer for a two-dimensional array (**EXCESS**) whose elements are **integer**-valued, one of which is an **integer** counter for set members (**N.COLLECTION**), and two of which are set pointers (**F.COLLECTION** and **L.COLLECTION**). The preamble also defines a class of permanent entities (**SAMPLE**) and a class of temporary entities (**POINT**). Each entity of type **SAMPLE** has two set pointer attributes (**P.COLLECTION** and **S.COLLECTION**), an integer set membership flag (**M.COLLECTION**), a **real** attribute (**PRICE**), and a **text** attribute (**NAME**). These attributes are stored as one-dimensional arrays, of dimension **N.SAMPLE**. Each entity of type **POINT** has a **text** attribute (**IDENTITY**) and a **real** attribute (**COLLECT.TIME**). These attributes are stored in individual locations within the temporary entity structures.

Figure 4-10 illustrates the storage of the attributes of the **N.SAMPLE** permanent entities of the class **SAMPLE**. Figure 4-11 illustrates the layout of an entity record for a temporary entity of the class **POINT**. Figure 4-12 shows the arrangement in memory of the system attributes **VALUE**, **EXCESS**, **F.COLLECTION**, **L.COLLECTION**, and **N.COLLECTION**.

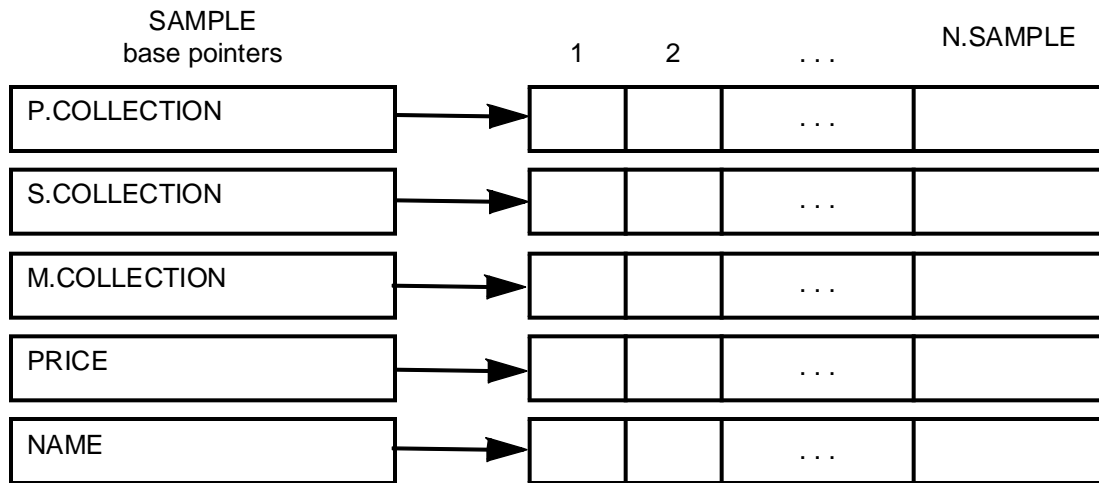
## 4.8 Sets: Their Declaration and Use

Sets are declared in **every** statements when their owner and member entities are defined. Every set must have an owner, either an entity or **the system**, and can have either permanent or temporary entities as members, but not both.

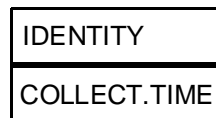
Sets named in **every** statements have the following properties:

1. Owner entities have first and last-in-set pointers named **F.set** and **L.set**.
2. Member entities have predecessor and successor pointers named **P.set** and **S.set**.
3. Set members are ranked on a first-in, first-out basis when they are put in a set.
4. Each member entity has a membership named **M.set** that is a non-zero value if an entity is in the set, and zero if it is not. Note that **M.set** is non-zero if an entity is in *any* set with the given name. A non-zero value does not guarantee the entity is in one specific set.

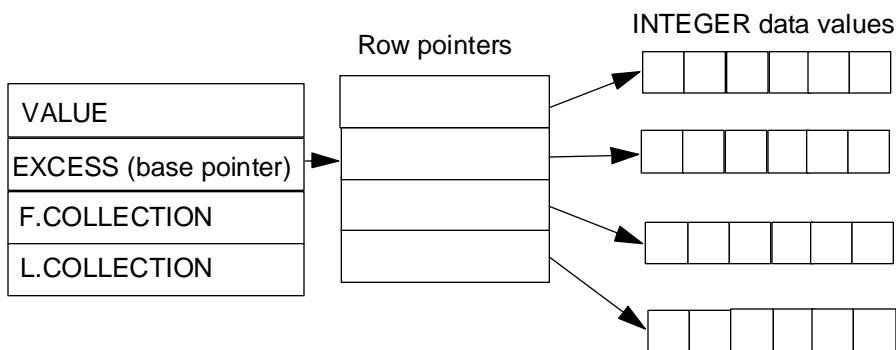
5. Each owner entity has a counter attribute named **N.set** whose value is the number of member entities currently in the set.



**Figure 4-10. Storage of Attributes of a Permanent Entity**



**Figure 4-11. Storage of Attributes of a Temporary Entity**



**Figure 4-12. Storage of System Attributes and Set Pointers**

In general, all set owner and member attributes are treated as **integer**-valued and have names formed by prefixing a letter and a period to the set name. The declarations:

```
permanent entities
    every CITY owns a CLUB
temporary entities
    every RESIDENT may belong to the CLUB
```

define three attributes for the owner entity of **CLUB** and three attributes for its member entities. Because **CITY** is a permanent entity, its owner attributes are stored as three arrays, with base pointers **F.CLUB(\*)**, **L.CLUB(\*)**, and **N.CLUB(\*)**. **RESIDENT**, being a temporary entity, has its member attributes, **P.CLUB**, **S.CLUB**, and **M.CLUB**, stored in locations within each individual entity.

Every program commences execution with empty sets. As a program proceeds, statements are executed that file entities in sets, examine sets, and remove entities from sets. Set memberships change dynamically when **file** and **remove** statements alter set pointers, changing relationships that affect set membership and set ranking. The **file** statement has two basic forms:

- 1a. file arithmetic expression first in set
- 1b. file arithmetic expression last in set
- 2a. file arithmetic expression  
before arithmetic expression in set
- 2b. file arithmetic expression  
after arithmetic expression in set

The words **first** or **last** are optional. When both are omitted, **file last** is implied; the statements:

```
file arithmetic expression last in set
```

and

```
file arithmetic expression in set
```

are equivalent.

In each of the forms, the words **the** or **this** are optional before the expression or the set name, as in:

```
file the BIRD in the NEST
file this JOB first in this QUEUE
file MYDOG after YOURDOG in the KENNEL
```

Used in this context, each arithmetic expression must evaluate to an entity identifying value. It must be either the pointer value addressing a temporary entity, obtained from a previous **create** statement, or an integer number indexing one of the **N.entity** permanent entities of a specific type.

In case 1 above, the indicated item is filed at the head (tail) of the set. In 2, the position of filing is specified relative to some entity already in the set. The actions that take place when a **file first** statement is executed are illustrated by two examples. The examples use a set whose owner and member entities are both temporary, but they can as well be both permanent, or one permanent and one temporary. The set and the entities are defined by the statements:

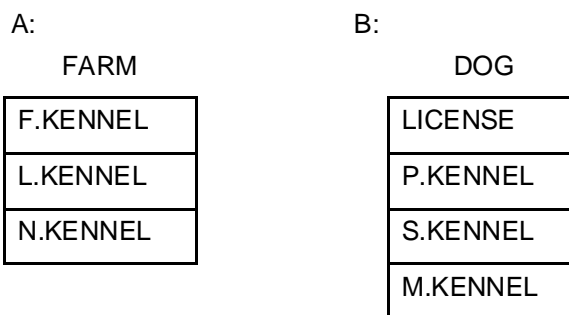
```
temporary entities
every FARM owns a KENNEL
every DOG has a LICENSE
and belongs to some KENNEL
```

The two illustrations are included in the program segment shown below. We first consider the situation before and after the first dog is filed in a kennel. Later we examine a subsequent situation. Assume a **FARM** has been created whose identifying value is stored in the global variable **FARM**. This could have been done by the statement **create a FARM**.

Program segment:

```
read NUMBER.OF.DOGS
for I = 1 to NUMBER.OF.DOGS
do
  create a DOG
  read LICENSE(DOG)
  file DOG first in KENNEL(FARM)
loop
```

The entity **FARM** is shown in figure 4-13a. After the first dog is created, its entity will appear as in figure 4-13b.

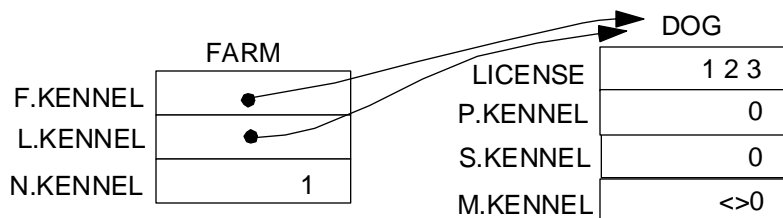


**Figure 4-13. Entity Structures for FARM and DOG**

At this point the variables **F.KENNEL**, **L.KENNEL**, **N.KENNEL**, **P.KENNEL**, **S.KENNEL**, and **M.KENNEL** are all zero, indicating that **KENNEL(FARM)** is empty and **DOG** is not in some **KENNEL**. A **M.KENNEL** is equal to 0.

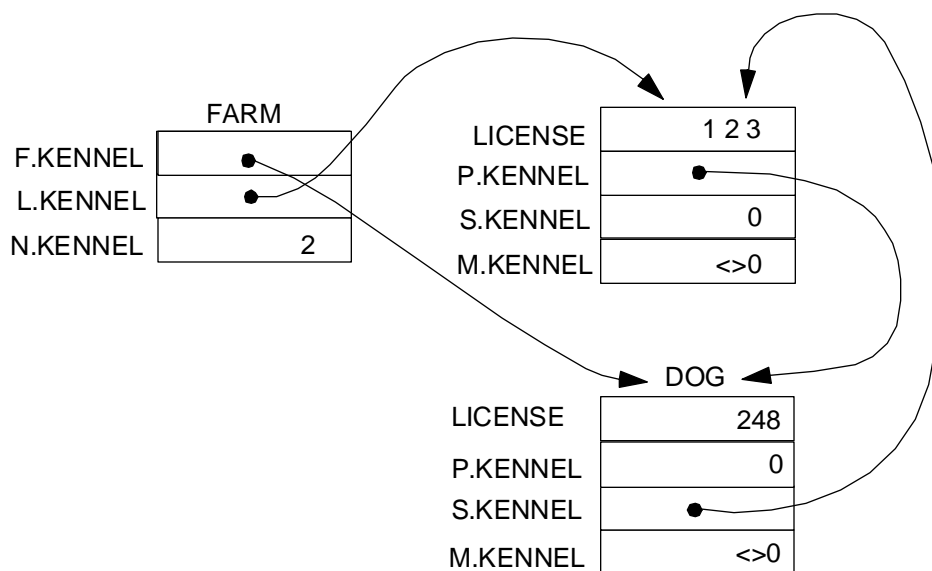
After the **file** statement is executed, the entity records are as shown in figure 4-14. The owner entity **FARM** points to the member entity **DOG**, which, being the only entity in **KENNEL(FARM)**, is

both first and last. Because **DOG** is alone in **KENNEL(FARM)**, it has no predecessor or successor entities.



**Figure 4-14. Entity Records**

After the second **DOG** is created and filed, the entity records take the form shown in figure 4-15. With two members in the set, the first and last pointers lead to different entity records. The first entity, pointed to by **F.KENNEL(FARM)**, points ahead to the second entity with its successor pointer. The second entity points back at the first entity with its predecessor pointer. Both the predecessor pointer of the first entity and the successor pointer of the last entity are zero, indicating their respective roles.



**Figure 4-15. Entity Records**

An important point to note is that the global variable **DOG** now points to the second **DOG** created. The entity record of the first **DOG** created can only be accessed through the pointers to it, **L.KENNEL(FARM)** and **S.KENNEL(DOG)**. These pointers illustrate the general form of an attribute reference:

attribute (entity identification)

Because an entity identification can itself be an attribute, as in the case of a pointer, nested entity references can be made, as in:

```
S.KENNEL(F.KENNEL(FARM))
```

which reads as "the successor of the first in **KENNEL** of **FARM**" and has the same value as **S.KENNEL(DOG)** because **F.KENNEL(FARM) = DOG**. Any level of entity nesting is possible as long as all nested expressions evaluate to entity identifiers.

When a third **DOG** is created and filed, the entity records are as shown in figure 4-16. Additional creations and filings are analogous.

A **file last** statement has an effect similar to **file first**, but operates on the opposite end of a set. If our example program segment were written with the statement **file DOG last in KENNEL(FARM)**, after executing three creates and files the entity records would appear as in figure 4-17.

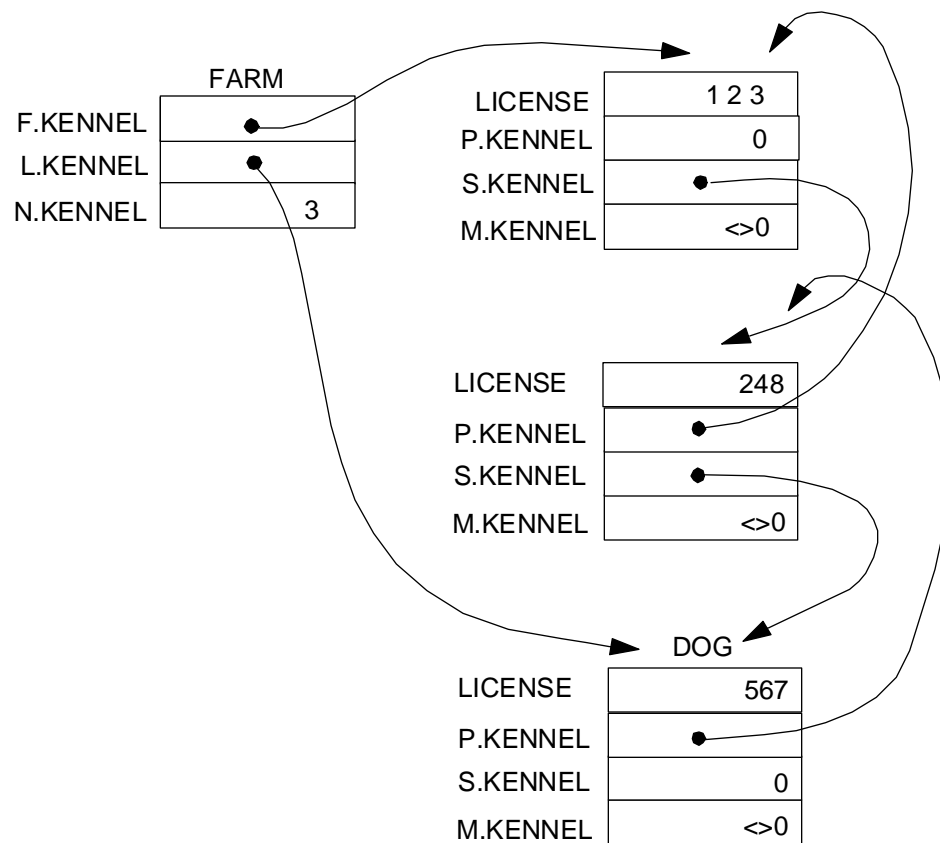
The **file before** and **file after** statements are described with a different example. Assume the entity record organization shown in figure 4-18 was created by the following program statements:

```
create a DOG called MYDOG
file MYDOG first in KENNEL(FARM)
create a DOG called YOURDOG
file YOURDOG first in KENNEL(FARM)
```

The statements:

```
create a DOG
file the DOG after YOURDOG in KENNEL(FARM)
```

insert the entity record for the newly created **DOG** after the entity record pointed to by the variable **FIDO**. The resulting entity record organization is shown in figure 4-19.



**Figure 4-16. Entity Records**

Entities are removed from sets by **remove** statements. Two basic forms of removal are possible.

- 1a. remove first variable from set
- 1b. remove last variable from set
2. remove arithmetic expression from set

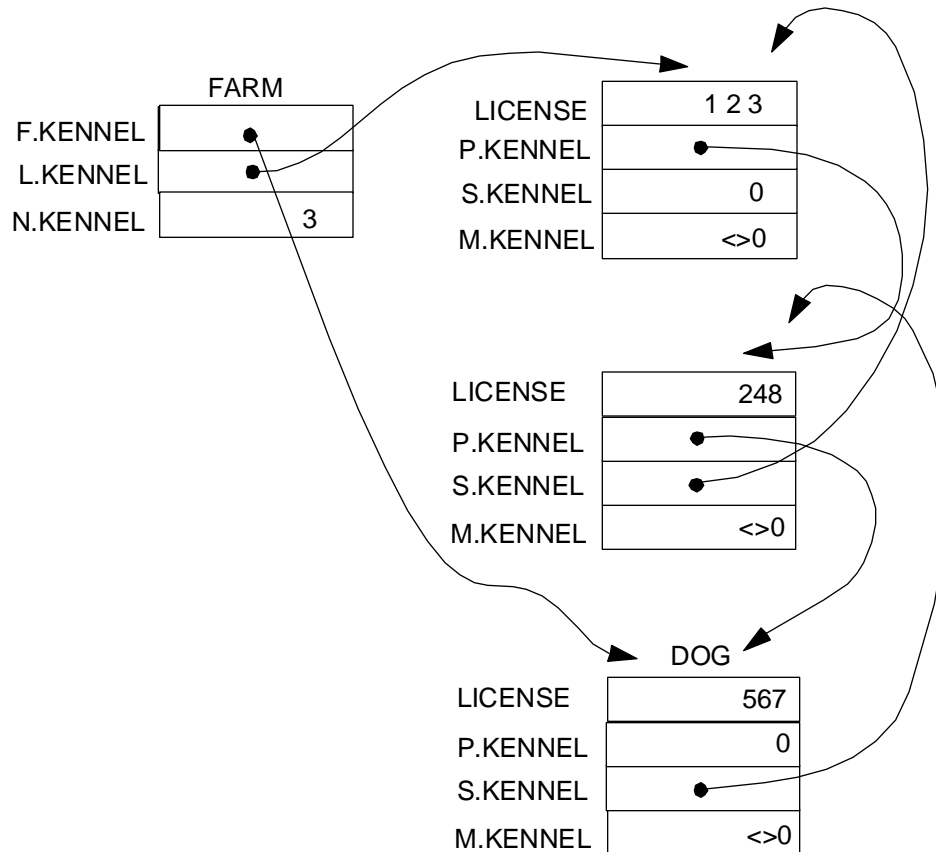
The word **the** is optional after **remove**, as is either of the words **the** and **this** before the set name. In addition, either of the words **this** or **above** can be used before the expression in form (2).

A **remove first** or **remove last** statement removes from a set the entity pointed to by the first or last pointer attribute of the set owner. The identification number of the removed entity is assigned to the variable in the **remove** statement. For instance, in the situation shown in figure 4-19, the statement:

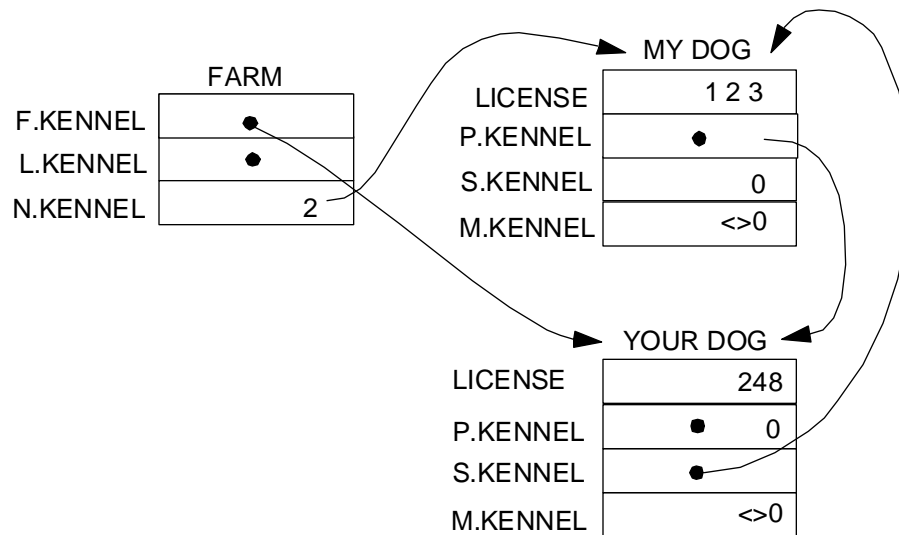
```
remove the first HOUND from KENNEL(FARM)
```

removes the first entity (**MYDOG**) from **KENNEL(FARM)**, makes the second entity first, and puts a pointer to **MYDOG** in **HOUND**. The attribute values of **MYDOG**, which now can also be called **HOUND**,

are unchanged except for **M.KENNEL** which is now 0. Although **MYDOG** is no longer in **KENNEL(FARM)**, its attribute **S.KENNEL** still points to **DOG**. In set membership, pointer values are meaningless once an entity is removed from a set. If the variable name **MYDOG** were replaced by **DOG** in figure 4-18, this figure would show the organization of **KENNEL(FARM)** after **MYDOG** had been removed from figure 4-19.







**Figure 4-18. A Set with Two Members**

If an attempt is made to remove the first or last member from an empty set, the program terminates with an error message.

A **remove specific entity** statement extracts a particular entity from a set. The entity identification number is given by the arithmetic expression. Referring again to figure 4-19, the statement:

```
remove this DOG from KENNEL(FARM)
```

converts the set shown in that figure to the set shown in figure 4-18. If the arithmetic expression is not an identification number of an entity currently in the set (signaled by a non-zero value in its membership attribute), the program terminates with an error message.

The presence of a membership attribute in an entity permits both error checking (cannot file **x** after **x** because **x** is not in the set; cannot remove **x** because **x** is not in the set; cannot destroy **x** if it is a member of some sets; cannot file **x** in a set if it is already in it) and questioning about set membership. The logical expressions:

```
arithmetic expression is in set
```

and

```
arithmetic expression is not in set
```

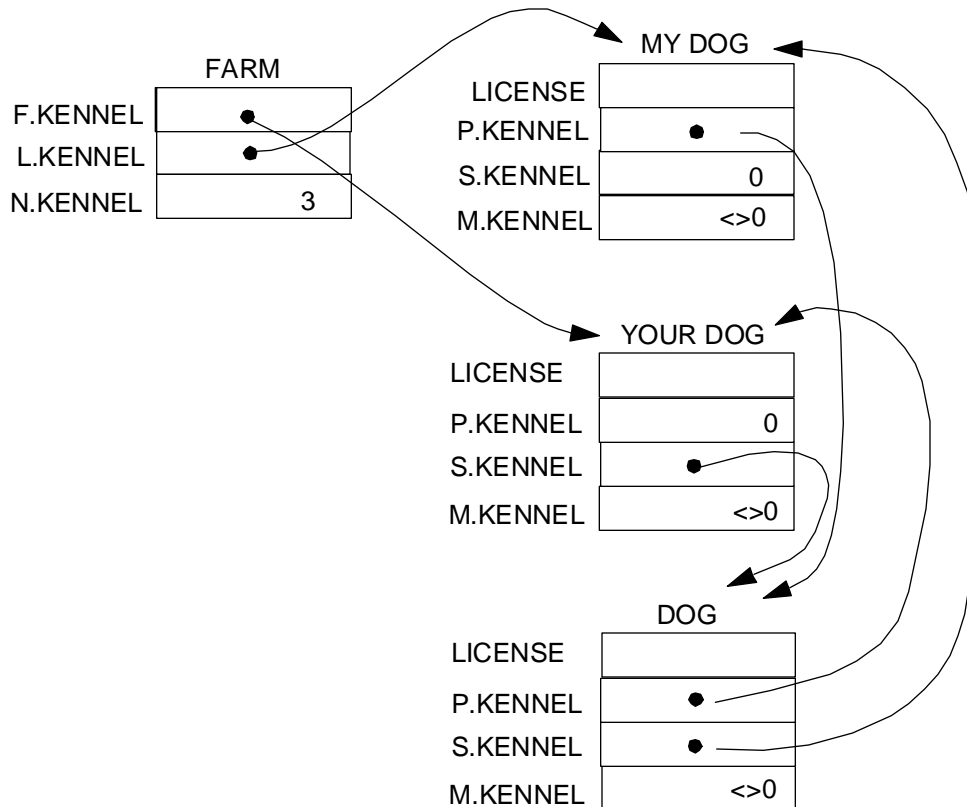
can be used in **if** statements and **with** clauses to take actions conditional on set membership. As options, the words **the** and **this** can precede the arithmetic expression, and the words **a**, **an**, **the**, or **some** the set name. Examples are:

```
if MYDOG is not in some KENNEL,
```

or

with this DOG in a KENNEL,

In these statements, the set name **KENNEL** cannot be subscripted. It is impossible for an entity to belong to more than one set of a given class at a time. A **DOG** can belong to **KENNEL(FARM)** or **KENNEL(HOUSE)**, but not to both simultaneously. A membership attribute signals only membership of a named set, not specific owner-membership details.



**Figure 4-19. A Set with Three Members**

Each set's first pointer is used to determine whether or not a specific set has members. The logical expressions:

```
set is empty
```

and

```
set is not empty
```

are available. As with the preceding expressions, the words **the** and **this** are allowed before the set name to improve readability. Using the **is not empty** and **is empty** logical expressions, one can write statements such as:

```

    if KENNEL(FARM) is not empty,
        remove the first DOG from KENNEL(FARM)
    else
and

    if SEX(PERSON) = "MALE"
        and FAMILY(PERSON) is empty,
            call BACHELOR.ACTION given PERSON
    else

```

The sets pictured in all preceding illustrations rank on a first-in, first-out, priority scheme. That is, **file last** is the default condition. Other rankings are possible. For example, in a set defined by the declarations:

```

every COUNTRY owns an ARMY
every PRIVATE has a HEIGHT and a WEIGHT
    and belongs to an ARMY

```

it might be desirable to rank the various privates in the army sets by weight or height, rather than by the order in which they entered the set. Furthermore, this ranking may be desired in ascending or descending order. This can be done by including a set definition statement after the **every** statements that first mention a set and after any attribute definition statements that might be associated with the **every** statement. A set definition statement, like an attribute definition statement, begins with **define**. The following statements define the set **ARMY** as being, respectively, ranked in descending order by the **HEIGHT** attribute of the entities in it; ranked in ascending order by the same attribute; ranked in descending order by the **WEIGHT** attribute of the entities in it; ranked in descending order by the **HEIGHT** attributes, and, for those entities whose **HEIGHT** attributes have equal value, ranked in ascending order by their **WEIGHT** attributes.

1. ARMY as a set by high HEIGHT
2. define ARMY as a set by low HEIGHT
3. define ARMY as a set ranked by WEIGHT
4. define ARMY as a set ranked by high HEIGHT, then by low WEIGHT.

Example 3 shows that omission of the words **high** or **low** implies **high**. Example 4 shows how rankings can be cascaded, one after another, by **then by** clauses to resolve ties when ranking attributes are equal. As many **then by** clauses can be used as are needed in any given application. A comma must precede each **then by** clause.

Because ranked sets are defined with respect to ranking values of their members, it is not permissible to use **file before** or **file after** in such sets since doing so would destroy the ranking concept.

If a set is to be ranked only by entry time of entities into it, a short form can be used. Depending on whether the ranking gives highest priority to the earliest or latest arrival, the **define** statement is written as:

```
define ARMY as a fifo set
```

or

```
define ARMY as a lifo set
```

If the first form is used, entities are stored on a first-in, first-out basis. If the second form is used, entities are stored on a last-in, first-out basis.

All the statements described thus far assume that every set has a full complement of ownership and membership attributes, that is, that both first and last, predecessor and successor pointers, and counter and membership attributes are defined. To perform all of the available set manipulations, they must all be present. When set needs are more modest, sets with fewer pointers can be designed with a gain in efficiency.

In some cases, not all of the automatically defined set pointers are needed. This is true in **FIFO**- and **LIFO**-defined sets, where entities are never inserted in the middle of a set, but only at the beginning or end. A **FIFO** set need have only first, last, and successor pointers. A **LIFO** set need have only first and successor pointers. **FIFO** and **LIFO** set organizations are shown in figure 4-20.

A clause can be appended to a set declaration statement to delete unused set attributes. Any or all of the three owner-entity and three member-entity attributes may be deleted. If the first-in-set attribute is deleted, the **is empty** logical expression cannot be used. If the membership attribute is deleted, the **is in set** logical expression cannot be used. Table 4-2 below defines the statements that cannot be used when certain set attributes are deleted.

The deletion clause is of the form:

```
without attribute list attributes
```

The attribute list consists of one or more of the letters **F**, **L**, **P**, **S**, **N**, and **M**. The presence of a letter indicates that the attribute formed by prefixing it and a period to the set name is not automatically generated. For example, the following statement defines a **LIFO** set:

```
define ARRIVALS as a LIFO set without L,P,N
and M attributes
```

Note that although it is possible to delete all attributes, doing so completely destroys the concept of a set. The programmer is cautioned against deleting set attributes without carefully considering the consequences.

When required, two or more sets having the same properties can be declared in the same **define** statement. A list of set names can appear after the word **define**, and the word **sets** used instead of **set**.

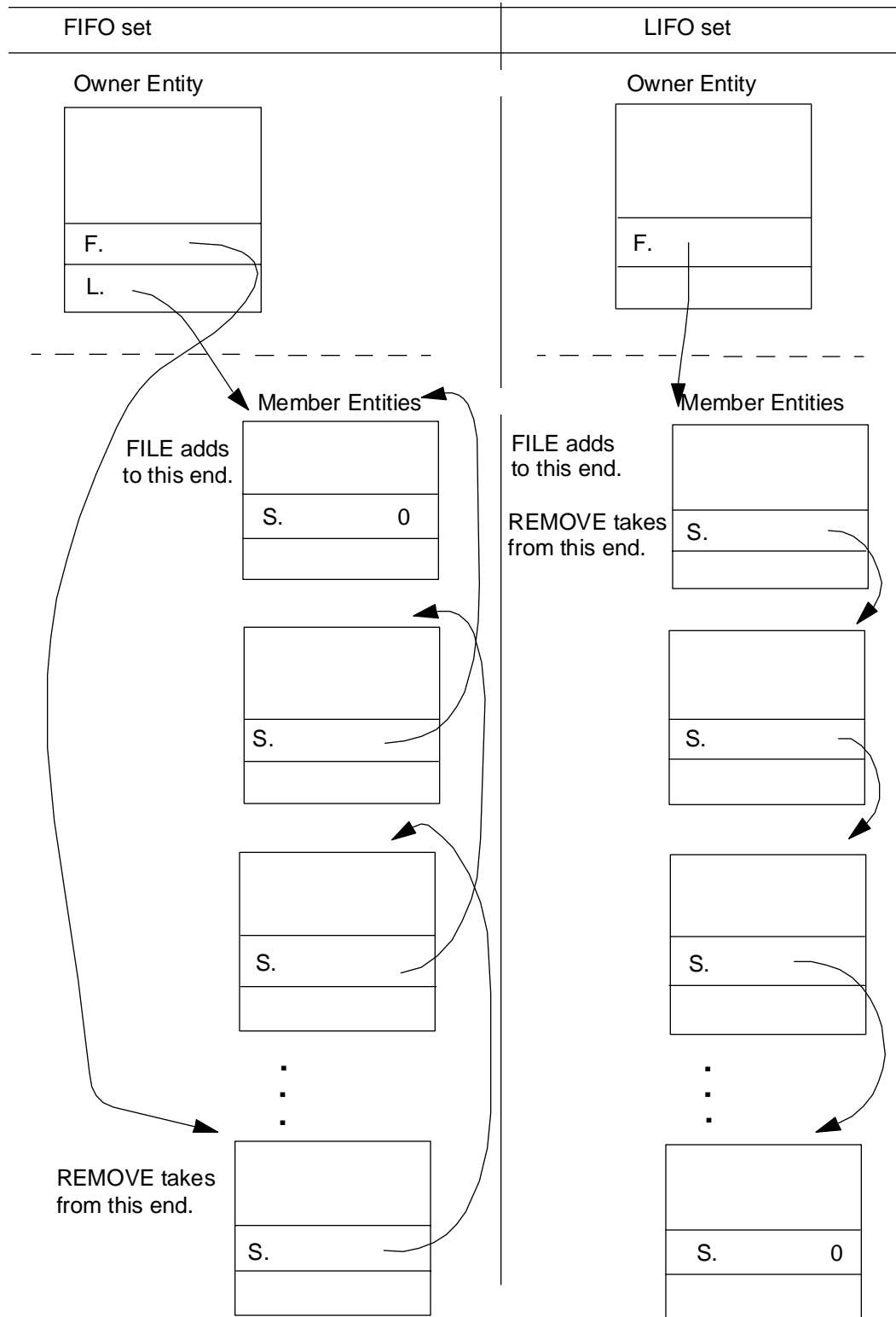


Figure 4-20. FIFO and LIFO Set Organizations

## 4.9 Entity Control Phrases

Two forms of the **for** statement make it possible to step through collections of entities, just as the **for v = E1 to E2 by E3** statement makes it possible to step through successive elements of arrays. One form deals exclusively with permanent entities and the other deals with sets.

Permanent entities, having their attributes stored as arrays, are indexed sequentially. The first entity of the permanent entity class **AUTO** has index **1**, the second **2**, ..., and the  $n^{\text{th}}$  **N.AUTO**. To step through a sequence of index numbers from **1** to **N.entity** for a particular permanent entity class, use the control phrases:

```
for each entity
```

or

```
for each entity called variable
```

The first form is equivalent to the statement **for entity = 1 to N.entity**, where **entity** is the global variable with the same name as the entity class. Thus, the statement **for each AUTO** is interpreted as **for AUTO = 1 to N.AUTO**. The words **every** and **all** may be used in place of **each**, if desired.

The second form above is interpreted as **for variable = 1 to N.entity**, where the variable named in the **called** phrase, instead of the global variable with the same name as the entity, takes on the sequential index values. This variable can be global or local, and cannot be subscripted.

These control phrases may be combined as desired with other **for**, **with**, **unless**, **while**, and **until** control phrases.

The following statements illustrate a typical permanent entity **for** phrase application.

Program preamble:

```
permanent entities
  every MALE has an AGE and a SALARY
```

Main program:

```
read N.MALE
create every MALE
for every MALE, read AGE(MALE), SALARY(MALE)
:
for every MALE with AGE(MALE) ge 21
do
  add SALARY(MALE) to SUM
  add 1 to N
loop
:
```

Experience has shown that some programmers prefer to write **for each JOB**, rather than **for I = 1 to N.JOB** even if **JOB** has not been defined as a permanent entity. That is, they prefer not to make up a local variable name (**I** in this instance) just to step through a sequence of values from **1** to **N (N.JOB** in this instance), but would rather use a name that is easy to remember and has some meaning. To facilitate this, the phrase:

```
include entity name list
```

can be appended to a **permanent entities** statement, as in:

```
permanent entities include ADULT, COUNTRY and FISH
```

This phrase defines the listed names as permanent entities, without attributes, but with the associated global variables **entity** and **N.entity**. The above statement defines the global variables **ADULT, N.ADULT, COUNTRY, N.COUNTRY, FISH**, and **N.FISH** and permits such phrases as:

```
for every ADULT
for each COUNTRY
```

and

```
for all FISH
```

to be used. The following short example illustrates why this might be a useful shorthand.

Program preamble:

```
permanent entities include ELEMENT
```

Main program:

```
read N.ELEMENT
reserve LIST(*) as N.ELEMENT
for each ELEMENT, let LIST(ELEMENT) = 1
```

It should be clear that such a statement is impossible for temporary entities. Scattered throughout memory, rather than stored sequentially, temporary entities cannot be indexed by ordinal numbers; they can only be pointed to by set pointers. To process all the temporary entities of a given class, the entities must be stored in a set as they are created, and must be processed by a statement that deals with the set. This statement, which by its nature deals with both permanent and temporary entities, has two basic forms:

1. for each variable of set
- 2a. for each variable from arithmetic expression of set
- 2b. for each variable after arithmetic expression of set

Form 1 selects entities that are members of an indicated set, in order of their ranking, assigning the entity pointer values to the named variable. If the set is empty, all of the statements controlled by

the **for** statement are bypassed. The control variable can be either local or global, and cannot be subscripted. Form 2a does the same task as form 1, except that it starts with the set member identified by the indicated expression. Form 2b is similar to 2a, but starts with the set member that follows the identified member. If the identified member is not in the set (denoted by a 0 in its membership attribute), the program terminates with an error message. In both 1 and 2, the words **every** and **all** can be used instead of **each**, and the words **in**, **on**, and **at** used as synonyms for **of**.

To step backward through a set, the phrase:

```
in reverse order
```

is placed after the set name. Set control can range from simple statements such as:

```
for every JOB in QUEUE
```

to complicated statements such as:

```
for all FISH after MINNOW(I) in POND in reverse order
```

Many variations of **for** statements are possible. In the following illustrations, we assume that permanent entities with identification numbers **1**, **2**, **3**, **4**, **5**, and **6** are filed in a set in the order of **1**, **3**, **2**, **4**, **6**, **5**. They may have arrived in this order and been stored as **FIFO**, or they may have been ranked on some attribute value. The method of ranking is not important in this example. Table 4-1 shows different control statements and indicates the sequence of entities that are passed on to the controlled statements by each. The entities are filed in a set named **FILE**. The local variable **J** is used within the control loop for the selected entity index numbers.

Table 4-2 lists the set attributes that are required for the different set operations described.



**Table 4-1. Illustrative Set Control Statements**

Control Statement	Identification Number Sequence
for each j in file	1 3 2 4 6 5
for each j from 4 in file	4 6 5
for each j after 4 in file	6 5
for each j in file in reverse order	5 6 4 2 3 1
for each j in file after 4 in file in reverse order	4 2 3 1
for each j in file until j=3	2 3 1
for each j in file in reverse order until j=3	5 6 4 2
for each j from 2 in file until j=6	2 4
for each j in file with j ≠ 5	1 3 2 4 6

**Table 4-2. Required Set Attributes**

Statement	Attributes Required					
	F	L	P	S	M	N
file in a ranked set	x			x		
file first	x			x		
file last	x	x		x		
file before	x		x	x		
file after	x			x		
remove first	x			x		
remove last	x	x	x	x		
remove specific	x		x	x		
is empty	x					
is in set					x	
Automatic checking <sup>†</sup>					x	
for each V in set	x			x		
for each V in set in rev.		x	x			
for each v from W in set				x		
for each V from W in set in rev.			x			
for each V after W in set				x		
for each V after W in set in rev.			x			
<sup>†</sup> Following sections describe automatic set diagnostics performed only when a membership attribute is included.						

#### 4-10. Common Attributes

An entity is characterized by its attributes. The attributes with which it is declared determine the values it can hold and the relationships it can have with other entities. Sometimes it is desirable that more than one entity type be able to have some characteristics in common, although the entity types may be different in other ways. By declaring that a number of different entity types have certain common attributes, it becomes possible to treat them all in the same way for some "generic" operations. An example of such a common attribute declaration is:

```
every TANKER has a SPEED, a CARGO,
and belongs to the HARBOR.SET
every TUG has a SPEED
and belongs to the HARBOR.SET
```

Because **SPEED** is an attribute common to both **TANKER** and **TUG**, it is possible to use a statement such as:

```
if SPEED(SHIP) is not zero
```

without regard to whether **SHIP** is a pointer to an instance of **TANKER** or a **TUG**.

When temporary entities belong to common sets or own common sets, their set pointers are, of course, common attributes. It becomes possible to write:

```
for each SHIP in HARBOR.SET
  with SPEED(SHIP) not zero
do
  .
  .
  .
```

—so the harbor master can track all the ships steaming around in the harbor.

Under certain SIMSCRIPT II.5 implementations, it is sufficient to name common attributes and sets in **every** statements, as shown. Other implementations require the use of "word numbers" as described in the relevant user's manuals. The above declarations could be rewritten as:

```
every TANKER has a SPEED in word 1,
  a CARGO, and belongs to the HARBOR.SET
and has a P.HARBOR.SET in word 2,
and a S.HARBOR.SET in word 3,
and a M.HARBOR.SET in word 4
```

```
every TUG has a SPEED in word 1,
  and belongs to the HARBOR.SET
and has a P.HARBOR.SET in word 2,
and a S.HARBOR.SET in word 3,
and a M.HARBOR.SET in word 4
```

The entity structures of **TANKER** and **TUG** would look like figure 4-21.

	TANKER		TUG
word 1	SPEED		SPEED
word 2	P.HARBOR.SET		P.HARBOR.SET
word 3	S.HARBOR.SET		S.HARBOR.SET
word 4	M.HARBOR.SET		M.HARBOR.SET
word 5	CARGO		

**Figure 4-21. Entity Structures for TANKER and TUG**

Word numbers are described in detail in Chapter 6.

Care should be taken not to reference **CARGO** with a pointer which could be identifying an instance of a **TUG** entity. Thus:

```

for each SHIP in HARBOR.SET
  with CARGO(SHIP) greater than 100
  .
  .

```

would be incorrect if there were, in fact, any **TUG** entities in the **HARBOR.SET**. Clearly **TUG** entities do not have any **CARGO**.

In general, where common sets are used, it is good practice to declare a common attribute which can serve to discriminate between the different entity types sharing membership of a common set. Recall that in the context of permanent entities, attribute references are actually references to attribute arrays. Multiple definition of such an array is not permitted. Hence, permanent attributes cannot be declared as common.

## 4.11 Compound Entities

At times it is convenient for several entities jointly to have attributes and own sets. Such entities are called compound entities. Statements such as:

```

permanent entities
every MAN and WOMAN owns a FAMILY and has
  a BANK.ACCOUNT
every CITY, COUNTY, STATE has a CENSUS
every MODEL, COLOR, YEAR, MFG has a SALES.VOLUME

```

define compound entities composed of 2, 3, and 4 permanent entities, respectively. The first defines four two-dimensional arrays: **F.FAMILY**, **L.FAMILY**, **N.FAMILY**, and **BANK.ACCOUNT**, each dimensioned as **N.MAN BY N.WOMAN**. The second defines a three-dimensional array **CENSUS** dimen-

sioned as **N.CITY BY N.COUNTY BY N.STATE**. The third defines a four-dimensional array dimensioned in a similar way. Compound entities are defined by statements of the form:

```
every compound entity name list has attribute name list
and owns set name list.
```

As in the case of individual entity definitions, **has** and **owns** clauses can appear in the same or different statements. The word **have** can be used for **has** and **own** for **owns**. By definition, the individual entities of which compound entities are composed must exist. If a compound entity **MAN AND WOMAN** is declared, there must be an entity type **MAN** and an entity type **WOMAN**.

A compound entity name list consists of entity names that have either been declared previously in **every** or **include** statements, or, by their presence in a compound entity declaration, are declared as entities of the type specified in the current background condition, that is, by the last **permanent entities** or **temporary entities** statement. Three kinds of compound entities are possible: those composed exclusively of permanent entities; those composed exclusively of temporary entities; and those composed of both permanent and temporary entities.

Members of sets owned by compound entities can be either permanent or temporary entities. Set membership is declared as usual. Moreover, "compound sets" can have any of their six set attributes deleted and be defined as **FIFO**, **LIFO**, or **ranked**. The following statements might appear in a program in conjunction with the first declaration above:

```
temporary entities
every CHILD belongs to a FAMILY and has an AGE
define FAMILY as a set ranked by AGE
without N and M attributes
```

Attributes of compound entities and sets owned by compound entities are subscripted. Subscripting takes place in the order in which compound entities are defined. Thus, in the statements:

```
let BANK.ACCOUNT(I,J) = 1000
file this CHILD in FAMILY(MAN,WOMAN)
```

the variables **I** and **MAN** can range from **1** to **N.MAN**, and the variables **J** and **WOMAN** can range from **1** to **N.WOMAN**. Compound entities cannot belong to sets. In fact, compound entities have no independent existence, but rather define the existence of compound attributes, subscripted by the named component entities.

Arrays are allocated to "permanent" compound entities when their individual entities are created. They need not be created together, although they usually are. Given the declarations:

```
permanent entities
every MAN has a JOB and a SALARY
every WOMAN owns some INVESTMENTS
```

```
every MAN and WOMAN owns a FAMILY and has a
    BANK.ACCOUNT
```

the statement:

```
create each MAN and WOMAN
```

reserves arrays for the attributes of **MAN** and **WOMAN** and the compound entity **MAN, WOMAN**. The **create** statement is in fact interpreted as several **reserve** statements:

```
reserve JOB(*) and SALARY(*) as N.MAN
reserve F.INVESTMENTS(*), L.INVESTMENTS(*) and
    N.INVESTMENTS(*) as N.WOMAN
reserve F.FAMILY(*,*), L.FAMILY(*,*), N.FAMILY(*,*) and
    BANK.ACCOUNT(*,*) as N.MAN by N.WOMAN
```

Attributes of permanent compound entities can be released in the normal way with a **destroy each** statement such as:

```
destroy each MAN and WOMAN
```

## 4.12 Implied Subscripts

Preceding sections described how attributes are defined and illustrated their use. Examples showed that attributes resemble subscripted variables when they appear in programs. Every attribute reference is of the form:

```
attribute name(entity identification)
```

For attributes of individual entities, the entity identification is either an index or a pointer value. For attributes of compound entities, the entity identification is a list of index or pointer values.

The automatic definition of global variables with the same names as declared entities was also mentioned. It was seen that in the context of **create**, **destroy**, and **for each**, where no variable was explicitly named, the name of the appropriate global variable was understood.

Because all attributes of permanent or temporary entities are declared in the program preamble, either explicitly, or implicitly by declaring set membership or ownership, it is possible to assume a default or implied subscript if one is omitted from an attribute or set reference. The implied subscript used is the variable having the same name as the entity associated with the attribute or set-referenced. In the case of compound entities, subscripts are implied in the order they appear in the defining **every** statement. For obvious reasons, common attributes, shared by more than one entity, cannot have implied subscripts. Some examples of entity definitions and implied subscripts follow.

## 1. Declaration:

```
permanent entities
  every PERSON has an AGE
```

Use:

```
let AGE = 1
```

is interpreted as:

```
let AGE(PERSON) = 1
```

Whenever the attribute **AGE** appears without an entity reference, the variable **PERSON** is used as the index value. There is always a global variable associated with each entity class, **PERSON** in this case. It is possible, within a routine, to define a of the same name, in which case the current value of this local variable is used as the implicit subscript. That is, any unsubscripted use is interpreted as shown above. If a local variable exists, then, consistently, it takes precedence over the global name. The practice of declaring such local variables allows implicit subscripting to be used while minimizing the danger of side effects.

## 2. Declaration:

```
temporary entities
  every SHIP owns some CARGO
  every CONSIGNMENT belongs to a CARGO
```

Use:

```
create a SHIP
.
.
create a CONSIGNMENT
file CONSIGNMENT in CARGO
.
.
```

which is interpreted as:

```
create a CONSIGNMENT called CONSIGNMENT
file CONSIGNMENT in CARGO(SHIP)
```

## 3. Declaration:

```
permanent entities
  every CITY,STATE has a POPULATION
```

Use:

```
let POPULATION = 400000
```

interpreted as:

```
let POPULATION(CITY,STATE) = 400000
```

```
let POPULATION(NEW.YORK) = 8000000
```

interpreted as:

```
let POPULATION(NEW.YORK,STATE) = 8000000
```

Note that because attributes are stored as arrays, and the use of the unsubscripted name in a free-form **read** implies input of the entire attribute array, when implied subscripts are used in free-form **read** statements to reference attributes of permanent entities, the entire attribute array is input.

Although implicit subscripting may be convenient, the absence of subscripting renders it difficult to distinguish attributes from simple variables. Recalling that periods following a name are ignored by the SIMSCRIPT II.5 compiler, a commonly-used notation is to append two periods to a name to indicate an implied subscript. This is purely a programming convention, used to distinguish attributes. It has no effect on the interpretation of the statements. It will be used in subsequent examples to make clear when implicit subscripting is being used.

## 4-13 Displaying Attribute Values

Specific attribute values can be output by conventional **print** and **write** statements. An attribute reference appearing in an output list calls for the retrieval and display of a single value, just as does a subscripted variable or function reference. Some examples of attributes used in **print** and **write** statements are:

```
print 1 line with POPULATION(STATE) as follows
POPULATION IS *****
```

```
write I, INDEX(I), NAME(INDEX(I)) as /, 2 I 5, T *
```

```
for each CARROT in BUNCH,
write LENGTH(CARROT) as I 4
```

Implied subscripts can be used in **print** and formatted **write** statements, as well as in computational statements. Attributes declared by the statement:

```
permanent entities
every BOOK has a PAGE.COUNT, a SUBJECT and an
AUTHOR
```

can be displayed by the statement:

```
for every BOOK,
write PAGE.COUNT.., SUBJECT.. and AUTHOR..
as I 4, 2 T 12
```

The **list** statement can be used to display all the attributes of an entity without writing all their names. Three forms are available:



1. `list attributes of entity called expression`

displays the attributes of the particular entity referenced. The statement can be used for both permanent and temporary entities. The format used is that employed for displaying values of expressions or unsubscripted variables. A short form:

```
list attributes of entity
```

displays the attributes of the entity whose index or identification number is contained in the global variable with the same name as the entity.

2. `list attributes of each entity`

displays the attributes of all the entities in a permanent entity class. The format used is that employed in listing one-dimensional arrays. If only one attribute of a permanent entity class is to be printed, it must be done by referencing the pointer to the array containing the attribute values, for example, by a statement of the form:

```
list attribute
```

3. `list attributes of each entity in set`

displays the attributes of all the entities, permanent or temporary, filed in an indicated set. Because the attribute labeling is generated only for the entity class named, the labeled output is only meaningful for sets containing one class of entity. Attributes other than common attributes, of entities of other classes filed in the set, may be displayed incorrectly, and in some cases, such as **text** mode attributes, may cause conversion errors.

**List** statements of type 2. and 3. can be modified by **with**, **unless**, **while**, and **until** phrases.

The use of each of these statement forms is illustrated in the following examples.

Entity and set declaration:

```
permanent entities
every COUNTRY owns a FLEET
every SHIP has a NAME, belongs to a FLEET
    and owns a CREW
temporary entities
every SAILOR has a SERIAL.NO, a RATING, a SKILL
    and belongs to a CREW
```

Use of **list** statements:

1. `remove the first SAILOR from CREW(VESSEL)`  
`list attributes of SAILOR`
2. `for each SAILOR in CREW(SHIP) with RATING.. greater than 4,`  
`find PERSON = THE FIRST SAILOR`  
`list attributes of SAILOR called PERSON`

3. read N.COUNTRY and N.SHIP  
create each COUNTRY and SHIP  
list attributes of each COUNTRY
4. list attributes of each SAILOR in CREW(QUEEN.MARY)
5. list attributes of SHIP called 4

## 4.14 Some Sample Programs

The programs in this paragraph illustrate the concepts and statements described above. You can follow them closely and identify the features used in each one. As a useful exercise you can reformulate and reprogram the examples using different concepts and statements.

### 4.14.1 An Inventory Control Example

This simple model processes two transaction types — orders for goods and reception of new stock. The data associated with each are transaction type, an item code number, and a quantity. As this business deals with a fixed range of items, these may be modelled using permanent entities. Note the extensive reliance on implicit subscripting throughout.

#### Program 4-1.

---

```
preamble
  normally mode is integer
  permanent entities
    every ITEM has an ITEM.NAME
      a REORDER.POINT,
      a CONTROL.LEVEL,
      a STOCK.LEVEL,
      a DUE.IN,
      a DUE.OUT
  define ITEM.NAME as a text variable
end

main
  define TRANSACTION as a text variable
  read N.ITEM
  create each ITEM
  for each ITEM
    read ITEM.NAME(ITEM), REORDER.POINT(ITEM),
    CONTROL.LEVEL(ITEM), STOCK.LEVEL(ITEM),
    DUE.IN(ITEM), DUE.OUT(ITEM)
  until data is ended
  do
    read TRANSACTION, ITEM, QUANTITY
    if TRANSACTION = "ORDER"
```

```

    if STOCK.LEVEL.. > QUANTITY
        subtract QUANTITY from STOCK.LEVEL..
    else
        add (QUANTITY - STOCK.LEVEL..) to DUE.OUT..
    always
    if (STOCK.LEVEL.. + DUE.IN..) < REORDER.POINT..
        let ORDER=CONTROL.LEVEL..+DUE.OUT..-DUE.IN..-
            STOCK.LEVEL..
        add ORDER to DUE.IN..
        print 1 line with ORDER, ITEM, ITEM.NAME.. thus
ORDER **** UNITS OF STOCK NO. **  DESCR.  *****
    always
else
    ' ' RECEPTION
    subtract QUANTITY from DUE.IN..
    if DUE.OUT.. > QUANTITY
        subtract QUANTITY from DUE.OUT..
    else
        add (QUANTITY - DUE.OUT..) to STOCK.LEVEL..
        let DUE.OUT.. = 0
    always
loop
list attributes of each ITEM
end

```

---

As an exercise, this model may be elaborated on to identify each customer by amending the input data and generating a shipment notice for each order, keeping track of backorders for customers, and shipping backorders according to some rational policy.

## 4.14.2 A Data Analysis Application

## Program 4-2.

---

```

preamble
  permanent entities
    every COUNTY has a NAME and a STATE
    every YEAR has a NATIONAL.GNP, and a RC.PRICE.RC
    every COUNTY,YEAR has a POPULATION, a LOCAL.GNP,
      and a LOCAL.GNP.PERCAPITA
    every YEAR,CAR has a NATIONAL.SALES, a PRICE,
      and a SALES.GNP.RC
    every COUNTY,YEAR,CAR has a LOCAL.SALES,
      and a LOCAL.SALES.PERCAPITA
    define LOCAL.GNP.PERCAPITA, LOCAL.SALES.PERCAPITA
      as real variables
    define NAME, STATE as text variables
end

main
  read N.COUNTY, N.YEAR, N.CAR
  create every COUNTY, YEAR and CAR
  for every COUNTY,
  do
    read NAME(COUNTY) and STATE(COUNTY)
    for every YEAR,
      read POPULATION(COUNTY,YEAR), LOCAL.GNP(COUNTY,YEAR)
  loop
  for every YEAR,
  do
    read NATIONAL.GNP(YEAR)
    for every CAR,
      read NATIONAL.SALES(YEAR,CAR) and PRICE(YEAR,CAR)
  loop
  for every COUNTY, for every YEAR, for every CAR
    read LOCAL.SALES(COUNTY,YEAR,CAR)
  for every COUNTY, for every YEAR,
  do
    let LOCAL.GNP.PERCAPITA = LOCAL.GNP/POPULATION
    for every CAR,
      let LOCAL.SALES.PERCAPITA = LOCAL.SALES/POPULATION
  loop
  for every CAR, for every YEAR,
  do
    for every COUNTY,
    do
      compute A = sum, B = sum.of.squares of
        LOCAL.GNP.PERCAPITA
      compute C = sum of LOCAL.SALES.PERCAPITA
    
```

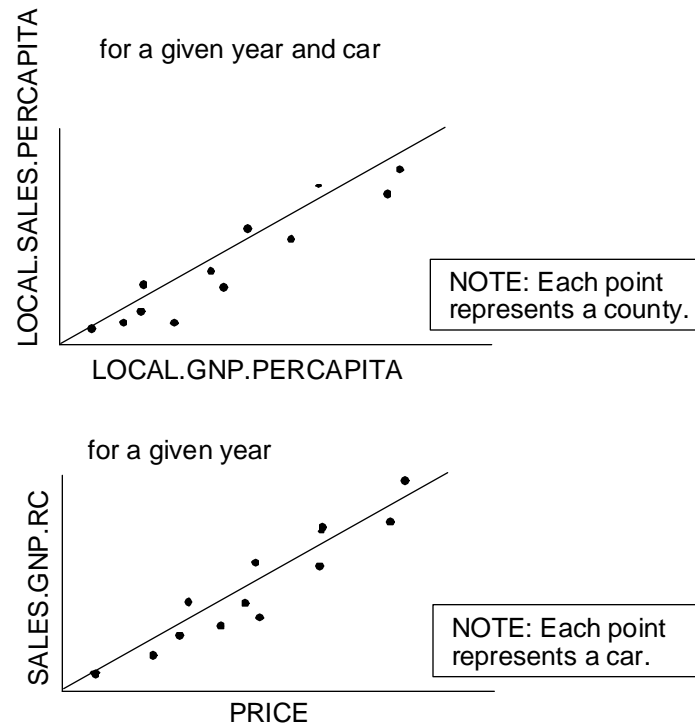
```

        compute D = sum of LOCAL.GNP.PERCAPITA *
            LOCAL.SALES.PERCAPITA
    loop
    let SALES.GNP.RC = (N.COUNTY*D - A*C) / (N.COUNTY*B - A**2)
loop
for every YEAR,
do
    for every CAR
    do
        compute A = sum, B = ssq of PRICE
        compute C = sum of SALES.GNP.RC
        compute D = sum of PRICE*SALES.GNP.RC
    loop
    let RC.PRICE.RC= (N.CAR*D - A*C)/(N.CAR*B - A**2)
loop
list SALES.GNP.RC, RC.PRICE.RC and NATIONAL.GNP
stop
end

```

---

This program reads data on auto sales and prices for different population units, and computes regression coefficients that allow the following graphs to be drawn (figure 4-22).



**Figure 4-22. Display of Result Produced by Data Analysis Program**

Ensure that you understand the computations the program performs and the reason why the individual loops are written as they are. Rewrite the program to make it more efficient.

### 4.14.3 An Analysis of Prime Numbers

#### Program 4-3.

---

```

preamble
  normally mode is integer
  the system owns the PRIMESET
  temporary entities
    every PRIME has a VALUE and belongs to the PRIMESET
end

main
  read N
  for I = 2 to N,
  do
    'CREATE PRIME NUMBERS
    for each PRIME in PRIMESET
      with MOD.F(I, VALUE) eq 0
      find the first case
      if none
        create a PRIME
        let VALUE.. = I
        file PRIME in PRIMESET
      always
    loop
  for each I of PRIMESET
    with S.PRIMESET(I) ne 0
    compute MAX = the max(I) of VALUE(S.PRIMESET(I)) - VALUE(I)
  print 2 lines with N.PRIMES, VALUE(MAX),
    VALUE(S.PRIMESET(MAX)) thus
  MAXIMUM GAP AMONG THE FIRST ***** PRIMES
  OCCURS BETWEEN ***** AND *****
  stop
end

```

---

### 4.14.4 Dynamic Definition and Use of Attributes

Because the notation for subscripting array elements is the same as that used for entity attributes, there are obvious difficulties in attempting to directly reference elements of an array that is an attribute of a temporary entity. In fact, this cannot be done. It is possible, however, to associate array attributes with entities, through some explicit programming. The following statements illustrate how to create, use, and destroy array attributes.

### Declaration:

```
preamble
  temporary entities
    every ENTITY has an ARRAY
  define ARRAY as an integer variable
  define DUMMY as a 2-dimensional array
end
```

### Creation:

```
create an ENTITY
reserve DUMMY(*,*) as 3 by N
let ARRAY(ENTITY) = DUMMY(*,*)
let DUMMY(*,*) = 0
```

### Use:

```
file ENTITY in SET
.
.
remove the last ENTITY from the SET
let DUMMY(*,*) = ARRAY(ENTITY)
for J = 1 to DIM.F(DUMMY(I,*)),
  read DUMMY (I,J)
```

### Destruction:

```
remove ENTITY from SET
let DUMMY(*,*) = ARRAY(ENTITY)
release DUMMY
destroy ENTITY
```



## 5. Discrete Simulation Concepts

---

### 5.1 Introduction

Chapters 1 through 4 of this book described the features of a general-purpose programming language which provides for the high-level description of data structures and their manipulation. Level 5 of SIMSCRIPT II.5 provides concepts and language features for application in the simulation of discrete systems. This chapter assumes familiarity with the aims and techniques of discrete-event simulation. It describes the features by which SIMSCRIPT II.5 provides a uniquely powerful tool for aiding such systems study. The topic is described in a number of current texts. The principal text, which develops the principles of simulation using SIMSCRIPT II.5 as the modelling language, is *Building Simulation Models with SIMSCRIPT II.5*, by E. C. Russell, published by CACI Products Company.

Simulation, as described here, is the use of a numeric model of a system to study its behavior as it operates over time. Discrete-event simulation deals specifically with modelling of those systems in which the system state is deemed to change instantaneously at discrete points in time, rather than continuously. This chapter presents language concepts and features designed to aid in conceptualizing such systems and in modelling them in a computer program.

### 5.2 Describing a System Model

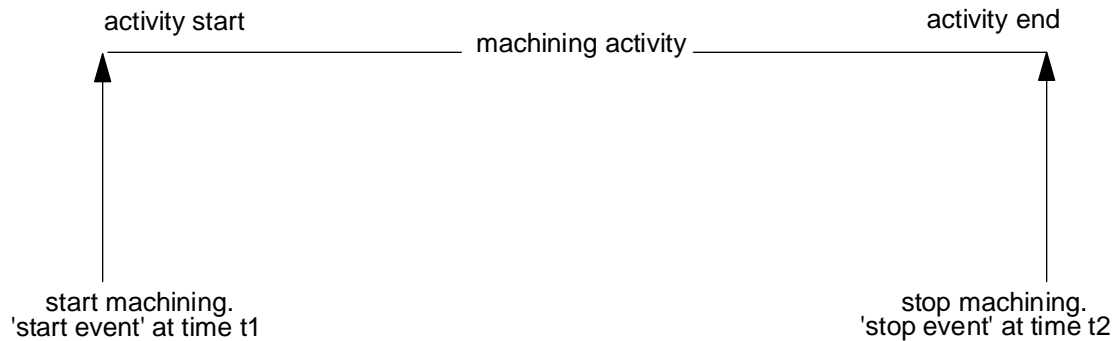
The basic components of a dynamic system are activities. The analysis of a supermarket operation, for example, might yield such activities as the selection of merchandise by a customer, or the checking out of goods for a customer, among others that deal with different aspects of supermarket operations. Two important characteristics of activities are: (1) that they take time, and (2) that they (potentially) change the state of a system.

When constructing a simulation model, the activities must be identified and represented in a way that enables the model, when operating, to reproduce the time-dependent behavior of the system being simulated. That is, the activities must be modelled in such a way that, when each occurs, the system state changes in the proper way. This imposes requirements for (1) correctly modelling the characteristics of activities, and for (2) sequencing the simulated execution of activities, so that the order of performance of activities within a model corresponds to the order in which the same activities occur in the real system.

The concepts embodied in Levels 1 through 4 are the essence of activity descriptions. Systems are described (modelled) in SIMSCRIPT II.5 in the language of entities, attributes, and sets. Keeping track of simulated time and organizing the execution of subprograms through which system activities are represented are the essential functions provided by Level 5.

An activity within a system is bounded by two instantaneous events: when the activity starts, and when it stops. Thus, the event is the simplest component of an activity description. The important

properties of an event are: (1) it occurs at some instant of time, and (2) the occurrence is instantaneous. Figure 5-1 illustrates an activity delimited by two events.



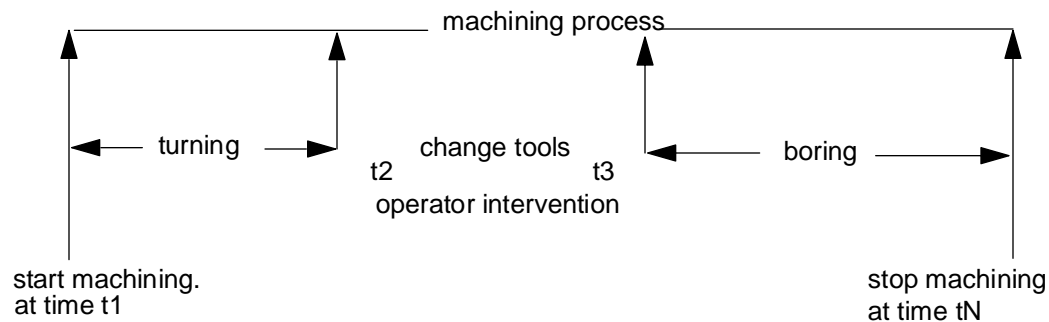
**Figure 5-1. An Activity Delimited by Two Events**

To model an activity, using events, those events that delimit the activity must be identified. Any necessary tests and conditional or unconditional state changes associated with the beginning or end of the activity may be specified for each of these events. The duration of the activity may be specified by scheduling the start event for a certain instant in simulated time, followed by the stop event scheduled for some later time. When the initial event is called into activation, it alters the system state in the specified manner. It may indeed be responsible for scheduling the activity terminating event. After these state changes are performed, control is passed back to the SIMSCRIPT II.5 scheduling mechanism. After the apparent passage of the appropriate simulation time, the second event, the stop event, is executed, performing the state-changes associated with the termination of the activity. Either of these events may involve the scheduling of further events, perhaps of different types, at suitable intervals in simulation time.

The changes in a system that occur when an activity starts or stops, i.e., in the instant of time an activity begins or ends, are associated with events rather than activities. As these events comprise all significant system state-changes, the passage of time between events need not be accurately followed. Rather the passage of simulation time is driven by the sequence of events, advancing always to the time of the next significant event. This is the crucial difference between discrete-event and continuous-time simulation. In discrete-event simulation, state-changes take place at specified points in time at which interactions between system components occur. In continuous-time simulation, interactions and state-changes take place continuously. To model continuous changes, techniques such as numeric integration must be employed. The choice of simulation methodology depends on the characteristics of the system under study, and the way in which it must be understood.

Some activities have no apparent duration and may be modelled as single events. Such activities might represent, for example, the preparation of a report, issued periodically. Activities may be thought of as occupying zero simulation time if no interactions with other system components occur, and the activity duration is short enough not to affect the timing of other activities or events.

Frequently, however, it is found that an activity comprises events other than those that delimit its duration. It may interact with other activities, causing or suffering interruptions or delays. Such an activity may be better represented by a collection of related events with some logical ordering of their sequencing. Even a simple activity may be thought of as two events, with the logical ordering that it must start sometime before it can stop. In SIMSCRIPT II.5, such a collection of related events may be represented by a process. A process may be viewed as a collection or sequence of related events separated in time. The previous activity may be elaborated to illustrate the process concept by including some extra, but related, events (see figure 5-2).



**Figure 5-2. A Process May Be Considered to be Comprised of a Sequence of Events Occurring in Time**

To model activities in SIMSCRIPT II.5, the significant events in the life of the system and the logic of their interactions must be identified. Subprograms can be written, using the previously-described data structures to model the physical components of the system, and incorporating the logic of the event interactions. The more complex activities are conveniently modelled using the process concept to collect related events. SIMSCRIPT II.5 then provides a timing mechanism, which organizes execution of these subprograms, managing any interactions, so as to order the events in a temporally correct sequence.

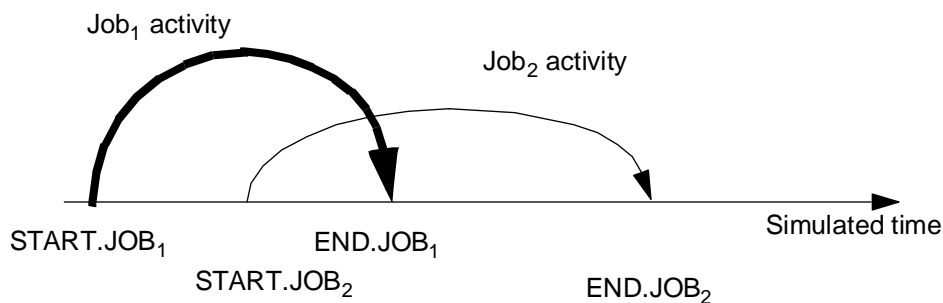
While it has not been pointed out explicitly why the normal main-routine-subprogram structure is not adequate for the simulation task, it is not difficult to see why this is so. Consider the following situation: A simulation model has one kind of entity — call it a **PERSON** — that performs one kind of activity — call it a **JOB**. Let the job activity be delimited by the two events **START.JOB** and **END.JOB**. Routines are written to describe the logic of both events. Should it be desired to simulate two people performing such a job concurrently, the simulation must execute the routine **START.JOB** for each **PERSON**. Now, if two events should occur when the simulation time has the same value, they can be thought of as happening simultaneously. If the two people are to start at

the same time, these programs must be executed simultaneously; that is, in parallel. On a sequential computer, this is, of course, impossible.

Within the event **START.JOB**, the event **END.JOB** will be scheduled to occur after some estimated job performance delay time. When the event **END.JOB** occurs for the first **PERSON**, the simulation clock will be advanced to some higher value. That is, it will indicate that simulated time has passed. But this advancement of the clock is not correct, as the event **START.JOB** for the second **PERSON** cannot yet have been executed. Therefore, some mechanism, other than **call**, is required to indicate that **END.JOB** is to be executed only after all events that have lower clock times associated with them have been executed.

The alternative provided by the SIMSCRIPT II.5 system is to **schedule** an event for occurrence in future simulated time. In figure 5-3 two jobs are started and ended at different times to illustrate the concepts of event occurrence and event scheduling. Table 5-1 lists the order in which subprograms representing the **START.JOB** and **END.JOB** events of figure 5-3 must be executed.

In a SIMSCRIPT II.5 simulation model, the logic of any state-changes and activity interactions associated with an event are described in an **event** routine. Several related events with the logic to indicate their ordering in time may be incorporated in a **process** routine, to describe an entire activity. The timing mechanism for both event and process routines is similar. It is more easily described initially for events, which may be thought of as the limiting case of a simple process (a single event delimits both the beginning and end of an activity that has no perceptible duration).



**Figure 5-3a. Two Overlapping Activities**

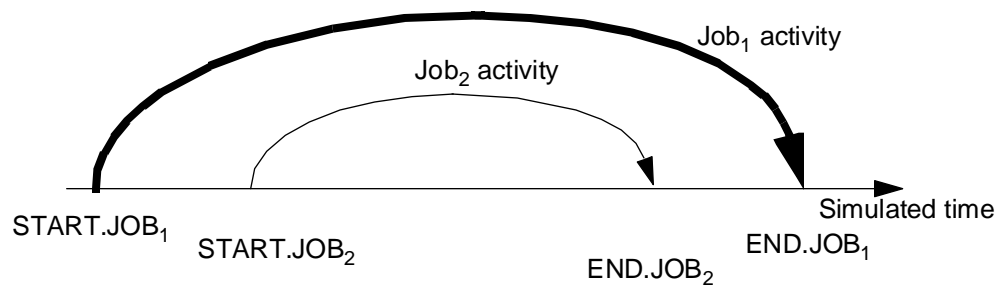


Figure 5-3b. Two Nested Activities

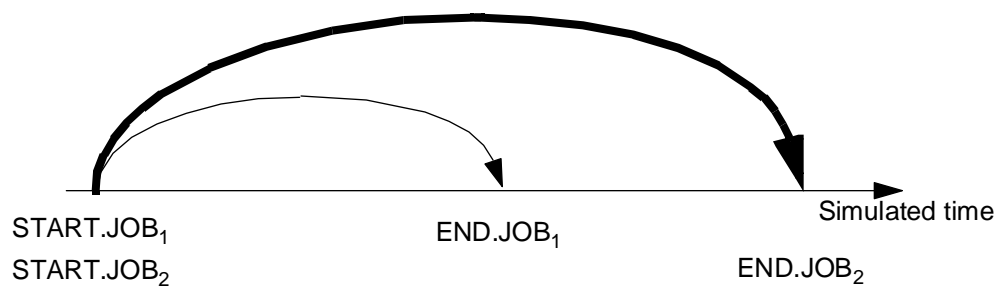



Figure 5-3c. Two Activities with a Common Event Time

Table 5.1. Figure 5-3 Event Order

Time	Figure 5-3a.	Figure 5-3b.	Figure 5-3c.
	START.JOB <sub>1</sub>	START.JOB <sub>1</sub>	$\left( \begin{matrix} \text{START.JOB}_1 \\ \text{START.JOB}_2 \end{matrix} \right)$ in parallel
	START.JOB <sub>2</sub>	START.JOB <sub>2</sub>	
	END.JOB <sub>1</sub>	END.JOB <sub>2</sub>	END.JOB <sub>1</sub>
	END.JOB <sub>2</sub>	END.JOB <sub>1</sub>	END.JOB <sub>2</sub>

### 5.2.1 Event Declaration

A routine is declared to be an **event** routine rather than a callable subprogram by use of the word **event** rather than **routine** in the routine definition. The flow of control within an event routine behaves in the ordinary way, in that control is passed to the start of the event and leaves by a **return** statement. Typical event routine declaration statements are:

```
event ARRIVAL given LOCATION and ALTITUDE
event DEPARTING(DESTINATION)
event ALLOCATION(SUM, PERSON1, PERSON2)
```

These event routine definitions are similar to routine definitions; values appear to be received as input arguments, described in any of the normal forms. Events cannot have **yielding** arguments because they are not called directly from other subprograms and, hence, have no place to which these values may be returned. The way in which argument values are transmitted to event and process routines will be discussed later. The general form of an event routine definition is:

```
event name ( optional input argument list )
```

### 5.2.2 Event Notices

There may be a number of different event types or event classes in a program. For each class there may be many instances at different times. Associated with each instance of each class is an event notice, used to maintain information about the event. An event notice is a temporary entity that has five special predefined attributes. One of these attributes, **time.a**, contains the simulation time at which the event is to occur. An event notice is filed in a future events set, ranked on this attribute. The SIMSCRIPT II.5 timing routine is responsible for successively removing event notices from the future events set, updating the apparent simulation time and initiating the execution of the appropriate event routine. Another attribute, **unit.a**, concerns the way in which the event is scheduled, for instance, whether it is scheduled from data external to the program. External events need not, for the present, be considered specially. They are discussed in a later section. The remaining attributes are those required for membership in the future events set; as the name of this set is **ev.s**, the attribute names **p.ev.s**, **s.ev.s**, and **m.ev.s**, represent the predecessor, successor, and membership attributes.

Event notices may, like any other temporary entity, have additional user-defined attributes. These may be either variables or functions, and may denote ownership or membership of other sets. Event notices, however, must be declared separately from nonevent notice entities. The **event notice** statement is used in the preamble to declare an event and any user-defined attributes. The statement:

```
event notices
```

when placed before a group of **every** statements, denotes that event notices rather than temporary or permanent entity declarations follow. The special attributes required by an event notice are defined automatically. They must not be redefined, and they must not be equivalenced (see Chapter 6 for a discussion of equivalencing). For this reason, the explicit placement of event notice attributes is restricted, usually within the first five entity words. This depends on the implementation, and the appropriate user manual should be consulted.

Commonly, event notices have only the specially defined attributes and no additional attributes or set pointers. They are used only to trigger events within simulated time. When this is the case, the phrase:

```
event notice name list
```

may simply be added to the **event notices** statement to identify the names listed as event names, indicating that associated event notices requiring system-defined attributes are to be defined for them. Such events might be declared by a preamble statement:

```
preamble
event notices include ARRIVAL, and WEEKLY.REPORT
every JOB.OVER has a NEXT.JOB and owns some PEOPLE
```

The layout of the event notice entities might then appear as shown in figure 5-4. Note that the order that the predefined attributes take within the event notice is implementation-dependent.

ARRIVAL	WEEKLY.REPORT	JOB.OVER	
TIME.A	TIME.A	TIME.A	predefined attributes
EUNIT.A	EUNIT.A	EUNIT.A	
P.EV.S	P.EV.S	P.EV.S	
S.EV.S	S.EV.S	S.EV.S	
M.EV.S	M.EV.S	M.EV.S	
		NEXT.JOB	user-defined attributes
		F.PEOPLE	
		L.PEOPLE	
		N.PEOPLE	

**Figure 5-4. Possible Layout of Event Notice Entities**

### 5.2.3 Process Declaration

A routine is declared to be a **process routine** in a similar manner, but the word **process** must be substituted in the routine definition. For example:

```
process ALLOCATE.TRAIN given NO.OF.CARS, DESTINATION
```

The general form of the process routine declaration statement is:

```
process name ( optional input argument list )
```

Associated with every declared process is an entity called a process notice. The construction of the process notice is similar to an event notice, being filed in the same way in the future events set **ev.s**, but it has some extra predefined attributes that have meaning only for a process.

Each process routine must be declared in the **processes** section of the preamble. Process declarations are otherwise identical to event declarations. All the conventions for defining event

notices or temporary entities apply. Like event notices, processes and the corresponding process notices may be defined using the **every** statement, if user defined attributes are to be declared, or with the **include** phrase, if no user attributes are defined. For example:

```
processes MACHINE.JOB, CHECK.JOB
every ALLOCATE.TRAIN has a NO.OF.CARS, a DESTINATION
```

In general, characteristics attributed to events or processes may be taken to apply equally to both unless stated otherwise.

### 5.2.4 Scheduling Events and Processes

Process and event notices may be filed in the future events set, scheduling their associated routines for activation at specific instants in future simulation time, using a **schedule** statement, which has the general form:

```
schedule an event at time expression
```

or

```
a process at time expression
```

This statement creates an event or process notice, sets its **time.a** attribute (the time for which it is to be scheduled) to the value of the time expression and files the notice in the appropriate event set. The time expression must evaluate to a real variable or constant. The words **activate**, **re-schedule**, and **cause** are all synonyms for **schedule**. The word **schedule** is commonly used in conjunction with events and **activate** with processes. These statements are interpreted to mean:

```
activate a process called variable at time expression
```

and

```
schedule an event called variable at time expression
```

where **process** is the name of the process routine variable associated with the entity class. It may be seen that this is similar to the usage of **create** and **destroy** for entities. A **schedule** statement may be written with an explicit variable name, as in:

```
schedule an ARRIVAL called RUSH.ORDER at time expression
```

If an event or process notice already exists (as a temporary entity, it may have been created previously), a **schedule** statement may specify that it be filed in the future events set using the word **this** rather than **an**:

```
schedule this event called variable at time expression
```



The word **this** inhibits creation of a new entity. The pointer value identifying the particular event notice, which must be of class entity, is assumed to be stored in the named variable. The statement form:

```
schedule this event at time expression
```

obviously uses the pointer value currently held in the variable having the same name as the event. A global variable of this name, of course, is always defined, although a local redefinition may also exist.

Several variations of these statement forms are permitted. The words **a** and **an** are synonyms, as are the words **this**, **the**, and **the above**. Examples are:

```
schedule an ARRIVAL at time expression
schedule the above ARRIVAL called RUSH at time expression
schedule this ARRIVAL at time expression
```

The first statement creates an event notice before scheduling. The second and third statements use event notices of type arrival, whose identification numbers are stored in **RUSH** and **ARRIVAL**, respectively.

### 5.2.5 Processes and Events Scheduled for the Same Time

It can happen that several different processes or events are scheduled for the same time; for example, the arrival of one job, the completion of another, and the preparation of a report. Resolving these conflicts is important in situations where events or processes interact with each other or with entities in the model. A statement of the form:

```
priority order is process or event name list
```

imposes a priority ordering on the processes and events named, so that in cases where process notices of different kinds have the same event time, the process notice of the higher-priority process type is selected first. The assigned priority is determined by order of appearance in the **priority** name list. The first process named is given the highest priority. If no **priority** statement appears in a program, the priority of events and processes are determined by the order in which they first appear in preamble declarations.

The priority of a process is associated with the process class. The class of a process or event notice is assigned one of the values **1**, **2**, **3** ... according to either its declared priority or declaration order. Three different processes, for example, declared without priority in the preamble, will be assigned the classes 1, 2, and 3, respectively, in the order in which they are declared. If only a subset of the processes or events declared are listed in a **priority** statement, the remaining processes are given lower priority than the ones listed, and are ranked among themselves in the order of first appearance in declarations. A global variable, **events.v**, has as its value the total number of different process and event classes declared.

It is, of course, possible to have more than one process or event of the same kind scheduled to occur at the same or different times in the future. For example, a machine-shop simulation may have many identical machining activities in progress concurrently. Completion of two or more of these may be scheduled to occur at exactly the same time. If this happens, the timing routine uses a “first scheduled-first occurs” rule to “break the tie.” The order in which simultaneous events of equal priority are executed is determined by the sequence in which they were previously scheduled. Although several events can appear to take place at the same instant in simulated time (the simulation clock has the same value during the execution of each), there are often good reasons for wanting to impose a priority ordering. This may be done by specifying the **break ties** statement:

```
break process/event name ties by high attribute name
```

or

```
break process/event name ties by low attribute name
```

which gives priority to the process with the high (low) attribute value when two or more process notices of the same type have the same process time. The attributes are, of course, ones that have been defined in **every** statements for the process named. In cases where more than one set of tie-breaking attributes are needed, clauses of the form:

```
, then by high attribute name
```

or

```
, then by low attribute name
```

can be added to the **break ties** statement. As many such clauses may be added as are necessary. Processes defined by the statements:

```
process
every DISPATCH has a VALUE, a DUE.DATE and a PRIORITY
```

might have ties resolved among competing process notices by statements such as:

1. break DISPATCH ties by high PRIORITY
2. break DISPATCH ties by high PRIORITY, then by low DUE.DATE
3. break DISPATCH ties by high VALUE, then by LOW PRIORITY,  
then by high DUE.DATE

In statement 1, among **DISPATCH** processes scheduled to occur at the same simulated time, the process notice with the largest **PRIORITY** attribute will occur first. In 2, among process notices scheduled to occur at the same simulated time and having identical **PRIORITY** values, the notice with the smallest **DUE.DATE** will occur first; and similarly for 3 and other variations.

### 5.3 The Simulation Mechanism

A SIMSCRIPT II.5 simulation is controlled by the timing routine that organizes the execution of event and process routines in simulated time. Every simulation program must contain the statement:

```
start simulation
```

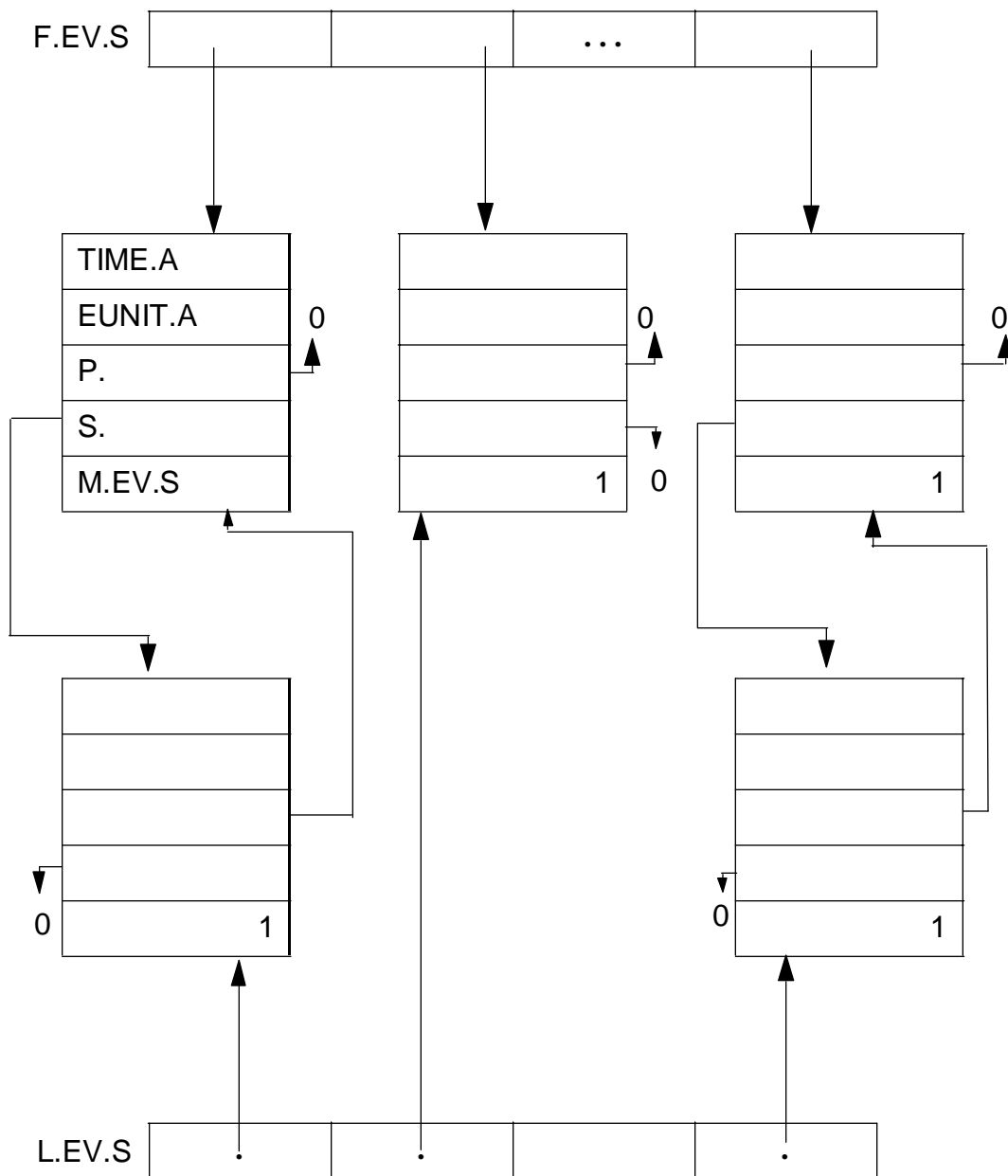
which passes control of further program execution to this timing routine. In order to set the system in motion, the model must have been initialized by previously executed statements, defining the initial state of the system and scheduling one or more initial events or process activities. The overall outline of a SIMSCRIPT II.5 simulation model will generally have the form:

```
declarations
initialization of system variables, entities and sets
scheduling of initializing processes and events
start simulation
terminating control statements
```

The statement **start simulation** passes control to the simulation timing mechanism. For the purpose of explaining the simulation mechanism, events and event notices are considered. The timing mechanism for a process behaves in the same way, but a process may be considered to comprise a sequence of events occurring over a period of time. The timing mechanism removes the most imminent event notice from the future events set, updates the simulation time to the event time indicated, and passes control to the routine for this event. Upon completion of this event, the timing routine again turns to the future events set to determine the next event routine to be executed. This sequencing continues until all event notices in the future events set are exhausted. When this happens, control is returned to the statement directly after the **start simulation** statement. It must be remembered that statements executed during event and process routines may be continually interacting with the future events set, dynamically scheduling further events.

As long as there are events to be executed, the timing routine, initiated by the **start simulation** statement, is in control. The common way to end a simulation is to cease scheduling future events and let the timing mechanism exhaust the contents of the future events set. Another method, of course, is to halt all execution, using a **stop** statement within some scheduled event or process routine.

The future events set, shown in figure 5-5, in which event and process notices are filed, is in fact a singly subscripted set. Each subscript value denotes a different process or event class. In a simulation declared to have six different event classes, there are six "parallel" event sets. Each event class has a global variable, **i.event**, associated with it, denoting the subscript value of the event class. These values are assigned, usually, by order of declaration of event classes, but may be altered by **priority** statements.



**Figure 5-5. The Future Events Set Organization**

A system-defined global variable, **events.v**, has as its value the number of event classes. The future events set is named **ev.s**, denoting “events set.” The first- and last-in-set attributes **f.ev.s** and **l.ev.s**, are defined as one-dimensional attributes of the system, and are dimensioned by **events.v**. The attributes **p.ev.s.**, **s.ev.s**, and **m.ev.s** are, of course, attributes of the event and process notice entities. The routines **FF** and **RS** are defined for the set. Scheduling an event,

then, causes an event notice of the appropriate class to be filed and ranked on its **time.a** attribute in the set corresponding to its class, usually by the routine **t.ev.s** that is the standard file first routine for the set **ev.s**. Events named in **break ties** statements are filed by a special routine for that event class. Each time control passes to the timing routine, at the start of simulation or at the completion of any event, the next event to be executed is selected by searching the even sets in order of priority, as indicated by **i.event** values, and taking the one that has the lowest value of future time, **time.a**. In the case of ties, the first one selected is taken. Thus, priority across event classes is determined by the **i.event** ordering. Priority within a class is determined by ranking within set, which in turn depends either on filing order or, if specified, on break ties filing. When an event notice is selected and removed from the future events set, this event represents the next significant time instant in the life of the system. The simulation time that is maintained in a system-defined global variable, **time.v**, is advanced, therefore, to take on the value of its **time.a** attribute. Another global variable, **event.v**, is set to reflect the class of the event about to be executed. The number of event or process notices filed in an event class at any time is available by reference to (**i.event**). Although this has the name of the standard **N.set** attribute, and is used in the same way, it is, for considerations of efficiency, implemented as a system function.

### 5.3.1 The Simulation Clock

Throughout the progress of a simulation, the current value of simulated time is maintained by SIMSCRIPT II.5 in a **double** global variable named **time.v**. Before the start of simulation, **time.v** is zero. From then on, **time.v** increases, by discrete jumps, representing the passage of time between events. Each time a notice is selected from the future events set, the value of the time attribute of the selected process, **time.a**, is used to update **time.v**. It can happen that the value of **time.v** remains the same before and after the updating, and all events that occur while **time.v** is constant appear to happen simultaneously. The phrase:

at time expression

used in a **schedule** statement, states when, in future simulated time, the event is to occur. This expression is **real**-valued. It is the value that is stored in the **time.a** attribute of the process or event notice, that is compared against other event times during event selection, and that becomes **time.v** when an event is selected for execution. An absolute time is always specified in an **at** phrase. The phrase:

at 0.00

might be used to schedule an event that is to initiate the simulation. An incremental form:

at time.v + 1.5

states that the event is to occur at the current simulation time plus 1.5 time units. If the basic time unit is interpreted as hours, the phrase may be read, "in one and one-half hours from now". If the

basic time unit is interpreted as microseconds, the phrase reads as, "in one and one-half microseconds from now."

Many simulations represent activities in real time, where the time units commonly used are minutes, hours, and days. Some standard conversion factors allow SIMSCRIPT II.5 to recognize these time units. The standard units of **time.v** are presumed to mean days (e.g., 1.47 is one and forty-seven one-hundredths days). The phrases:

```
in arithmetic expression days
in arithmetic expression minutes
in arithmetic expression hours
```

are understood to mean that the named event is to occur at **time.v** plus the specified number of days, hours, or minutes. The word **units** can be used instead of **days**, and the word **after** substituted for **in**. Conversions are made by taking the units of **time.v** as days and using two, **real** mode, conversion variables, **hours.v** and **minutes.v**, initialized by the SIMSCRIPT II.5 system to 24 and 60, respectively. These values may be changed at any time to reflect a different measurement of simulated time.

If time is to be simulated in units of days, hours, and minutes, it can be convenient to reconvert absolute values of **time.v** to these units. Three system functions described in table 5-2 provide this capability. A simulation time of zero is assumed to correspond to the start of the first hour within the first day of a week.

These functions may be useful in displaying results of a simulation, tracing simulation activity, or in imposing realistic constraints on the execution of events in simulated time. Two examples illustrate these uses:

1. A check to allow arrival events to occur only on weekdays or a Saturday:

```
if WEEKDAY.F(time.v) greater than 6,
    reschedule this ARRIVAL at TRUNC.F(time.v)+1
always
```

2. A process trace statement put at the head of a process routine:

```
write WEEKDAY.F(time.v), HOUR.F(time.v) and MINUTE.F(time.v) as
"MACHINING ACTIVITY STARTS ON DAY", I 2,
"AT TIME", I 2, ":", I 2, /
```

A third kind of event scheduling uses the word **now** (or **next**, its synonym) in statements such as:

```
schedule an ARRIVAL now
```

Processes or events scheduled with a **now** phrase occur as soon as control passes back to the timing routine. They precede any scheduled processes or events that may have the same scheduled time. If two or more are scheduled to occur **now**, they are ranked on their **priority** if they are of differ-

ent classes, on their **break ties** attributes, if these are specified, or on a first-in, first-out basis if no **break ties** attributes have been specified.

**Table 5-2. Time Conversion Functions**

Name	Argument	Function Mode	Function Values	Examples
<code>weekday.f</code>	REAL time expression	integer	1 - 7 day of current week	<code>weekday.f(5.32)</code> = 6
<code>hour.f</code>	REAL time expression	integer	0 - 23 hour of current day	<code>hour.f(5.32)</code> = 7
<code>minute.f</code>	REAL time expression	integer	0 - 59 minute of current hour	<code>minute.f(5.32)</code> = 40

Corresponding to the **schedule** statement is a **cancel** statement, which removes a specified process or event notice from its future events set, before it has been selected for execution. This negates the action of the schedule statement that filed the event notice. It is written:

```
cancel this process/event
```

and

```
cancel this event called variable
```

As usual, the first form is interpreted as:

```
cancel this event called event
```

The words **the** or **the above** can be substituted for **this** when necessary. The event notice removed is not automatically destroyed. If required, it may be explicitly destroyed, as may any temporary entity. An attempt to **cancel** an event that has not been scheduled, and is therefore not filed in the future event set, terminates the program with an error message.

### 5.3.2 Assigning Event and Process Attributes

If an event or process notice is declared to have user-defined attributes, values may be assigned to these in two ways: through standard attribute (entity) references in assignment statements, and also within a **schedule** statement specifying the notice. Recall that a statement such as:

```
schedule an event given expression list at time expression
```

uses the time expression to set **time.a(event)** attribute. It will also assign the values given in the expression list to successive attributes of the event notice, starting with the first user-defined attribute. If fewer expressions are listed than there are attributes, the remaining attributes are ini-

tialized to zero. If no expression list appears, all, if any, user-defined attributes are set to zero. Thus, the preamble definition:

```
processes
    every SERVICE has a SERVER, a CUSTOMER,
        and may own a TRANSACTION.SET
```

followed in some routine by the statement:

```
schedule a SERVICE giving TELLER(N) and F.QUEUE at time expression
```

assigns the values of **TELLER(N)** and **F.QUEUE** to the attributes **SERVER** and **CUSTOMER**, respectively, but leaves the set-ownership attributes set to zero. Following the conventional notation of the **call** statement, a number of argument list forms may be used: the word **given** may be used, or the argument list enclosed in parentheses. No **yielded** phrase may be used. Examples are:

```
schedule an ARRIVAL giving ORIGIN now
reschedule this SERVICE giving A and B in 2 days
```

As these attributes are initialized at the time of scheduling, their values are unchanged by filing and removing them from the future event set. Thus, they provide a means for passing values to event and process routines. There are some difficulties, however, attached to accessing these values within the routines. Upon entry to an event routine, the associated event notice is usually destroyed, and so the attributes are no longer accessible. This is not the case for process notices. A process has a lifetime associated with the duration of an activity, whereas an event is instantaneous. Process notices are not automatically destroyed until completion of all activity represented by the process. The automatic destruction of an event notice is suppressed by appending the phrase **saving the event notice** to the **event** routine definition, as in:

```
event ARRIVAL saving the event notice
```

In this way, the attributes can be accessed within the event routine, or even later. The global variable with the name of the event is set by the timing routine to the event notice pointer before execution of the event routine is initiated, and so may be used to subscript the attributes. The event notice may be later destroyed as for any temporary entity. Care should be taken not to alter the value of this variable, by **schedule** statements, for example, until all attributes have been accessed, or before using it in destroying the event notice. It must not, of course, be redefined as a local variable, as this makes access to the global value impossible. In the case of processes, a system-maintained global variable, **process.v**, holds at all times either a pointer to the process notice of the currently executing process, or a zero value if no process routine is executing. Thus, this variable may be used within a process routine or within subprograms called from a process routine, to access the attributes of the associated process notice. Such a subprogram can test **process.v** to determine whether, in this instance, it has been called from a process or a nonprocess routine.

A second way in which the values of attributes passed to an event or a process routine may be made available is to define a list of given arguments to the routine. At entry to the routine, and in the case



of events, before the event notice is destroyed, the values of the user-defined attributes are assigned, in order, to these local argument variables. Only as many attributes as have corresponding argument positions are copied. Specification of more arguments than there are user-defined attributes has no meaning, and is not permitted. Care must be taken in selecting these argument names. Should they be chosen as identical with the declared attribute names, then the local argument usage will always take precedence, rendering subsequent access to the entity attributes themselves impossible. This may be of significance in the process case, where the process notice must retain information across the sequence of events within the process activity. The above event routine definition could be written as:

```
event ARRIVAL given ORIGIN
```

where the now local argument **ORIGIN** will be initialized from the attribute value specified at the time of scheduling.

Event notices that have not been destroyed may be reused, as in a case when the word **this** is required in the scheduling statement, avoiding the creation of a new event notice entity. Care should be taken, if this is done, that event notices be used only in appropriate event classes. It will become apparent that this is the mechanism by which processes may represent more than one of the events within an activity. The following examples demonstrate some of these points.

1. Accessing the attributes of a saved event notice. The event notice entity is saved for filing in a user-defined set:

```
event DEPARTURE(NAME, DESTINATION) saving the event notice
  let DEPARTURE.TIME(DEPARTURE) = time.v
  add 1 to PASSENGER.LIST(DESTINATION(DEPARTURE))
  file DEPARTURE in DEPARTURES.SET
  return
end
```

2. Event notice reused to schedule another similar event. A separate entity is created for program-defined manipulations:

```
event ARRIVAL given NAME, ORIGIN saving the event notice
  define NAME, ORIGIN as text variables
  create a JOB
  let IDENTITY(JOB) = NAME
  let PLACE(JOB) = LOCATION
  file JOB in LIST.OF.JOBS
  reschedule this ARRIVAL("WALDO", "ALASKA") in 5 days
  return
end
```

3. A simple instantaneous process routine which behaves like an event. Note that the process notice is not destroyed until exit from the routine and so the attribute **IDENT** may be accessed from within the routine.

```

process TASK
  write IDENT(TASK), time.v as
    /, "TASK: ", T 10, "STARTED AT: " D(4,2),/
  activate a COMPLETION giving IDENT(TASK) in 2 days
  return
end

```

The important points to remember about process and event activation are:

1. **time.v** is set to the **time.a** attribute at activation
2. A global variable with the same name as the event or process is given the value of the event or process notice pointer. The attributes may be accessed through this variable.
3. In the case of events only, the event notice is destroyed unless a **saving** phrase is used, and
4. When the **return** statement is executed, control passes to the timing routine to select the next process.

### 5.3.3 Process Interactions

Up to now, processes have not appeared to differ greatly from events. However, it has been stated that processes may represent an activity that has a duration in simulated time. Such an activity, in its simplest form, has two delimiting events. The start event of the activity is represented by the initiation of the process routine. The terminating event must take place after some lapse of simulated time. In the simple case, this lapse of time can be estimated. In an event-based simulation, a terminating event would be scheduled at this interval in the future. Within a process routine or a subroutine called from a process routine, however, either of two statements may be used to halt the process execution for a given lapse of simulation time. These statements are:

```
work time-expression
```

and

```
wait time-expression
```

The effect of these statements is to file the process notice associated with the process back in the future events set, after adjusting the **time.a** attribute to indicate the future time at which execution of the process routine should resume. When simulation time has advanced so that the process notice becomes again eligible for execution, this execution is resumed at the statement following the **work** or **wait**. Other events and activities may, of course, be executed during the time lapse. The two statements differ only in the status attributed to the process during the passing of simulation time. This status is recorded in a special attribute of the process notice, where it may be interrogated by any other executing routine. These statements allow for the representation of determined passages of simulation time during an activity. The time to spend in a waiting or working state must be known when the statement is executed. The time to carry out a specified machining task on an au-

tomatic tool, for example, may be estimated from dimensions and material of the workpiece and an activity accordingly set to **work** for this time.

There are cases when the time lapse depends on the interaction of other activities. If the machining task demands that the machine be reset, say, by operator intervention at some stage, then the activity must delay when this point in the process is reached until an operator is available, which may depend on concurrent activities within the machine shop. To represent this circumstance, a process routine may **suspend** its own activity to continue only on an explicit command issued by some other event or process routine, naming the suspended process. Reactivation causes execution to continue at the statement following the **suspend** statement. The statement is simply the word **suspend**, optionally followed by the the word **process**. The suspended status is also recorded in the process notice status attribute. The following example indicates that execution of the **SHIP** process cannot continue until a berth becomes free, which depends on the departure of another vessel:

```
process SHIP
.
.
if BERTH.STATUS not equal to .EMPTY
    file SHIP in BERTH.QUEUE
    suspend
always
```

Some other process, which may be a concurrent execution of the **SHIP** process, but representing another ship, might include the statements:

```
if BERTH.QUEUE is not EMPTY
    remove first SHIP from BERTH.QUEUE
    reactivate this SHIP now
else
    let BERTH.STATUS = .EMPTY
always
.
.
```

### 5.3.4 Interrupting and Resuming a Process

Only a process that is executing may suspend itself. Any executing process, or routine, however, may interrupt another process that is active but not executing (i.e., while the process to be interrupted is in a **wait** or **work** state). The interrupted process is placed in an interrupted state. When this happens, the process notice is removed from the future events set, and the time that the process would have remained in the **work** or **wait** state is recorded in the **time.a** attribute of the interrupted process notice. An interrupted process may be returned to the active state, that is, replaced in the future events set, by a **resume** command issued by any other process or routine naming the interrupted process. The **time.a** attribute at the time of resumption is used to schedule the end of the **work** or **wait** state. It is incremented by the current **time.v** before being used as a ranking attribute for filing.

A process routine has three code segments in addition to those of an event routine. At first entry, an initializing segment calls a set-up routine that allocates storage space for saving the process environment (the given arguments and local variables). Subsequent re-entries restore the process environment from this save area. The address of this recursive storage area is maintained in the **rsa.a** attribute of the process notice. The second additional code segment calls a library routine that saves the local environment each time the process is delayed or suspended by a **wait/work/request/suspend**. Whenever this occurs, execution control is returned to the timing routine.

Finally, when a process executes a **return** statement, the recursive save area for this process routine invocation is released, the process notice is destroyed, and control is transferred to the timing routine.

The various process interaction and control statements described above have meaning only in the context of process routines. Although events and other routines may interrupt and resume processes, they may not themselves work, wait, or suspend. Some implementations of SIMSCRIPT restrict these last statements to process routines only. Some others allow them to be used effectively within the process context, but at a subprogram level lower than that of a calling process. Care should be taken that such commands are issued only when the subprogram has been called from a process routine at the highest level.

### 5.3.5 Processes and Resources

The previous sections have described possible process routine interactions that are supported by SIMSCRIPT II.5. The most common reason for such interactions is competition among concurrent processes for some limited resources. This is often why processes must suspend and wait for reactivation by others. SIMSCRIPT II.5 provides a **resource** modelling facility. Included in the resource concept are the automatic queuing of processes for unavailable resources and their automatic reactivation when the required resources becomes available. Special statements allow processes to request and relinquish specific resources.

Resources are declared in the **resources** section of the preamble. A resource is, in fact, represented as a permanent entity, but with some predefined attributes:

**U.resource** specifies the number of units of this resource currently available.

Each resource also has the owner attributes for maintaining two sets:

**Q.resource** is the set of processes currently waiting (queued) for this resource.

**X.resource** is the set of processes currently using (executing with) this resource.

Additional user-defined attributes may be specified, as for any permanent entity. However, in order that the required attributes be defined, the **resources** heading must precede any **every** statement that defines a resource with special attributes. Resources that require only the predefined attributes

may be specified in the optional **include** phrase. As resources are maintained in SIMSCRIPT II.5 as permanent entities, they must be created before they can be used.

The simplest form of a resource consists of a single unit of a single resource type. An example is a single-runway airport representation. This may be declared and created by the statements:

Preamble:

```
resources include RUNWAY
```

Program:

```
create every RUNWAY(1)
let U.RUNWAY(1) = 1
```

There is only one valid index value, **1**, for the entity. The "units" attribute for this index is also **1**. There is only one type of runway, and there is only one of them. To expand to multiple resources, there are two alternatives. The choice depends on the structure of the model:

1. Add more identical units of the resource. These are identical. They all serve from a single queue.
2. Add more resource elements. These may each have different properties, they must be specifically requested, and there may be different numbers of each available.

The first case may be illustrated by the example of a bank with three tellers:

```
create every TELLER(1)
let U.TELLER(1) = 3
```

To a bank customer, there is only one type of resource, **TELLER(1)**. There are, however, three of them and any one will satisfy a request for service. To illustrate the second case, suppose the airport expands to three runways, only one of which may take jet aircraft. In this case, the resource may be created as:

```
create every RUNWAY(2)
let U.RUNWAY(1) = 1      '' FOR ANY AIRCRAFT
let U.RUNWAY(2) = 2      '' LIGHT AIRCRAFT ONLY
```

Now, aircraft requesting a runway resource must be specific as to the runway type. Light aircraft may request either, basing their choice, perhaps, on examination of both **U.RUNWAY(i)** values. Jet aircraft may request only **RUNWAY(1)**.

### 5.3.6 Requesting and Relinquishing Resources

A process requests a quantity of any given resource using a **request** statement. The effect is as follows. If the requested quantity of the resource is available, it is given to the process, and the process continues execution at the statement following the **request** statement. If the requested quan-

tity is not available, the process is put in a passive state and filed in the queue of processes waiting for the particular resource.

An optional **with priority** expression may be added to the **request** statement. The queue is ranked on high **priority**. If the phrase is not present, the **priority** is treated as zero. An optional comma may be placed before the **with priority** phrase. Examples of the **request** statement are:

```
request 1 WORKER(2) with priority 2
request 2 MACHINE(JOB.TYPE)
request 3 UNITS OF MATERIAL with priority 5
```

As the resource name is in fact a permanent entity name, it should be subscripted. If it is not, the variable of the same name is used as an implicit subscript. This variable is initialized to 1 at resource creation, but care should be taken if it is subsequently altered, by **for each resource** statements, for example. Note that some implementations use an implicit subscript value of 1. It is recommended that explicit subscripting be used in all cases.

A process that has requested some units of a resource may **relinquish** some number of these, but not necessarily all it has. The number of units of the resource being relinquished is added to the total quantity available. If any processes are queued awaiting the resource, they are scanned from the front of the queue. Each is reactivated, with a corresponding reduction in the quantity of available units of resource, until one is found whose request cannot be satisfied. The scan is then terminated.

The process relinquishing the resource continues execution at the statement immediately following the **relinquish** statement. The **relinquish** statements corresponding to the above resource **request** statements would be:

```
relinquish 1 WORKER(2)
relinquish 2 MACHINE(JOB.TYPE)
relinquish 3 UNITS OF MATERIAL
```

By way of explanation, it was stated that processes may be filed in queues, either waiting for, or executing with, resources. This is not quite correct. Since a process may, in practice, require several resources concurrently, a special temporary entity (**qc.e**) is created at each **request** for a resource. It is these **qc.e** entities that are filed both in the set of resources associated with this process, (**process**), and also in either of the sets **x.resource** or **q.resource**, depending on whether the request has or has not been satisfied. Each **qc.e** also has a pointer attribute (**who.a**) pointing to the process notice of the requesting process. The attributes of the **qc.e** entity are shown in table 5-3. The **q.resource** set is ranked by high **pty.a**, thus permitting preemptive queuing prior to allocation of resources. The **q.resource** and **x.resource** pointers are equivalenced, as a process is either queuing or executing with any given resource.

**Table 5-3. Attributes of QC.E Entity**

Attribute	Description
<b>who.a</b>	The process pointer
<b>qty.a</b>	Integer Number of Resource units
<b>pty.a</b>	Integer Priority of request
<b>p.rs.s</b>	
<b>s.rs.s</b>	
<b>p.q.resource</b>	or <b>P.X.resource</b>
<b>s.q.rsource</b>	or <b>S.X resource</b>

### 5.3.7 Process Notice: Additional Attributes

The process notice has all the standard event attributes (**time.a**, **eunit.a**, **s.ev.s**, **m.ev.s**). In addition the following attributes are defined:

**Rsa.a**: A pointer to the recursive save area for the process.

**sta.a**: The current state of the process.

```

Passive (0)
Active (1)
Suspended (2)
Interrupted (3)

```

**sta.a** may briefly take other (implementation specific) values to indicate particular transitional states. For instance, a value of 4 could indicate that the process is to destroy itself.

**Ipc.a**: Corresponds to **I.event**. The process class attribute has the value of the event set subscript for process notices of this class. This value is initialized when the process notice is created.

**F.rs.s**: Attribute for owning a set of resources.

For example, the following process declarations:

```

preamble
processes
    include DESIGN, TEST
    every CREATION has a SCHEDULE and owns some MATERIALS

```

will create process notices that have the attributes shown in figure 5-6. The exact layout of the process notice is, as for event notices, implementation-specific.

A process notice may be destroyed, as may any temporary entity, using a **destroy** statement. Before specifying a destroy statement for a process that is in a **suspended** or **interrupted** state, consideration should be given to the following points:

1. Resources owned by the process are not automatically relinquished
2. Local **text** variables of the process and any active subroutines are not automatically erased
3. The storage of the **rsa.a** array is not automatically released.



	DESIGN	TEST	creation
predefined attributes	time.a	time.a	time.a
	eunit.a	eunit.a	eunit.a
	p.ev.s	p.ev.s	p.ev.s
	s.ev.s	s.ev.s	s.ev.s
	m.ev.s	m.ev.s	m.ev.s
	sta.a	sta.a	sta.a
	ipc.a	ipc.a	ipc.a
	rsa.a	rsa.a	rsa.a
	f.rs.s	f.rs.s	f.rs.s
user-defined attributes			schedule
			f.materials
			l.materials
			n.materials

**Figure 5-6. Attributes of Process Notices Created by Process Declarations Above**

### 5.3.8 External Processes and Events

A common validation technique used in simulation modelling is to exercise a model using event data derived from a record of events occurring in the system under study. This is termed trace-driven simulation. Alternatively, a collection of projected event times may, of course, be used to study the behavior of a modelled system.

To support this technique, SIMSCRIPT II.5 provides a mechanism by which, rather than scheduling events using statements within a program, they may be scheduled directly from event times presented as an input data stream.

It is possible for processes and events to belong to one or both of two categories: **internal** or **endogenous** as has so far been described, and **external** or **exogenous**, as described here. Each class of external events or processes has, as usual, an associated routine describing actions to be taken upon its occurrence. The difference between the two event categories lies in the manner in which the event is scheduled. (Note that the term "event" may be taken here to also mean the initiating event of a process.)

Events may be triggered from external input data by declaring them to be **external events** or **processes** in a statement of the form:

```
external processes are process name list
```

or

```
external processes are event name list
```

When an event name appears in an **external** process statement in the preamble, provision is made to create a new event notice each time an input data record containing the event name is read from the external data. This event notice is identical in form with those already described.

One of the predefined attributes in a process or event notice, **eunit.a**, records the unit number of the input device on which information about this event is input. For events and processes not triggered externally, this attribute remains zero. The logical unit numbers of devices on which external event data are to be input are declared in a statement of the form:

```
external process units are device list
```

or

```
external event units are device list
```

The words **process** and **event** are synonymous in this case. Devices may be specified as integer constants or as variables. If variables are used, they must be initialized to valid unit numbers before the start of simulation. If external events have been declared but no **external units** statement appears, the standard input unit is assumed to be a source of external event data. If such a statement does appear, and the standard input unit is also to be used for event data, it must be included in the list of external units.

A simulation program having the processes **TASK** and **REPORT** might contain the following statements in its preamble:

```
external processes are TASK and REPORT
external process units are DAILY.TASKS, WEEKLY.TASKS and 5
```

These statements indicate that the SIMSCRIPT II.5 system must be prepared to trigger the processes **TASK** and **REPORT** from external data, and that three input devices are to be used to input these data. These may be indicated mnemonically as being associated with information about particular events. However, the SIMSCRIPT II.5 system attaches no significance to these names. Any external event may be triggered by data read from any of the declared external units.

External events and processes may be included in **priority** statements, declaring their priority over other events and processes, whether internally scheduled or externally triggered. Note that the priorities are associated with the events or processes, and not in any way with the external units.

Events or processes that are declared to be **external** can be given priority over other classes of events but cannot be ranked among themselves by a **break ties** statement. No ranking attributes are assigned values by external triggering, as may be done by giving arguments in a schedule statement. Even if some instances of the event class are internally scheduled and have attributes initial-

ized, they must compete with the externally triggered event notices on a first-come, first-served basis.

Since an event or process routine can be activated in either of two ways, and each of these ways provides a different source of data for the routine, a logical expression is provided for use within such a routine to determine how this instance of the routine was initiated. The expression compares the keyword **process** or **event** with either of the property words **internal** or **external** and yields a true or false result. The form of the expression is:

```

    process is property or process is not property
and
    event is property or event is not property

```

as in the statements:

```

    if process is internal,
    read NAME and DESTINATION as B 20, (2) I 10
    always
and
    if event is external and data is ended,
    stop
    otherwise

```

### 5.3.9 Triggering Processes and Events Externally

Events are triggered externally by event data records appearing in chronological order on each of the external input devices. Such a data record contains the name of an event or process, the time at which it is to occur, and, optionally, data to be read by the event or process routine. The event data records are read one at a time, their information recognized and deciphered, and event or process notices created for the events or processes indicated. This paragraph deals with two issues: the operations performed by SIMSCRIPT II.5 when external process records are read and the format of the external data records.

When a **start simulation** statement is recognized, the first task performed by the timing mechanism is to read information about the first event on each of the external units. When an external data record is read, the event class is recognized and the event time computed from data on the record. An event or process notice is created, and the scheduled event time and the number of the unit from which the data record was read are stored in the **time.a** and **eunit.a** attributes of the notice. If the event notice has been declared with user-defined attributes, it conforms to the preamble declaration. However, none of the user-defined attributes is assigned values. The notice is then filed in the future events set corresponding to its class. Internally and externally generated notices are filed together. They are distinguished by the **eunit.a** attribute. A coded value of **eunit.a**, usually zero, denotes that a notice has been internally scheduled.

The format of an external data record is:

1. Process or event name, e.g., **REPORT**
2. Process activation time in any of three formats
3. Data for the process (optional)
4. **Mark.v** delimiting character (normally "\*")

The name and activation time are read in free form from the external data record. Optional data for the event or process routine may be in any programmer-defined format. A delimiting symbol is used by the system to advance properly from one set of external data to the next. As the optional data may span more than one physical record, and a routine may possibly leave some of these data unread, the SIMSCRIPT II.5 system must have a way of advancing to the start of a new set of event or process data when signaled by the timing routine. The SIMSCRIPT II.5 system searches for a delimiting character that matches the value of a global variable named **mark.v**. This is an alpha variable, which by default is an asterisk, "\*", but which may be assigned a different value under program control. This delimiter must terminate each set of external data, triggering an event or process.

### 5.3.10 Time and Date Expressions in External Data

There are three formats in which event times can be stated. The first is **decimal time units format**. In this format, time is specified as a **real**-valued decimal number such as 0.0, 15.56, or 20.0. The number is interpreted as the absolute time at which the event triggered by the external data record is to occur. In the second format, **day-hour-minute format**, three **integer** numbers specify the day, hour of the day, and minute of the hour at which the event is to occur. All three numbers must be present. Sample times and their interpretation are:

0 0 0	representing the start of simulation
0 12 30	12:30 in the afternoon of the first day
2 10 37	10:37 in the morning of the third day

Hours are numbered from 0 to 23 and minutes from 0 to 59. In the third format, **calendar time format**, the day is expressed as a calendar date, and the hour and minute of the hour as **integer** numbers. For example:

1/15/82 4 30 represents 4:30 in the morning on January 15, 1982

Using the calendar date format, the year can be expressed as 1982 or as 82. If the form **xx** is used, **19xx** is assumed. Years after 1999 and before 1900 must therefore be expressed completely.

Before the calendar format can be used, the calendar date of the start of simulation must be set to provide an origin against which calendar time specifications can be compared. This must be done

before the **start simulation** statement is executed. The origin is set by a call to a library routine. The arguments to this routine are as shown below:

```
call origin.r(integer month expression, integer day expression,
             integer year expression)
```

Because simulation time is maintained in **time.v** and saved in the **time.a** attribute of event and process notices as a **real** number, conversions must be made between calendar specifications and the SIMSCRIPT II.5 internal representation. The algorithm that performs this conversion assumes the origin date is a Monday, and that simulation starts at the beginning of that day (00.00 hours). **Time.v** is always set to zero at the start of simulation.

Four functions are provided to convert year, month, and day expressions into cumulative simulation times and vice versa. These functions are described in table 5-4. The examples assume that the origin time has been set to July 1, 1982, by the call:

```
call origin.r(7, 1, 82)
```

**Table 5.4 Calendar Date Conversion Functions**

Name	Arguments	Function Mode	Function Values	Example
<b>date.f</b>	3 INTEGER expressions	INTEGER	current simulation day month, day, year	<b>date.f(7,15,82) = 14</b>
<b>year.f</b>	REAL time expression	INTEGER	current year	<b>year.f(476.2) = 1983</b>
<b>month.f</b>	REAL time expression	INTEGER	1-12 current month	<b>month.f(476.2) = 10</b>
<b>day.f</b>	REAL time expression	INTEGER	1-31 day of current month	<b>day.f(476.2) = 21</b>

These functions may be used directly within statements to convert from calendar format times. For example:

```
schedule a DEPART at date.f(MONTH, DAY, YEAR) + SERVICE.TIME
```

Sample external event data records, containing no optional data, are:

```
SERVICE 1/15/80 05 35 *
ARRIVAL 14 05 35 *
DEPART 476.2 *
```

When an externally triggered event or process is eventually selected as the current one by the timing routine, the number of the unit from which the scheduling data was read is assigned to **read.v**, the current input pointer. **Rcolumn.v** is positioned to read the first column after the activation time, and control is passed to the event or process routine. In this routine, then, free-form or formatted **read** statements can be used to read any optional data, following the activation time data in the external data record. In this way event related data may be passed to this instance of the routine. For example:

```
external processes are SERVICE
.
.
process SERVICE
  define CUSTOMER.NAME as a text variable
  read CUSTOMER.NAME
  .
  .
  return
end
```

External event data card:

column number																																																	
0	1	2	3	4	5																																												
1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
SERVICE 525.30										<u>JOHNSON</u>										*																													
										data field read										<b>mark.v</b> character																													

↑  
position of **rcolumn.v** when timing routine transfers to event **ARRIVAL**

When an externally triggered instance of a event or process routine first returns control to the timing routine (recall that this may happen more than once for a process, through process interaction statements), any remaining optional data fields present must be skipped in the data stream until **mark.v** is encountered, signifying the next set of external process or event data. In no case should a process or event routine attempt to read more data than are written for it, that is, pass into the next set of external data. When a routine reads fewer data than are provided, the programmer can pass over it by searching for and moving to the next **mark.v** symbol, or leave this task to the SIMSCRIPT II.5 system.

External process data may only be coded in printable form. **Binary** mode may not be used for external process and event data.

The following routine demonstrates an externally triggered process that reads some external data and executes a **work** statement. In this example, at process reactivation, the true duration of service is computed (the process could possibly have been interrupted) and compared with the predicted service time:

```
process UNLOAD
  read ID(UNLOAD) and SERVICE.TIME(UNLOAD)
  let START.TIME(UNLOAD) = time.v
  work SERVICE.TIME(UNLOAD) days
  let DURATION = time.v - START.TIME(UNLOAD)
  let OVERRUN=DURATION-SERVICE.TIME(UNLOAD)
  print 1 line with ID(UNLOAD), OVERRUN thus
OVERRUN FOR ** WAS **.*.*** DAYS
  return
end
```

The important facts to remember about externally triggered events and processes are:

1. **Time.v** is, as usual, set to the process activation time
2. **Read.v** is set to the number of the unit on which the triggering data were encountered, and which may have further data for the process routine
3. **Rcolumn.v** is positioned to read the first column after the time data
4. When control returns to the timing routine, data fields on the current external unit are skipped until a **mark.v** delimiter is found, and the data following are used to schedule the next external process from that input unit. **Read.v** reverts to the standard input unit, and the timing routine then proceeds in the normal way to select the next event.

If a process may be triggered both internally and externally, and has arguments specified, these can only be initialized if the process has been internally scheduled. The routine can test whether it may expect the attribute values to be set, or whether it should accept data from the external unit as shown here:

```
process UNLOAD given ID and SERVICE.TIME
  if process is external
    read ID and SERVICE.TIME
  always
  let START.TIME(UNLOAD) = time.v
  work SERVICE.TIME days
  let DURATION = time.v - START.TIME(UNLOAD)
  let OVERRUN = DURATION - SERVICE.TIME
  print 1 line with ID, OVERRUN thus
OVERRUN FOR ** WAS **.*.*** DAYS
  return
end
```

Comparing this example with the previous one, note that **ID** and **SERVICE.TIME** have been declared as arguments. These names now refer to the local argument values, not the process notice attributes, although they may be initialized from these attributes if the process is scheduled internally. Thus, the names are not subscripted in this version.

## 5.4 Modelling Statistical Phenomena

As simulation is essentially a tool for drawing statistical inferences about the operations of stochastic systems, it is essential that a simulation modelling language should provide facilities for modelling statistical phenomena.

The principal mechanism of the SIMSCRIPT II.5 statistical sampling feature is the function **random.f**, which generates a stream of pseudorandom numbers between 0 and 1. Starting from an initial value, **random.f** generates successive **real** numbers that can be used in decision-making statements or as data in other statistical calculations. The numbers generated by **random.f** are statistically independent of one another. A multiplicative congruence algorithm is used. The parameters are dependent on characteristics of internal numeric representations, which may vary on different machines.

**Random.f** has one argument, an index number that selects one of several independent random number streams. **Random.f(1)** samples from random number stream 1, **random.f(5)** from random number stream 5, etc. All SIMSCRIPT II.5 programs are initialized with 10 random number streams. The starting numbers for these streams are contained in the **integer** system array. Traditionally, the first number in a pseudorandom number sequence is called the seed of the sequence. As pseudorandom numbers are generated, new values are assigned to **seed.v**, so that it contains the current seed expressed in **integer** form.

Should more streams be needed, a programmer can override the default condition by releasing **seed.v** and specifying his or her own array size, as in:

```
main
  release seed.v(*)
  read ARRAY.DIM
  reserve seed.v(*) as ARRAY.DIM
  read seed.v
end
```

The **random.f** function may be referenced in logical or assignment operations, as for any function. At each reference, a new number from a pseudorandom sequence is returned. For example:



1. if random.f(1) less than TRANSITION.PROBABILITY  
     let COUNT = COUNT + 1  
   always
2. for each CONTESTANT,  
   do  
     if random.f(CONTESTANT) greater than FINISH,  
       file CONTESTANT in POSSIBLE.WINNER  
     always  
     add 1 to STEPS(CONTESTANTS)  
   loop

**Random.f** can be viewed in two ways — as generating uniformly distributed pseudorandom variables between 0 and 1 or as generating probabilities. The above examples illustrate the use of the function in the probability sense.

SIMSCRIPT II.5 provides twelve functions for generating independent, pseudorandom samples from commonly encountered statistical distributions. Each of these functions has as its arguments the parameters that describe the distribution and a pseudorandom number stream index. Each time one of these functions is invoked, one or more pseudorandom numbers are generated from the indicated stream, using **random.f**, and an appropriate transformation is made to produce the correct sampling distribution. The functions, the arguments, and their properties are described in table 5-5.

If the stream number, *i*, is negative in any of these function calls, a quantity called an antithetic variate,  $1 - \text{random.f}(\text{abs.f}(i))$ , is generated. Antithetic variates are used in simulation experiments to reduce the variance of estimates of simulation-generated data. Discussions of their use can be found in most simulation texts.

These statistical functions are often used with simulation models to generate event times and activity durations. Some examples illustrate their use.

1. An activity generator process schedules task processes, assuming that the time between successive task initiations is an exponentially distributed quantity with mean time of **MEAN** days. For example:

```

process GENERATOR
  until time.v gt TIME.LIMIT
  do
    activate a TASK now
    wait exponential.f(MEAN, 1) days
  loop
  return
end

```

**Table 5-5. Statistical Distribution Functions**

Name	Arguments	Function Mode	Function Value
beta.f	$e_1, e_2, i$ REAL, REAL, INTEGER	REAL	Generates a beta-distributed <b>REAL</b> number with $e_1$ = power of $x$ , $e_2$ = power of $(1 - x)$ using stream $i$
binomial.f	$i_1, e, i_2$ INTEGER, REAL, INTEGER	INTEGER	Generates the <b>INTEGER</b> number of successes in $i_1$ independent trials, each having probability of success using stream $i_2$ .
erlang.f	$e, i_1, i_2$ REAL INTEGER REAL	REAL	Generates an Erlang distributed <b>REAL</b> number with mean = $e$ and $k = i_1$ using stream $i_2$ .
exponential.f	$e, i$ REAL, INTEGER	REAL	Generates an exponentially distributed <b>REAL</b> number with mean = $e$ using stream $i$ .
gamma.f	$e_1, e_2, i$ REAL, REAL, INTEGER	REAL	Generates a gamma-distributed <b>REAL</b> number with mean = 1 and $k = e_2$ using stream $i$ .
log.normal.f	$e_1, e_2, i$ REAL, REAL, INTEGER	REAL	Generates a log normally distributed <b>REAL</b> num- ber with mean = $e_1$ and standard deviation = $e_2$ using stream $i$ .
normal.f	$e_1, e_2, i$ REAL, REAL, INTEGER	REAL	Generates a normally distributed <b>REAL</b> number with mean = $e_1$ and standard deviation = $e_2$ us- ing stream $i$ .
poisson.f	$e, i$ REAL, INTEGER	INTEGER	Generates a Poisson-distributed <b>INTEGER</b> num- ber with mean = $e$ using stream $i$ .
randi.f	$i_1, i_2, i_3$ INTEGER, INTEGER, INTEGER	INTEGER	Generates an <b>INTEGER</b> number uniformly dis- tributed between $i_1$ and $i_2$ inclusive using stream $i_3$ .
triang.f	$e_1, e_2, e_3, i$ REAL, REAL, REAL, INTEGER	REAL	Generates a triangularly distributed <b>REAL</b> num- ber with minimum = $e_1$ , mode = $e_2$ , and maxi- mum = $e_3$ using stream $i$ .
uniform.f	$e_1, e_2, i$ REAL, REAL, INTEGER	REAL	Generates a uniformly distributed <b>REAL</b> number between $e_1$ and $e_2$ using stream $i$ .

**Table 5-5. Statistical Distribution Functions - Continued**

Name	Arguments	Function Mode	Function Value
weibull.f	$e_1, e_2, i$ REAL, REAL, INTEGER	REAL	Generates a Weibull-distributed <b>REAL</b> number with shape parameter = $e_1$ and scale parameter = $e_2$ using stream $i$ .

2. Although similar to the previous example, the **TASK** process now has a given argument assumed to have a Poisson distribution with a mean of 5. Note that two separate random number streams are to be used in sampling the distributions:

```

process GENERATOR
  until time.v gt TIME.LIMIT
  do
    let NUMBER = poisson.f(5.0, 1)
    activate a TASK giving NUMBER now
    wait exponential.f(MEAN, 2) days
  loop
  return
end

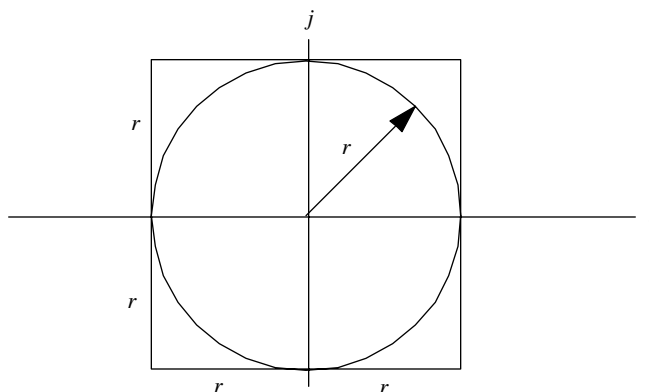
```

3. Evaluation of PI ( $\pi$ ):

In a rectangular coordinate system (figure 5-7), the equation of a circle is:

$$i^2 + j^2 = r^2$$

that is, any point (i,j) with  $i \leq r$  and  $j \leq r$  and  $i^2 + j^2 \leq r^2$  lies inside a circle of radius  $r$ . The area of the circle is  $\pi r^2$ . A square of side  $2r$  has an area =  $4r^2$ . The ratio of the area of the circle to the area of the square is  $\pi r^2 / 4r^2 = \pi/4$ .



**Figure 5-7. A Rectangular Coordinates System**

If we generate  $N$  points  $(i, j)$  within the square in a random fashion, some of the points will fall within the circle, and some will not. In fact, the proportion of those falling within the circle will be approximately  $\pi/4$  of all the points. If  $M$  is the total number of those that fall within the circle, then  $M/N$  is approximately equal to  $\pi/4$ . We can estimate the value of  $\pi$  as  $4M/N$ . The accuracy of this estimate improves as  $N$  increases, and is proportional to  $\sqrt{N}$ .

The program shown below uses the function `uniform.f` to generate points  $(i, j)$  that are randomly distributed within a square of side  $R$ . It does this by generating random numbers between 0 and  $R$  and assigning them in pairs to  $i$  and  $j$ .

Each such point  $(i, j)$  lies somewhere inside the square. If  $i^2 + j^2 \leq r^2$ , the point also lies within the circle, and 1 is added to  $M$  to record this fact. This procedure is repeated  $N$  times. Each time, a different  $i$  and  $j$  are generated and used to determine if the point  $(i, j)$  lies within the circle. At the end of  $N$  point generations, the approximation to  $\pi$  is printed.

```
main
  normally mode is real
  define HIT, I and NO.SAMPLES as integer variables
  read RADIUS and NO.SAMPLES
  let RADSQ = RADIUS**2
  let HIT = 0
  for I = 1 to NO.SAMPLES,
  do
    let XSAMPLE = uniform.f(0.0, RADIUS, 1)
    let YSAMPLE = uniform.f(0.0, RADIUS, 1)
    if XSAMPLE**2 + YSAMPLE**2 le RADSQ,    '' within circle
      add 1 to HIT
    always
  loop
  let APPROX.PI = 4 * HIT/NO.SAMPLES
  print 1 line with NO.SAMPLES, APPROX.PI  as follows
  THE ESTIMATED VALUE OF PI AFTER *** SAMPLES IS *.*****
  stop
end
```

When a sampling distribution cannot be characterized by one of the statistical sampling functions, declarations can be given that define table look-up sampling variables. A table look-up sampling variable has a list of possible numeric values together with their associated probabilities. It selects a sample value by generating a random number and matching it against the possible probability values. Table look-up variables, hereafter called **random** variables, are declared in statements of the form:

```
the system has a name random step variable
```

or

```
every entity has a name random linear variable
```

Such **random** variables must be declared as attributes, either of some entity or of **the system**.

The first form states that sampling is done from a **real**- or **integer**-valued sampling distribution in a steplike manner. The second states that sampling is performed with linear interpolation done between **real** sample values. The following illustrations describe how this is done.

Assume that a **random** variable, or attribute, has the sampling distribution in table 5-6 associated with it. Note that the cumulative probabilities in the left-hand column range from 0.0 to 1.0. Sampling is performed by generating a probability value using **random.f(1)**, matching it with a value in column 1, and selecting an appropriate value from column 2. Since samples from **random.f** are always between 0.0 and 1.0, and are uniformly distributed between these extremes, the samples drawn from column 2 will be chosen randomly.

**Table 5-6. Sampling Distribution (Example)**

Cummulative Probability	Sample Value
0.00	0.0
0.10	
0.20	1.0
0.25	
0.38	2.5
0.45	
0.60	3.0
0.77	9.0
0.90	
0.99	11.8
1.00	20.9
	30.0
	33.3
	50.0
	66.7

### 5.4.1 Random Step Variables

If the sampling variable is defined by the statement:

the system has a **SAMPLE** random step variable

sampling is done as follows in the statement **let x = SAMPLE**:

1. A random number is drawn from **random.f(1)**
2. This random number is compared with successive cumulative probability values until a value is found that equals or exceeds it
3. The column 2 value (table 5-6) associated with this cumulative probability value is returned as the value of the sample. Examples are:

If the random number drawn is 0.20, **SAMPLE = 2.5**

If the random number drawn is 0.45, **SAMPLE = 11.8**

If the random number drawn is 0.65, **SAMPLE = 30.0**

If the random number drawn is 0.95, **SAMPLE = 50.0**

### 5.4.2 Random Linear Variables

**Random** variables defined as **step** can be either **integer**- or **real**-valued. If the sampling variable is defined by the statement:

the system has a **SAMPLE** random linear variable

sampling is done as follows:

1. A random number is drawn from **random.f(1)**
2. This random number is compared with successive cumulative probability values until a value is found that equals or exceeds it
3. Interpolation is done between the column 2 value (table 5-6) associated with the stopping cumulative probability value and the column 2 value preceding it. If **i** represents the index of the stopping probability, **C(i)** the probability, and **v(i)** the sample value, the interpolation formula is:

$$\text{SAMPLE} = \text{V}(\text{i}-1) + \text{random.f} - \text{C}(\text{i}-1) [\text{V}(\text{i}) - \text{v}(\text{i}-1)] \\ \text{C}(\text{i}) - \text{C}(\text{i}-1)$$

Examples are:

If the random number drawn is 0.20, **SAMPLE = 2.5**

If the random number drawn is 0.45, **SAMPLE = 11.8**

If the random number drawn is 0.65, **SAMPLE = 23.6**

If the random number drawn is 0.95, `SAMPLE = 42.6`

**Random** values defined as **linear** can only be **real**-valued. Interpolations are done in **real** arithmetic, and the accuracy is determined by the machine representation. Rounding is done in the above examples for illustration only.

If the mode of **random** variables does not agree with the background mode, the mode must be specified in a **define** statement. This **define** statement may also be used to specify a random number stream other than the default stream (number 1). On some implementations, this stream number may be declared to be a variable, which must evaluate to the number of a valid stream, whenever used.

Example:

Define **SAMPLE** as a **random** attribute of an entity **JOB**. The values of **SAMPLE** are **real**. Sampling is done using **linear** interpolation and random stream 6.

```
every JOB has a SAMPLE random linear variable
define SAMPLE as a real, stream 6 variable
```

Sampling is always automatic. That is, a random variable behaves as a right-hand function. Whenever a random variable appears, a routine that performs sampling is executed. SIMSCRIPT II.5 generates these routines using random number stream 1 unless otherwise specified.

### 5.4.3 Programmer-Defined Random Variables

If you require a type of sampling other than step or linear, you must omit the words **step** or **linear** from the definition of the random variables and provide your own sampling function. Three system functions are provided for sampling (table 5-7). They correspond to the type of lookup previously described.

**Table 5-7. System Sampling Functions**

Function	Mode	Arguments	Description
<b>istep.f</b>	integer	<b>v,e</b>	Returns a random sample from table <b>v</b> using stream <b>e</b> .
<b>lin.f</b>	real	<b>v,e</b>	Returns a random sample from table <b>v</b> using interpolation and stream <b>e</b> .
<b>rstep.f</b>	real	<b>v,e</b>	Returns a random sample from table <b>v</b> using stream <b>e</b> .

Because of the special storage assigned to **random** variable sample values and probabilities, special input treatment is necessary. When a variable defined as **random** appears in a free-form **read** statement, the following occurs:

1. Pairs of free-form data values are read until a **mark.v** character appears.

2. The first of each pair is assumed to be a probability. The second is assumed to be a sample value.
3. A system-defined, three-attribute entity, **random.e**, is created for each pair. The probability value is assigned to its first attribute, **prob.a**. The sample value is assigned to its second attribute, referred to as **ivalue.a** if the variable is **integer**, or **rvalue.a** if the variable is **real**.
4. The entities are filed in a set having the same name as the **random** variable. The third attribute in each **random.e** record is a pointer named **s.variable**.
5. Occupies the space declared for the **random** variable or attribute.

Input probabilities can be cumulative or individual. If cumulative, the last probability must be 1.0. If individual, they must sum to 1.0. All **random** variables have their probabilities stored cumulatively. If any probability appears as less than 0 or greater than 1, the program terminates with an error message.

The following examples illustrate how **random** variables are defined and used.

Definition:

```
the system has a RANDVAR random step variable
define RANDVAR as an integer variable
```

Input statement:

```
read RANDVAR
```

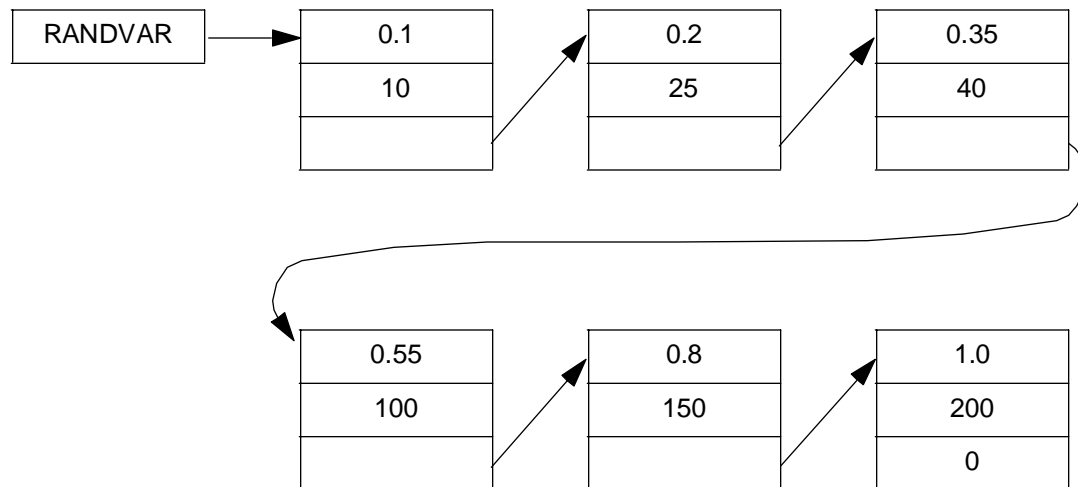
Input data:

```
0.1 10 0.2 25 0.35 40 0.55 100 0.8 150 1.0 200 *
```

The sampling probabilities are expressed cumulatively in six pairs of sampling values. These pairs are stored in six entities in a set named **RANDVAR**.

Storage of **RANDVAR** sample values is shown in figure 5-8.





**Figure 5-8. Storage of RANDVAR Sample Values**

Use of the **random** variable:

```

let NEXT.VALUE = RANDVAR
if RANDVAR greater than LIMIT,
.
.
.

```

If the input data had the form:

```

0.1 10 0.1 25 0.15 40 0.2 100 0.25 150 0.2 200 *

```

the data would be stored in the same form. Individual probability values are accumulated as the data are read.

**Random** variables cannot appear in any other form of **read** statement, because input of a **random** variable "value" obviously means something special. If **RANDVAR** is an attribute of a permanent entity, one can say **read RANDVAR(I)** but not **read RANDVAR**, because the latter statement is interpreted as a free-form array read statement. Only a single **random** variable data list can be read at one time. If **RANDVAR** is an attribute of a temporary entity, **read RANDVAR** is interpreted as **read RANDVAR(entity)**, using implied subscripting.

## 5.5 Simulation Analysis

The principal outputs of simulation experiments are statistical measurements. Such quantities as the average length of a waiting line and the percentage of idle time of a machine are typical examples.

Two features, **accumulate** and **tally**, provided in SIMSCRIPT II.5, allow such information to be gathered during a simulation run, without requiring any other explicit action to be specified within the program. These two preamble statements can instruct the compiler that automatic data collection and analysis are to be performed at appropriate places in a program. The program text can

remain clear of any explicit statements which might obscure the logic of the model. A statement of the form:

```
tally compute list of name
```

performs computations similar to those of the **compute** statement, but in a global manner, over time, rather than locally to an instance of its use. Each time the named variable changes value, appropriate actions are taken to collect the statistics requested in the compute list. **Name** may be the name of an unsubscripted global variable, unsubscripted system attribute, or an attribute of a temporary, permanent, or permanent compound entity. If **name** is an attribute of a permanent entity, as many variables are reserved to store the statistical counters as there are elements of **name**. If **name** is an attribute of a temporary entity, each entity record is generated with statistical counter-variable attributes. **Name** cannot be a function attribute, a **random** variable, or a dimensioned array.

Some examples illustrate the use of the **tally** statement and the attributes and functions generated by it.

1. Use of **tally** with an unsubscripted global variable:

Preamble:

```
preamble
  define TIME as a real variable
  .
  .
  tally MEAN.TIME as the mean,
  and VAR.TIME as the variance of TIME
  .
  .
```

Preamble generates:

- (a) A statistics-gathering function routine, which is called whenever an assignment is made to **TIME** anywhere in the program. The function counts the number of times **TIME** changes value, and records the sum and sum of squares of the values of **TIME**.
- (b) Global variables [**A.1**, **A.2**, **A.3**] to record the **number**, **sum**, and **sum.of.squares** of **TIME** for the computations of **mean** and **variance**.
- (c) Functions **MEAN.TIME** and **VAR.TIME** which use the values of the global counters to compute **mean** and **variance** whenever they are referenced.

The **tally** variables may be used in statements such as:

```
print 1 line with MEAN.TIME AND VAR.TIME as follows
MEAN = **.* **  VARIANCE = *.*.* **
if (VAR.TIME/MEAN.TIME) le TOLERANCE
.
.
```

2. Use of **tally** with an attribute of a permanent entity:

Preamble:

```

preamble
  permanent entities
    every PERSON has some CASH.IN.POCKET
  .
  .
  tally AVERAGE.CASH as the mean
    and MAX.CASH as the maximum of CASH.IN.POCKET
  .
  .

```

Preamble generates:

- (a) A statistics-gathering function routine with one argument, the index number of the referenced entity.
- (b) Attributes for the **sum** and **number** for each entity. These are permanent attribute arrays with **N.PERSON** elements.
- (c) A function **AVERAGE.CASH** to compute **mean** from **sum** and **number**.
- (d) Attribute **MAX.CASH** for each entity. **MAX.CASH** is a permanent attribute array with **N.PERSON** elements.

The **tally** may be used in statements such as:

```

for each PERSON,
  list AVERAGE.CASH(PERSON) and
    MAX.CASH(PERSON)
for each PERSON,
  compute MEAN.CASH as the mean of
    AVERAGE.CASH(PERSON)

```

3. Use of **tally** with an attribute of a temporary entity:

Preamble:

```

preamble
  temporary entities
    every JOB has a NUMBER.OF.OPERATIONS
  .
  .
  tally TOTAL as the sum of NUMBER.OF.OPERATIONS
  .
  .

```

Preamble generates:

- (a) A statistics-gathering function routine with one argument, the pointer to the referenced entity.

- (b) An additional attribute named **TOTAL** for the temporary entity **JOB**.

The **tally** variables may be used in statements such as:

```

for each JOB in QUEUE(MACHINE),
do
    if TOTAL(JOB) le MAX.ALLOWED,
        remove the JOB from QUEUE(MACHINE)
        perform NEXT.JOB given JOB
    always
loop

```

Statistical computations of a different sort are made when the word **accumulate** replaces **tally**. These calculations introduce simulation time into the average, variance, and standard deviation calculations, weighting the collected observations by the apparent length of simulation time for which these values have held. Table 5-8 compares the **tally** and **accumulate** computations. To be concise, some additional notation must be defined:

$T_L$  The simulated time at which an **accumulated** variable was set to its current value

$T_0$  The simulated time at which **accumulation** starts

**Accumulate** and **tally** statements cannot both be declared for the same variable. A programmer must decide whether a variable is time-dependent or not, normally a simple task, and specify one or the other. An illustration of the use of the **accumulate** statement is given in the following example.

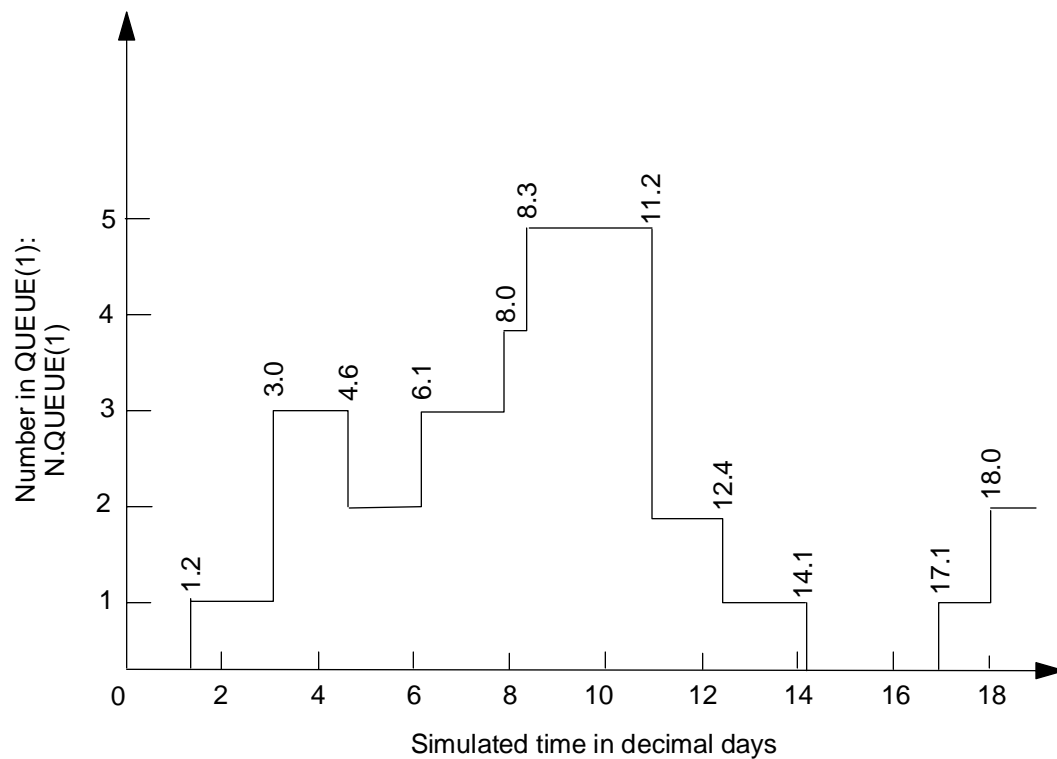
```

preamble
    permanent entities
        every MACHINE has a STATUS, a
            PROCESSING.SPEED and owns a QUEUE
    temporary entities
        every JOB has a VALUE and belongs to a QUEUE
    accumulate AVG.QUEUE as the mean
        and MAX.QUEUE as the maximum of N.QUEUE
    accumulate MACHINE.STATE as the mean of STATUS
end

```

**Table 5-8. Tally and Accumulate Computations**

Statistic	Tally	Accumulate
NUMBER	N	N
SUM	$\Sigma X$	$\Sigma X * (\text{TIME.V} - T_L)$
SUM.OF.SQUARES	$\Sigma X^2$	$\Sigma X^2 * (\text{TIME.V} - T_L)$
MEAN	SUM/NUMBER	$\text{SUM} / (\text{TIME.V} - T_0)$
MEAN.SQUARE	SUM.OF.SQUARES/ NUMBER	$\text{SUM.OF.SQUARES} / (\text{TIME.V} - T_0)$
VARIANCE	MEAN.SQUARE - MEAN**2	MEAN.SQUARE - MEAN**2
STD.DEV	SQRT.F(VARIANCE)	SQRT.F(VARIANCE)
MAXIMUM	Largest X	Largest X
MINIMUM	Smallest X	Smallest X

**Figure 5-9. A Sample Time-Series**

**Table 5-9. Accumulate Computations**

N.QUEUE (1)	Time Value Began (2)	Time Value Ended (3)	Increment (4)=(3)-(2)	Area (5)=(1)*(4)	Sum (5)
0	0	1.2	1.2	0	0
1	1.2	3.0	1.8	1.8	1.8
3	3.0	4.6	1.6	4.8	6.6
2	4.6	6.1	1.5	3.0	9.6
3	6.1	8.0	1.9	5.7	15.3
4	8.0	8.3	0.3	1.2	16.5
5	8.3	11.2	2.9	14.5	31.0
2	11.2	12.4	1.2	2.4	33.4
1	12.4	14.1	1.7	1.7	35.1
0	14.1	17.1	3.0	0	35.1
1	17.1	18.0	0.9	0.9	36.0

The sums in table 5-9 are maintained for the computation of **AVG.QUEUE(1)**. If, at simulated time **11.2 (time.v=11.2)**, **AVG.QUEUE(1)** appears in a statement such as **list AVG.QUEUE(1)**, it is computed from table 5-9 data as **31.0/11.2=2.77**. That is, the average number of jobs in **QUEUE(1)** from **time.v=0** to **time.v=11.2** is **2.77**. If at some time between changes in **N.QUEUE(1)**, say at **time.v=0**, a value for **AVG.QUEUE(1)** is requested, it is computed as **[16.5+5(10-8.3)]/10=2.5** by the function **AVG.QUEUE**.

More complete information on the values attained by tallied global variables, system attributes, and attributes of permanent entities can be obtained by requesting a frequency count of the number of times a variable takes on specified ranges of values. Statements of the form:

```
tally name1 (r1 to r2 by r3) as the histogram of name2
```

define an array **name1** with  $(r2 - r1)/r3 + 1$  elements, one for each element of **name2**, plus an additional element for overflows. If **name2** is the name of a permanent attribute, an array of histograms will be defined. The interval between **r2** and **r1** is divided into classes **r3** units wide. If a sample falls between **r1** and **r1 + r3**, the value of the element **name1(1)** is incremented by 1. If it falls between **r1 + r3** and **r1 + 2r3**, **name1(2)** is incremented, and so forth.

Thus, the average value of a variable, and the distribution of values it takes at different times, over the duration of a simulation run, may be requested by preamble statements such as:

```

preamble
  define VALUE as a real variable
  tally AVERAGE as the mean and
    FREQUENCY(0 to 100 by 5) as the histogram of value

```

Whenever **VALUE** changes, observations are summed to provide data for computing **AVERAGE**, and counts are made in 21 interval counters that indicate the number of times **VALUE** is between 0 and 5, 5 and 10, 10 and 15, etc. If a value is less than **r1**, it is counted in the first cell. If equal to or greater than **r2**, it is counted in the last cell. The range specifications of the histogram are usually defined as constants, but in some implementations may be defined as variables. In the latter case, the range variables must be assigned meaningful values before the monitored variable is first referenced.

The histogram array may be displayed, as a subscripted array, in any of the normal ways. The display formatting has the responsibility for labelling the individual element values of the histogram array. Note that histograms cannot be compiled for attributes of temporary entities because the latter may not have subscripted attributes.

Histograms are defined differently for variables that appear in **accumulate** statements. What is of interest is not how many times values within a given range appear, but the total time spent in the different ranges of values during a simulation run. This allows, for instance, for the calculation of state probabilities. Consider the following example:

```

preamble
  permanent entities
    every MACHINE has a STATUS, and owns a QUEUE
    .
    .
  accumulate MEANQ as the mean of N.QUEUE
  accumulate STATE.PROBS(0 to 2 by 1)
    as the histogram of status
  ' ' POSSIBLE VALUES OF STATUS ARE:
  ' '     STATUS = 0 MACHINE IDLE
  ' '     STATUS = 1 MACHINE IDLE BUT COMMITTED
  ' '     STATUS = 2 MACHINE ENGAGED
    .
    .
end

```

As simulation proceeds, the value of **STATUS** changes for the different machines. Each time **STATUS** changes, the length of time the machine was in that particular state is added to the proper element of the array **STATE.PROBS**. Since **MACHINE** is a permanent entity, and **STATUS** is therefore a one-dimensional attribute array, **STATE.PROBS** is a two-dimensional array. The first dimension is **N.MACHINE** and the second is 3, derived as  $((2-0)/1 + 1)$ .

The percentage time, and therefore the state probabilities, spent in each state by each machine can be obtained by:

```

for each MACHINE,
  print 1 line with
    STATE.PROBS(MACHINE,1)/time.v,
    STATE.PROBS(MACHINE,2)/time.v,
    STATE.PROBS(MACHINE,3)/time.v    as follows
PROBABILITIES OF BEING IN STATES 0, 1 AND 2 ARE *.* , *.* , *.*

```

and adaptive decisions can be made within a model by such statements as:

```

if STATE.PROBS(1,1)/time.v < STATE.PROBS(2,1)/time.v,
  call ACTION(1)
else
  .
  .

```

Each **tally** or **accumulate** statement also generates a routine for reinitializing the counters used in calculating its statistical quantities. These routines can be invoked at any time by statements of the form:

```

reset the totals of variable list

```

Thus, the declarations of the above preamble make the following statements possible:

```

reset totals of N.QUEUE(MACHINE)
reset totals of STATUS(5)
reset totals of N.QUEUE(5) and STATUS(5)
for each MACHINE,
  reset totals of N.QUEUE(MACHINE)

```

In cases where both periodic and cumulative statistics are required, the **tally**, **accumulate**, and **reset** statements can be qualified so that multiple statistical counters are used. The statement forms are:

```

tally variable as the name1 statistics of name2
tally variable(n to n by n) as the name1 histogram of name2
accumulate variable as the name1 statistics of name2
accumulate variable(n to n by n) as the name1 histogram
  of name2
reset name1 totals of name2

```

Daily, weekly, and cumulative statistics for **N.QUEUE** in the above preamble could be requested using qualified names as shown below:

```

accumulate
  DMEANQ as the daily mean,
  WMEANQ as the weekly mean and
  MEANQ as the overall mean of N.QUEUE

```

Periodic events could then print the relevant statistics at daily and weekly intervals in simulation time, resetting only the appropriate counters by using the qualifiers in the statements:



```

reset the daily totals of N.QUEUE
reset the weekly totals of N.QUEUE

```

or

```

reset the daily and weekly totals of N.QUEUE

```

If a **reset** statement does not specify one of the declared qualifying names, all counters associated with the relevant variable are reinitialized. Where variables are used in histogram range specifications, they should be only altered following a **reset** statement, and before any subsequent reference to the monitored variable.

It should be noted that the compiler can only generate the necessary statistics-gathering logic in those cases where values are referenced using their globally known names. If a variable is passed to a routine as an argument, where it is referenced by another name, the appropriate actions cannot be taken. If it is returned as a yielded argument, of course, the changes will be noted upon return from the routine. An exception, however, is the case where an array base pointer is passed as an argument. As such pointers effectively pass the array values by reference, the actual elements of a monitored array may be referenced under a different name, that of the local argument of the called routine. Such usage cannot be detected by the compiler and, hence, no statistics can be maintained for these references.

A final note on statistics-gathering concerns the minimization of storage requirements for computations of statistical quantities. It may happen that the statistics of changes to a program variable is required, but the actual value of the variable is not needed for any other purpose. Consider the following example:

```

preamble
.
.
temporary entities
    every JOB belongs to a QUEUE,
    has a DUE.DATE and an OVERRUN
.
.
tally AVG.LATE as the mean of OVERRUN
end

process JOB.STATS
.
.
for each JOB in QUEUE
let OVERRUN = DUE.DATE(JOB) - time.v
.
.

```

If the logic of the program does not require the value of **OVERRUN** for any other purpose than to compute the average, it is possible to perform these **tally** computations on **OVERRUN** without its

value being stored. This alternative provides the convenience of **tally** and **accumulate** specifications without wasting entity storage space by storing unnecessary information. Declare **OVERRUN** as a **dummy** variable in the preamble declaration:

```
define OVERRUN as a dummy variable
```

This declaration saves one location in each **JOB** entity created. Such savings, resulting from **dummy** specifications, can be significant in models requiring a large number of statistical computations on many entities.

Any preamble-defined variables and attributes can be declared as **dummy**, but these should only be used for **tally** or **accumulate** purposes.

## 5.6 Model Verification and Debugging

Even carefully prepared programs are rarely error-free. Errors in a program fall into two categories: syntactic errors and logical errors. Errors in the syntax of SIMSCRIPT II.5 programs are detected and reported by the language compiler. Error and warning messages are displayed, referring, where appropriate, to the program statement line where the error was detected, and usually identifying the incorrect word or symbol. Such errors may then be corrected and the program resubmitted for compilation. A listing of the error messages produced by the compiler, together with an explanatory message for each, is contained in each SIMSCRIPT II.5 user's manual. The compiler also produces a numbered listing of the statements within each program section compiled, including the preamble section. Following this listing of each section is a cross-reference listing that names each global and local variable, entity type, and subprogram referenced, specifying for each its mode, dimensionality, and the line numbers in which references appear. Variables used as implicit subscripts are included in this cross-reference. Careful examination of the cross-reference can identify misspelled variable names, which may otherwise by default be taken as declarations of new local variables, references to undeclared functions, which may be taken as references to subscripted arrays, and other typographical errors in program preparation.

If syntax errors are detected within subprograms (but not within the preamble section), it is only necessary to recompile those incorrect routines, preceding them with a copy of the preamble statements as input to the compiler. This feature of separate routine compilation facilitates the preparation of large programs containing many routines.

Recall that some special routines may be generated by the compiler to perform such tasks as set management, entity creation, and statistics gathering. If the preamble has not been altered, the redundant regeneration of these routines may be suppressed by prefixing the word **old** to the preamble definition. In addition, even the compiled listing of this preamble may be suppressed by titling it **very old preamble** in the definition.

Alternatively, we should explain that certain statements and programming constructs in SIMSCRIPT II.5 are implemented by generating a number of additional SIMSCRIPT II.5

statements (unseen in the normal listing) which are then interpreted by the compiler. A special compilation option may be specified that allows these statements, and any compiler-generated routines, to be included in the program listing. It is also possible to obtain a listing of the object code generated by the compiler. Although these listings are not normally of use, they can serve to determine the precise actions specified and thus prove helpful in pinpointing the source of some complex errors.

Eventually all routines in a program will have been compiled without error. These routines can be submitted, with any required data, for execution. The SIMSCRIPT II.5 user's manual for a specific implementation should be consulted for details on the management of the object code modules produced by the compiler and their linking and execution. Errors in program logic may then become apparent, either by the abnormal termination of the program or by the production of results that are deemed incorrect.

The possible reasons for abnormal termination are many and varied. They may arise either from error conditions detected by the operating system of the machine on which the system is implemented or those detected by the SIMSCRIPT II.5 system. In the first case, the action to be taken must be determined by the operating system response to the error condition, which may be independent of the SIMSCRIPT II.5 system.

When the SIMSCRIPT II.5 system detects an error condition, it endeavors to supply meaningful information that will help you to identify and correct the source of error. An error message is produced that describes the reason for termination. A traceback is also produced, which names the currently executing subprogram, usually identifying the line of program source text corresponding to the error location, and lists any arguments and local variable values. This information is then listed for each subprogram in the hierarchy of such subprograms, leading back to the program initiation in the **main** routine.

The precise format of this traceback, and the options that may be selected to vary its format, are implementation dependent. Consult the user's manual. In general, variables are listed by name and mode, and their values interpreted in a meaningful way. A report on the status of any input/output devices, the current contents of the future events set, and memory usage statistics are usually included.

On completing the error traceback report, the SIMSCRIPT II.5 system attempts to call a routine with the predefined name **snap.r**. If you have included a routine of this name, it will be executed at this point. This routine may include any valid SIMSCRIPT II.5 statements and provides a mechanism by which a specially written routine may be added to augment the normal traceback output. **Snap.r** may also be written to produce additional information on the status of a program, by listing the contents of selected global variables. Examine the program status at the time of error, in conjunction with an up-to-date program listing. This will often identify an error in program logic.

Many of the SIMSCRIPT II.5 implementations provide for comprehensive checking and potential error detection: array subscript bound checking, invalid entity referencing, set membership and

ownership checking, and so forth. These checks may usually be suppressed by selecting compilation options for well-tested programs, at some gain in execution speed. Unless performance is critically important, however, it may prove worthwhile to retain these checks. Rarely can a complex program claim to be fully tested, and this checking proves most valuable in the early identification of errors.

Should the traceback and error reporting prove inadequate to determine the error source, or indeed, should the error be manifest through incorrect program output, rather than by any error termination action, there are several programming aids that can help to track the progress of computation.

The most common error situation is that data values are known before one stage of the processing, but the results of the data manipulation appear incorrect at a later stage. Simulation modelling provides a particularly difficult case, where the ordering of many interacting computational processes may not be clearly determined. In such circumstances, it is usually helpful to rerun the program and incorporate a number of additional display actions which more closely follow the changing values of the key variables. Thus, the section of program logic in error may be isolated. SIMSCRIPT II.5 provides a number of ways by which additional display output may be obtained with minimal alteration to the program text.

The most direct way is to include extra display statements at chosen significant points within the logic. The use of **list** statements minimizes the programming required to obtain clearly labeled output. The traceback output may also be requested at any point, without any error condition, by including the statements:

```

    trace
or
    trace using device
```

The use of left- and right-hand monitoring routines enables all references to selected variables to be noted. Their values may be checked, modified if necessary, and any required display output generated. By including a single preamble declaration, together with the monitoring routines, at recompilation, almost any variable, with some restrictions, may be selected for monitoring, requiring no change to its referencing within the program. These changes may be easily reversed when monitoring is no longer required.

Two checking statements, **before** and **after**, which may be included in the preamble, may be used to monitor a number of the more complex operations performed in SIMSCRIPT II.5. These statements name programmer-supplied routines, which are to be called **before** or **after** the specified operations. These operations are **after creating** or **before destroying** named entities, and **filing in** or **removing** from named sets. As the future events set is of special importance in simulation modelling, two special forms of these statements, using the words **scheduling** or **canceled**, apply to certain of the operations on this set.

To use **before** or **after** tracing, routines having the same number of input arguments as are transmitted for the operation being monitored are written and included with the program. These arguments will be used to pass entity pointers or index values, and any required subscripts, to the user-supplied checking routines.

Suppose, for example, during the validation of a simulation model, it is desired to display the simulation times at which any **SHIP** entities are filed in a **BERTH.SET**. The statements to do this might be:

Preamble:

```

permanent entities
    every HARBOR may own a BERTH.SET
    .
    .
temporary entities
    every SHIP has a TONNAGE
        and may belong to a BERTH.SET
    .
    .
before filing in BERTH.SET call CHECK
    .
    .

```

Routine:

```

routine CHECK given SHIP, SUB1
    define SHIP and SUB1 as integer variables
    list time.v, attributes of SHIP, SUB1
    return
end

```

As shown, the routine must be written to accept the correct number of set subscripts. **BERTH.SET**, here, is one-dimensional and the dimension identifies the owning **HARBOR**. As in the case of monitored variables, these calls may be added to or removed from a program, with minimal effort, and require no modification to any existing program routines.

Table 5-10 lists the variations of the **before** and **after** statements, with the arguments passed to the routines called.

**Table 5-10. Before and After Arguments**

Operation	Before	After
<b>creating an entity</b>	(not allowed)	Entity identifier
<b>destroying an entity</b>	Entity identifier	(not allowed)
<b>scheduling an event</b>	Entity identifier, time	Entity identifier, time
<b>canceled an event</b>	Entity identifier	Entity identifier
<b>filing in a set</b>	Entity identifier, set subscripts	Entity identifier, set subscripts
<b>removing from a set</b>	Entity identifier, set subscripts	Entity identifier, set subscripts
Note: In <b>file before</b> and <b>file after</b> statements, the identifier of the second named entity is not passed as an argument.		

In some implementations the entity identifier passed for a **remove first** or **remove last** has a zero value.

Removals from the events set by the timing routine may not be monitored by the above statements, as these are not done in the usual way. SIMSCRIPT II.5 does provide a mechanism by which, under program control, the activation of events or processes may be monitored. A subprogram variable, **between.v**, may be assigned the name of a routine which will then be called immediately before each new activation of a process or event routine. At the time that the **between.v** routine is called, the simulation time, **time.v**, will already have advanced to the **time.a** attribute of the selected event or process notice, the global variable **event.v** has been updated to the event or process priority class, and the global variable of the same name as the event or process type holds the pointer to the event or process notice, allowing the attributes to be referenced. This event tracing may be inhibited at any time by resetting **between.v** to zero.

## 5.7 Synchronous Variables

Recall that it is possible for two or more process interactions or events to be scheduled for precisely the same instant in simulation time. The order of activation of the associated routines is then determined from the class or priority of each, while the value of **time.v** remains constant. This operation, however, may not prove satisfactory if two or more of these routines must access the same variable. If it is modified by the first, this modified value is the one accessed by the second. What is required is a mechanism by which such values appear unchanged until all events at an instant have been completed, and the simulation time has been advanced. Such a mechanism may be programmed, using the **between.v** feature. In the following example, we assume that the values which may be accessed by "parallel interactions" are elements of a one-dimensional array. A memo entity is created, through left-hand monitoring of these values (discussed in paragraph 6.10), for each assignment to any value. A routine called through the **between.v** variable updates the values appropriately, using an equivalenced name to inhibit monitoring, at the first change in simulation

time. A local saved variable is used in this routine to record the value of **time.v**, allowing an advance in time to be detected.

```

preamble
  the system owns a SYNCH.SET
  and has a (XARR, YARR)
  define XARR as a 1-dimensional array monitored on the left
  define YARR as a 1-dimensional array
  temporary entities
    every MEMO has a VALUE and an INDEX
    and belongs to the SYNCH.SET
  define INDEX as an integer variable
end

main
  let between.v = 'SYNCH.RTN'
  .
  .
  start simulation
end

left routine XARR(SUBSCRIPT)
  define SUBSCRIPT as an integer variable
  enter with ASG.VAL
  create a MEMO
  let INDEX(MEMO) = SUBSCRIPT
  let VALUE(MEMO) = ASG.VAL
  file MEMO in SYNCH.SET
  return
end

routine SYNCH.RTN
  define SAV.TIME as a saved variable
  if SAV.TIME ne time.v
    let SAV.TIME = time.v
    for each MEMO in SYNCH.SET
      do
        remove MEMO from SYNCH.SET
        let YARR(INDEX(MEMO)) = ASG.VAL(MEMO)
        destroy MEMO
      loop
    always
  return
end

```

A statement such as **let XARR(1) = XARR(1) + 1** does not appear to have any effect until simulation time advances. This example merely demonstrates the principle. It may be extended as required.

## 5.8 Simulation Example

The example described in this paragraph is designed to illustrate the SIMSCRIPT II.5 entity-attribute-set structure in a natural problem setting. For a complete development of simulation concepts and modelling techniques, refer to *Building Simulation Models with SIMSCRIPT II.5*, by E. C. Russell.

### 5.8.1 A Sample Model

To illustrate the naturalness, readability, and power of SIMSCRIPT II.5, we shall now model a simple job shop that operates as follows.

There are any number of machines clustered in groups called production centers. Each center has different machines, but within a center, machines are identical. The number of centers and the number of machines within centers will not change during a simulation run.

Jobs are orders that come into the shop from outside at times provided as input data. Each job consists of a sequence of tasks to be performed by specified machines. The routing of jobs through the shop and the processing time at each machine, are specified as input data.

After a job is processed by one machine group, it is routed to the next required production center. It is put into process at once if there is a machine available. Otherwise, it is put into the queue of jobs waiting for a machine in that center.

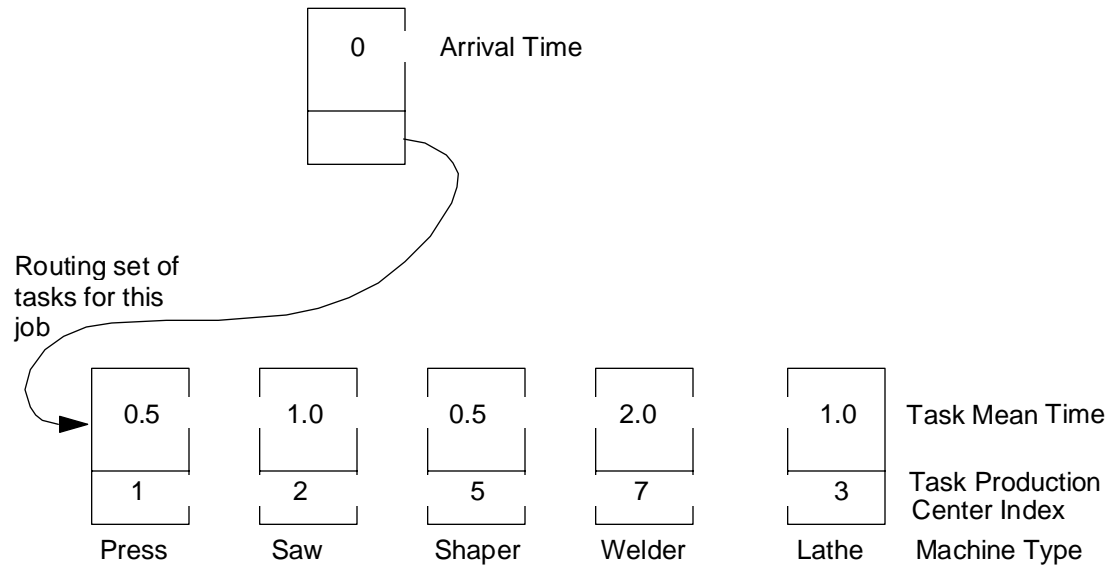
The purpose of the study is to evaluate the performance of the shop for a particular workload, measuring the delays experienced by jobs at each machine group, and overall delays in the shop. Experiments which might typically be conducted with such a model include: evaluating the impact of reconfiguring the machines in the shop, deciding whether the system could handle additional job types, considering whether reordering the tasks for certain jobs would improve turnaround, and studying the effect of different workloads.



## Production Centers

Index	1	2	3	4	5	6	7	8
Number of Machines	1	3	2	1	1	1	1	2
Type	Press	Saw	Lathe	Mill	Shaper	Grinder	Welder	Drill

## First Job



*The machines are modeled as a single resource comprising several production centers. Each center has a number of units representing its number of identical machines. The sequence of tasks for each job is represented as a set of temporary entities called the routing set.*

```

1  preamble
2      normally mode is integer
3
4      resources
5          every PRODUCTION.CENTER has a MACHINE.TYPE
6          define MACHINE.TYPE as a text variable
7
8      processes
9          every JOB has an ARRIVAL.TIME
10             and owns a ROUTING.SET
11             define ARRIVAL.TIME as a real variable
12
13      temporary entities
14          every task has
15              a TASK.DOER
16              a TASK.DURATION
17              and belongs to a ROUTING.SET
18          define TASK.DURATION as a real variable
19          define TASK.DOER as an integer variable
20
21          define ROUTING.SET as a fifo set
22
23          external events are JOBINIT and ANALYSIS
24          external event unit is 1
25
26          define CYCLE.TIME as a real variable
27
28          accumulate AVG.QUEUE.LENGTH as the average
29              of N.Q.PRODUCTION.CENTER
30
31          tally AVG.CYCLE.TIME as the average,
32              and NO.OF.JOBS.COMPLETED as the number of CYCLE.TIME
33
34          define LAST.REPORT.DATE as a real variable
35
36  end

```

*The Preamble contains the destination of the objects involved in the simulation — its processes and resources, its entities, attributes, and sets, and the required statistics.*

*Jobs passing through the shop are modelled by the **JOB** process.*

*The route each job follows through the shop is defined by an ordered list of **TASK**'s called the **ROUTING.SET**. Each **TASK** is a temporary entity with attributes defining the required machine (**DOER**) and processing time (**DURATION**).*

*Desired statistics are specified non-procedurally, with **accumulate** and **tally statements**.*

```

1  main
2      use 1 for input
3      read N.PRODUCTION.CENTER
4
5      create every PRODUCTION.CENTER
6
7      for each PRODUCTION.CENTER      do
8          read MACHINE.TYPE( PRODUCTION.CENTER )
9          U.PRODUCTION.CENTER( PRODUCTION.CENTER )
10     loop
11
12     start simulation
13
14     stop
15 end

```

*This routine sets up the production center data structure. The number of production centers is read and the centers are created. The type and number of machines for each center is then read until all production centers have been defined.*

*Simulation then begins with the first job arrival . . . **JOB.INIT**.*

*Number of production centers {8*

Type and number of each machine {	PRESS	1	SAW	3	LATHE	2	MILL	1
	SHAPER	1	GRINDER	1	WELDER	1	DRILL	2

*Data read by **MAIN***

```

1  event JOBINIT
2      define MACHINE.NAME as a text variable
3
4      create A JOB
5      let ARRIVAL.TIME.. = TIME.V
6
7      read MACHINE.NAME
8      until MACHINE.NAME = "$"DO
9          create a TASK
10         read TASK.DURATION..
11
12         for each PRODUCTION.CENTER
13             with machine.type(production.center) eq machine.name
14             find the first case
15             if found
16                 let TASK.DOER(TASK) = PRODCUTION.CENTER
17                 file the task in the ROUTING.SET
18             else
19                 write MACHINE.NAME as /, "NO FACILITIES FOR :", T *
20                 destroy the TASK
21             always
22                 read MACHINE.NAME
23         loop
24
25     activate this JOB now
26
27 end

```

*This event sets up the job data structure.*

*The first job arrives at time 0. The job's required machines and associated processing times are read. As the machine names are read, they are validated against the production center names. The validated task is then filed into the job's routing set.*

*The **JOB** process is activated.*

<i>First job arrives at time 0.</i>	{ JOBINIT      0 0 00												
<i>Routing and processing times for this job</i>	{PRESS 0.5      SAW 1.0 SHAPER 0.5 WELDER 2.0 LATHE 1.0 \$ *												
<i>Second and subsequent jobs with arrival times, routing and processing times.</i>	<table border="0"> <tr> <td style="vertical-align: top;">{</td> <td style="vertical-align: top;">JOBINIT      0 0 00</td> </tr> <tr> <td style="vertical-align: top;">{</td> <td style="vertical-align: top;">SAW      1.0 LATHE      4.00 GRINDER 0.5 SHAPER 2.0\$ *</td> </tr> <tr> <td style="vertical-align: top;">{</td> <td style="vertical-align: top;">JOBINIT      0 0 30</td> </tr> <tr> <td style="vertical-align: top;">{</td> <td style="vertical-align: top;">DRILL      1. SHAPER      1.00 LATHE 2.0 SHAPER 2.0 MILL 1.00 \$ *</td> </tr> <tr> <td style="vertical-align: top;">{</td> <td style="vertical-align: top;">JOBINIT      0 2 30</td> </tr> <tr> <td style="vertical-align: top;">{</td> <td style="vertical-align: top;">SAW      1.0 WELDER      1.00 DRILL 0.5 LATHE 1.5 MILL 2.00 \$</td> </tr> </table>	{	JOBINIT      0 0 00	{	SAW      1.0 LATHE      4.00 GRINDER 0.5 SHAPER 2.0\$ *	{	JOBINIT      0 0 30	{	DRILL      1. SHAPER      1.00 LATHE 2.0 SHAPER 2.0 MILL 1.00 \$ *	{	JOBINIT      0 2 30	{	SAW      1.0 WELDER      1.00 DRILL 0.5 LATHE 1.5 MILL 2.00 \$
{	JOBINIT      0 0 00												
{	SAW      1.0 LATHE      4.00 GRINDER 0.5 SHAPER 2.0\$ *												
{	JOBINIT      0 0 30												
{	DRILL      1. SHAPER      1.00 LATHE 2.0 SHAPER 2.0 MILL 1.00 \$ *												
{	JOBINIT      0 2 30												
{	SAW      1.0 WELDER      1.00 DRILL 0.5 LATHE 1.5 MILL 2.00 \$												

\*

*Data read by **JOBINIT***

```

1  process JOB
2      define TASK, REQUIRED as integer variables
3
4      until ROUTING.SET is empty
5          do
6              remove the first TASK from the ROUTING.SET
7              request 1 units of PRODUCTION.CENTER(TASK.DOER(TASK))
8              work TASK.DURATION.. HOURS
9              relinquish 1 units of PRODCUTION.CENTER(TASK.DOER(TASK))
10             destroy the TASK
11         loop
12
13         let CYCLE.TIME = TIME.V - ARRIVAL.TIME
14
15 end

```

*This process models the complete life cycle of a job through the shop.*

**UNTIL**            *Processing of this **JOB** is to continue until its **ROUTING.SET** is empty.*

**REMOVE**        *The first **TASK** in the set is removed for processing.*

**REQUEST**       *A **MACHINE** of type indicated by **TASK.DOER** is requested.*

*Execution of the requesting **JOB** process is suspended, if necessary, until a **MACHINE** becomes available. While a particular **JOB** process is suspended, other processes, including other instances of **JOB** process, will run using other machines.*

*As no priorities are specified, a first-in-first-out discipline is provided whenever more than one suspended process is waiting for the same type of resource.*

*Work on this **JOB** continues only when its **MACHINE** becomes available.*

**WORK**            *The **JOB** delays itself for a set time to model actual processing by a **MACHINE**.*

**RELINQUISH**    *The **MACHINE** is made available for other jobs.*

**DESTROY**        *Since this operation is complete, the **TASK** entity is destroyed.*

**LOOP**            *Mark end of **UNTIL** loop.*

*Numeric results are gathered “on the fly” by **accumulate** and **tally** statements contained in the Preamble. The final computation, is the total time, including delays, that it took to process this job.*

```

1  event ANALYSIS
2      print 1 line thus
      E X A M P L E   J O B   S H O P   S I M U L A T I O N
3
4      skip 2 output lines
5      print 1 line with LAST.REPORT.DATE * HOURS.V,
6      TIME.V * HOURS.V thus
      REPORTING PERIOD          ***.* HRS.  TO  ***.* HRS.
7
8      skip 1 output line
9      print 2 lines with NO.OF.JOBS.COMPLETED,
10     AVG.CYCLE.TIME * HOURS.V thus
      JOBS COMPLETED DURING PERIOD :          ***
      AVERAGE COMPLETION TIME :                *.* HRS.
11
12     call DETAILED.REPORT
13     let LAST.REPORT.DATE = TIME.V
14     reset totals of CYCLE.TIME
15     for each PRODUCTION.CENTER
16     reset totals of N.Q.PRODUCTION.CENTER
17
18 end

```

*This event is initiated at times specified in the input data shown below.*

*It prints the report heading, and three lines of statistics as shown on the sample report. Analysis then calls **DETAILED REPORT**, for completion of the report. The last few lines reset the statistics for the next reporting time.*

Two requests for	{	ANALYSIS	0 8 0
analysis and reports.		ANALYSIS	1 0 0
One request at 8 hours	}		
and the other at 1 day.			

*Format of time is  
days hours minutes (d h m)*

*Data read by **ANALYSIS***

```

1  routine DETAILED.REPORT
2      define GRAND.AVERAGE as a real variable
3      skip 1 output line
4      print 1 line thus
5      AVERAGE NUMBER OF JOBS WAITING FOR EACH PRODUCTION CENTER :
6
7      SKIP 1 OUTPUT LINE
8      PRINT 1 LINE THUS
9          MACHINE CENTER          AVERAGE QUEUE
10
11     skip 1 output line
12     for each PRODUCTION.CENTER
13     do
14         print 1 line with MACHINE.TYPE..., AVG.QUEUE.LENGTH
15         thus
16         *****. **
17
18         compute GRAND.AVERAGE as the average of AVG.QUEUE.LENGTH
19     loop
20     skip 1 output line
21     print 1 line with GRAND.AVERAGE thus
22     OVERALL AVERAGE QUEUE LENGTH :          **. **
23
24 end

```

*This routine is called by event **ANALYSIS** to output the table of machine groups and queue lengths shown on the sample report below.*

#### EXAMPLE JOB SHOP SIMULATION

```

REPORTING PERIOD          0.0 HRS.    TO      8.0 HRS.
JOBS COMPLETED DURING PERIOD :          2
AVERAGE COMPLETION TIME :          6.50 HRS.
AVERAGE NUMBER OF JOBS WAITING FOR EACH PRODUCTION CENTER :

```

MACHINE CENTER	AVERAGE QUEUE
PRESS	0.0
SAW	0.0
LATHE	0.0
MILL	0.0
SHAPER	.25
GRINDER	0.0
WELDER	.19
DRILL	0.0

```

OVERALL AVERAGE QUEUE LENGTH :          .05

```

*Sample report*

*Report requested after 8 hours of simulation*

There are many other ways to formulate the job shop model. A more realistic approach can be found in the book, *Building Simulation Models with SIMSCRIPT II.5*. In that version, there are any number of machines clustered in groups. Each group has different machines but within a group, machines are identical. Instead of having a routing associated with each job that comes into the shop, there are a number of job prototypes. Each job prototype consists of a sequence of tasks. Each task comprising the prototype has a specified machine group and mean task completion time. Task completion times are sampled from exponential distributions using the given mean.

Each job arrives according to a Poisson process, at which time its job prototype is randomly selected according to a statistical distribution provided as input data. Each job is routed through the sequence of machine groups needed to do its selected prototype's tasks.

The output report from that simulation is as follows.



## EXAMPLE JOB SHOP SIMULATION

## THE JOB TYPE DESCRIPTIONS

JOB NAME FIRST		TASK SEQUENCE	
		MACHINE	MEAN TIME
		CASTING_UNITS	2.08
		PLANES	.58
		LATHES	.33
		POLISHING MACHINES	1.00
JOB NAME SECOND		TASK SEQUENCE	
		MACHINE	MEAN TIME
		SHAPERS	1.75
		DRILL_PRESSES	1.50
		LATHES	1.08
JOB NAME THIRD		TASK SEQUENCE	
		MACHINE	MEAN TIME
		CASTING_UNITS	3.92
		SHAPERS	4.17
		DRILL_PRESSES	.83
		PLANES	.50
		POLISHING_MACHINES	.42

## THE JOBS WERE DISTRIBUTED AS FOLLOWS:

NAME	PROBABILITY
FIRST	.241
SECOND	.681
THIRD	1.000

RESULTS AFTER 40.01 HOURS OF CONTINUOUS OPERATION		
JOB TYPE	NO. COMPLETED	AVERAGE DELAY (HOURS)
FIRST	51	.18
SECOND	94	.32
THIRD	47	.18

## DEPARTMENT INFORMATION

NAME	NO. OF MACHINES	UTILIZATION	AVG. NO. OF JOBS IN BACKLOG	MAXIMUM BACKLOG
CASTING UNITS	14	.57	.01	2
LATHES	5	.60	.47	6
PLANES	4	.38	.04	2
DRILL_PRESSES	8	.59	.39	8
SHAPERS	16	.73	1.24	13
POLISHING_MACHINES	4	.44	.06	2

*Sample Report*

*Job shop model from "Building Simulation Models with SIMSCRIPT II.5"*



## 6. Advanced Topics

---

### 6.1 Introduction

This chapter describes a variety of SIMSCRIPT II.5 features which need not concern the first-time user, but which an experienced programmer may find of interest.

### 6.2 Programmer-Defined Array Structures: Pointer Variables

We stated previously that the allocation of storage space to an array is determined from the number of elements, or in the case of multidimensional arrays, from the product of the array dimension bounds. Although true in principle, this statement is a simplification. The storage allocation for the elements of a one-dimensional array, for example, is determined from both the number of elements and the declared mode of the array. Associated with this storage allocation is an array base pointer, which holds the address in the computer memory of the allocated storage space. In the case of a one-dimensional array named **x**, the associated base pointer is named **x(\*)**. Recall this usage in the **reserve** statement. The function of the **reserve** statement is to allocate computer storage to an array and assign the internal location of this storage as the value of the base pointer. An array base pointer is internally represented in a way similar to an **integer** variable. It can be manipulated as an integer variable. However, this is generally unnecessary and should be done with great care and full appreciation of the internal array representation.

A one-dimensional array **x**, allocated storage by the statement:

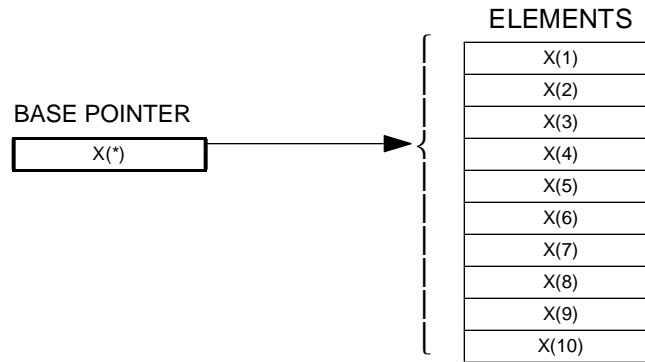
```
reserve x(*) as 10
```

is structured as a contiguous group of memory locations, pointed to by the array base pointer, as shown in figure 6-1. The base pointer itself is not contiguous with the array storage, but is allocated storage in the same way as an **integer** variable.

A two-dimensional array was introduced conceptually as an array of one-dimensional arrays. In fact, this is precisely how a two-dimensional array is internally represented. The base pointer of a two-dimensional array points not directly to the doubly subscripted variable elements, but to a one-dimensional array of pointers. Each element of this pointer array serves as a base pointer for the one-dimensional array representing an entire row of the two-dimensional array. Note that the base pointer itself and the array of row pointers are all pointer type variables, and therefore stored in an **integer**-like form. The representation of the fully subscripted variable elements depends on the declared mode of the array. A two-dimensional array **x**, which has been allocated storage by the statement:

```
reserve x(*,*) as 5 by 3
```

is stored as shown in figure 6-2.

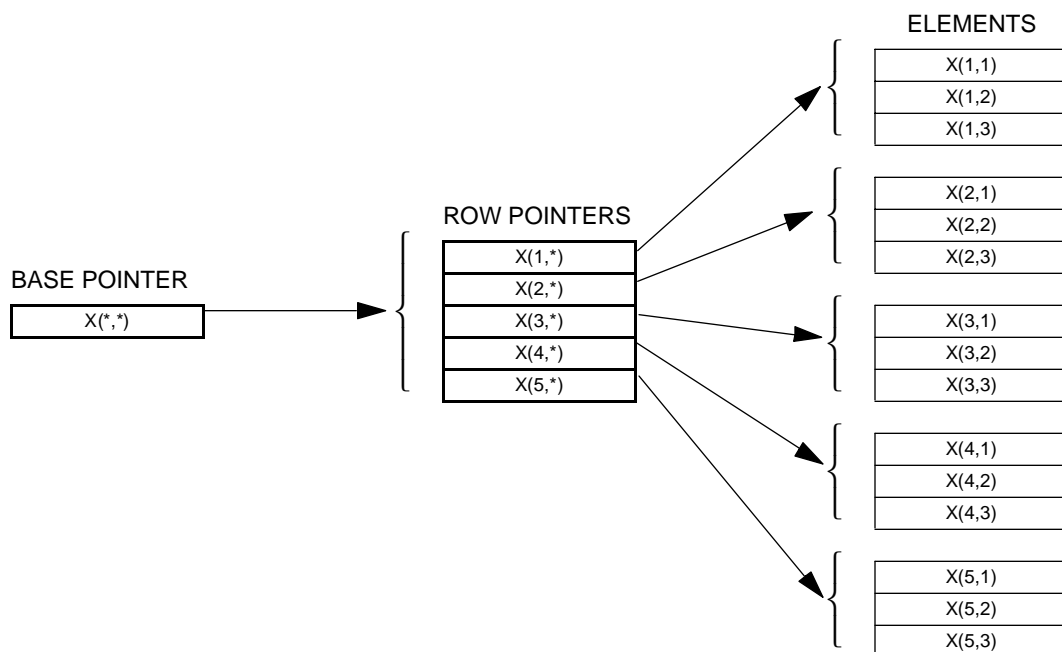


**Figure 6-1. One-dimensional Array X with Its Base Pointer**

A three-dimensional array is structured similarly. The base pointer points to an array of row pointers, each of which points to an array of column pointers, each of which, in turn, points to an array of element variables. A three-dimensional array **x**, which has been allocated storage by the statement:

```
reserve X(*,*,*) as 5 by 3 by 2
```

is stored as shown in figure 6-3. Every element reference with at least one asterisk in its subscript list is a pointer. Every fully subscripted element reference, that is, with no asterisk occupying any subscript position, is a reference to a single element variable. In internally evaluating an element reference, pointers are cascaded from one dimension to another, using subscripts from left to right.



**Figure 6-2. Base Pointers in a Two-Dimensional Array**

An appreciation of these internal structures is not essential to the use of subscripted variables. Arrays are allocated storage using the **reserve** statement, and array elements (subscripted variables) are referenced by previously described methods. Pointer words need not be mentioned explicitly. Also, the manner in which rows and columns of arrays are linked need not be taken into consideration.

An understanding of array representation, however, together with the ability to manipulate pointers as variables, permits the construction of arbitrary data structures suited to the specific requirements of different problems. Such pointer manipulation may be accomplished using the asterisk notation described above in SIMSCRIPT II.5 statements.

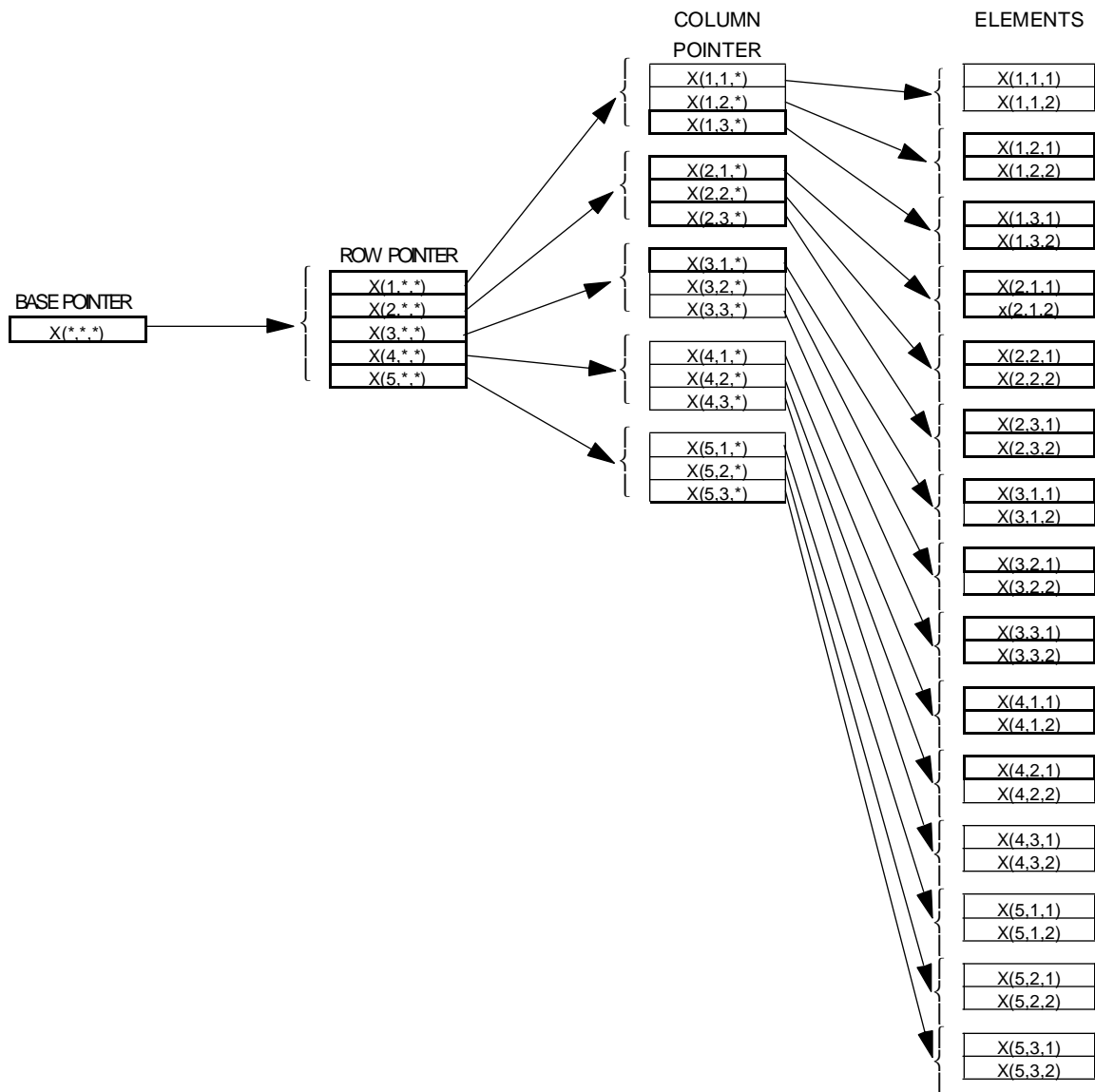


Figure 6-3. Base Pointers in a Three-Dimensional Array

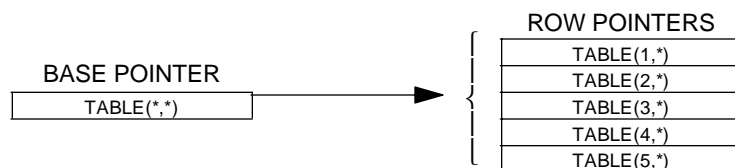
The utility and application of this feature are best described in a series of examples.

1. It can be used to construct a "ragged table," a two-dimensional array with a different number of elements in each row. The construction follows:

- (a) Set up a base pointer and an array of row pointers:

```
reserve TABLE(*,*) as 5 by *
```

This statement assigns an array of five elements, each of which contains an unassigned pointer, to the base pointer **TABLE(\*,\*)**. The asterisk in the array assignment clause **5 by \*** indicates that only pointers, not data values, are to be stored. After execution of this statement, the structure shown in figure 6-4 exists in memory. The base pointer points to the array of row pointers. The row pointers do not yet point to anything because arrays have not been assigned to them.



**Figure 6-4. Memory Structure After Reserve Statement**

- (b) Assign data arrays to each of the row pointers. A dimension must be given for each row, by reading a data value for each row. For example:

```
for I = 1 to 5,
do
  read D
  reserve TABLE(I,*) as D
loop
```

The **reserve** statement assigns an array of **D** elements to each of the row pointers **TABLE(I,\*)**, as **I** varies from 1 to 5. If the values of **D** read are **4, 2, 6, 1, and 3**, respectively, the final ragged table structure appears as shown in figure 6-5.

The ragged array **TABLE(I,J)** may be used in the same way as any rectangular array, with the only restriction that care must be taken not to reference a nonexistent array element, as, for example, **TABLE(4,3)** in figure 6-5.

2. The pointer mechanism may be used to make the processing of multiple-dimensioned arrays more efficient, eliminating the recomputation of unchanging subscripts when processing elements of a single dimension in some regular fashion. For example, the program segment described in (a) below can be made more efficient by rewriting it as shown in (b).

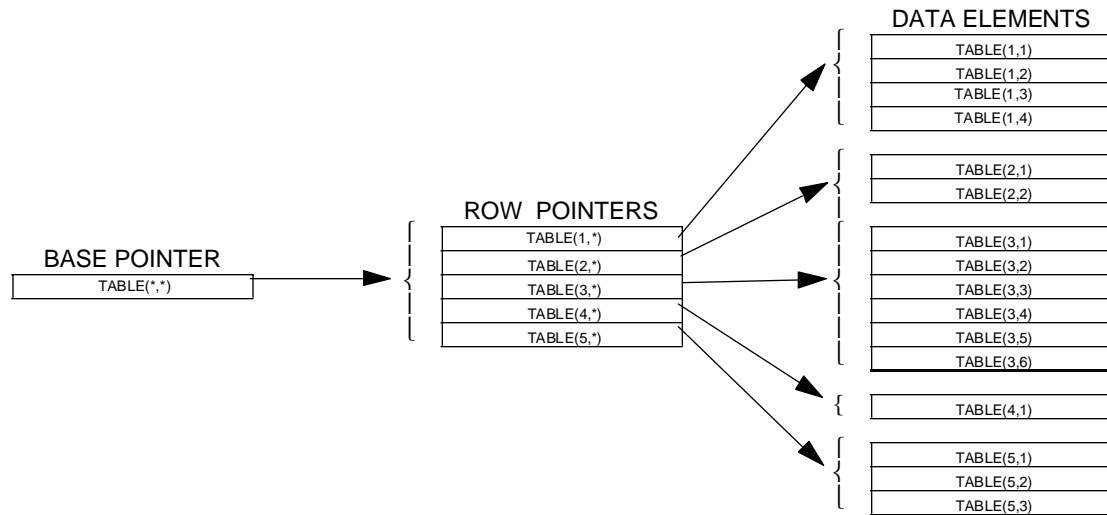
```

(a) for I = 1 to 10, read CUBE(J+7,K+L,I)
(b) let DUMMY(*) = CUBE(J+7,K+L,*)

      for I=1 to 10, read DUMMY(I)

```

where **DUMMY** has been defined as a one-dimensional array, of the same mode as **CUBE**, but has not been reserved. The revised statement eliminates the need for recomputing the subscripts of **CUBE** not affected by the **for** loop every time a new element is accessed. Little additional memory space is taken, for the array **DUMMY** never has more space allocated than is needed for its base pointer.



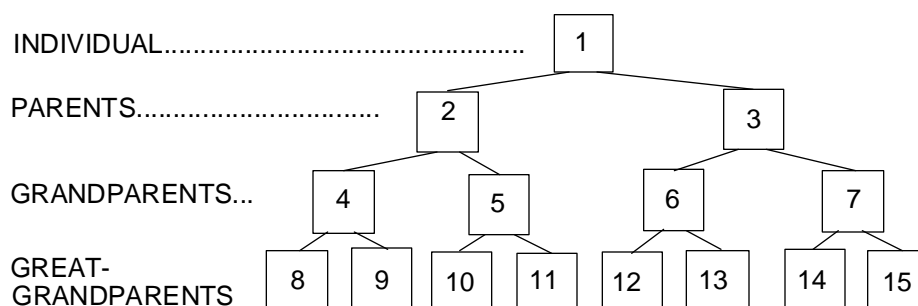
**Figure 6-5. Memory Structure After Assignment of Data Arrays to Row Pointers**

- It has already been stated that once an array has been reserved, it cannot be reserved again. The SIMSCRIPT II.5 system ignores instructions to reserve an array when the pointer to the array already has a value. When a program is first initialized, all array pointers are zero, making the first **reserve** possible. After this, the presence of a non-zero value in a pointer variable dictates whether or not a reserve will be executed. This makes it possible to use a reserve statement more than once to reserve multiple instances of an array by saving the value of the array base pointer and then resetting it to zero before the second and subsequent reserves. Any specific instance of the array may be accessed by restoring the value of the appropriate base pointer. The example below illustrates how such a mechanism can be employed:

A program is to be developed to store genealogical information in the form of a family tree. Such a tree has an individual at its apex, his parents at the next level, his parents' parents below that, and so on. Figure 6-6 illustrates a family tree containing four levels of genealogical information.

This information can be stored in a rectangular array, as depicted in figure 6-7. While simple enough to do, there is a waste of computer memory because of all the empty cells.

A more memory-conserving storage scheme is shown in figure 6-8. No more computer words are allocated than there are data to store. Our task is to show how this scheme can be programmed and used with the technique of array pointers.



**Figure 6-6. Family Tree**

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

**Figure 6-7. Family Tree Stored in a Rectangular Array**

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

**Figure 6-8. Family Tree Stored in a Ragged Table**

In the following program, the data of each level are stored in an array **TREE**. At level one, **TREE** has one element; at level two, two elements; at level three, four elements; ...; and at level **N**, **2N-1** elements. The array pointers for the **N** arrays are stored in a list called **LEVEL**, which has **N** elements,



one for each level of the genealogical tree. Assume that the number of levels in the tree and the names (coded as integer numbers) of the family members arranged in proper order on data records are given. A tree with the family data suitably arranged is first constructed using the following program:

```
preamble
  normally mode is integer
  define LEVEL and TREE as 1-dimensional arrays
end
read N                '' Number of levels
reserve LEVEL(*) as N
for I = 1 to N,
do
  reserve TREE(*) as 2**(I-1)
  read TREE
  let LEVEL(I) = TREE(*)
  let TREE(*) = 0
loop
stop
end
```

For  $N = 4$ , the memory structure at the end of program execution looks as shown in figure 6-9. To print out a person's Kth-level ancestors, write:

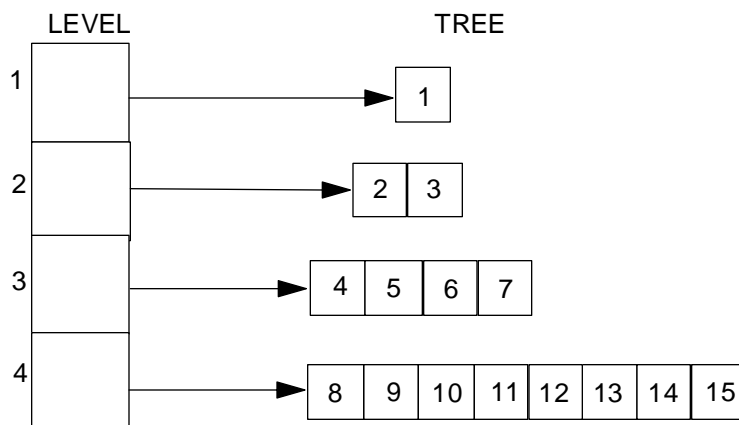
```
read K
let TREE(*) = LEVEL(K)
for I = 1 to 2**(K-1)
  print 1 line with TREE(I) as follows
Ancestor is **
```

To pick out specific ancestors, the tree can be searched until a matching code is found:

```
read CODE
for I = 1 to N,
do
  let TREE(*) = LEVEL(I)
  for J = 1 to 2**(I-1)
  do
    if TREE(J) equals CODE
      print 1 line with CODE, J and I as follows
Ancestor ** found in position * of level *
      stop
    otherwise
      loop
  loop
print 1 line with CODE as follows
UNABLE TO FIND AN ANCESTOR WITH THE CODE **
stop
end
```

This example resembles example (1) above, but the "ragged table" structure is explicitly implemented using one-dimensional arrays to further illustrate the way in which pointers may be manipulated.

An understanding of the use of pointer variables, then, enhances a programmer's ability to construct and use data structures. There are many potential applications: For example, rows of matrices can be interchanged by simply changing pointer values. Large matrices with many identical rows can be compressed by arranging several pointers to point to the same array row.



**Figure 6-9. Memory Structure for Family Tree, N = 4**

It may now be appreciated that the **reserve** statement may be restated as:

*reserve pointer list as array description*

where a pointer list consists of a list of array or array row base pointers, having at least one asterisk in their subscript list, and an array description describes the size and content of the array or arrays being reserved and pointed to. If an array description does not contain a notational asterisk, (i.e., the phrase **by \*** is not used), an array of data elements is reserved. If an array description contains a notational asterisk, the asterisk indicates that pointer words are being reserved and that subsequent **reserve** statements will be used to allocate data arrays to these words. It is only meaningful to have a single notational asterisk in an array description, as this is sufficient to indicate that pointers, not data, are being allocated at this level of the array dimensionality. This asterisk must follow any constants and expressions that define the dimensions of previous subscript positions. The following **reserve** statements illustrate these concepts:

```
reserve ARRAY(*,*) as 5 by 7
(Allocates a 5 by 7 data array.)
```

```
reserve ARRAY(*,*) as 6 by *
(Allocates six pointer variables.)
```

```
reserve ARRAY(*) as 6 by *
```

(Similar to above. **ARRAY(\*,\*)** is understood.)

```
reserve ARRAY(1,*) as 12
```

(Allocates twelve data elements to a pointer variable.)

```
reserve X(*),Y(*) and Z(*) as N, TABLE(J,*) as N+8
```

(Recall that several pointers can be assigned storage space of the same dimension and function (pointers or data), and that several array reservations can be made in the same **reserve** statement. Each pointer is, of course, assigned a separate block of storage.)

As shown in the fourth example above, a base pointer can be written as **x(\*)** regardless of the declared dimensionality of the array. For instance, if **x** is defined as three-dimensional, **x(\*)** is interpreted as **x(\*,\*,\*)**. Although convenient, this does little to elucidate the logic of the operation. In general, it is recommended that the full notation be used.

### 6.3 Still More on Changing the Flow of Computation

A variety of methods for directing the flow of control during program execution have already been presented. Additional power to direct the control flow is provided by allowing labels to be subscripted. A label name is subscripted in the same way as a variable, that is, by suffixing the label with a subscript expression enclosed in parentheses. Although labels used in this way appear similar to subscripted variables, there are some differences. The number of subscripts allowed on a label name is limited to one. A **reserve** statement is not used with subscripted labels; rather, labels carrying specific integer subscript values are defined in place, in the same way as unsubscripted labels. If any occurrence of a label is subscripted, all references to this label name must be subscripted. Although all subscripted labels must be defined with positive integer constants in their subscript positions, it is unnecessary for the subscripts to start with 1, or for them to be consecutive. Thus, **LABEL(4)** can be defined without having **LABEL(1)**, **LABEL(2)**, or **LABEL(3)** appear in the program. Control, however, should be transferred only to subscripted labels that have been defined. The general form of a subscripted label **go to** statement is:

```
go to label(arithmetic expression)
```

As in other forms of the **go to** statement, the word **to** is optional. When a subscripted **go to** statement is executed, control is transferred to the statement prefixed by the label name subscripted by the **integer** value of the expression in the **go to** statement. If no label has been defined with this subscript value, an undefined transfer will occur, usually terminating execution with an error message. Thus, care must be exercised when using this statement. For example, in a program containing the subscripted labels **A(1)**, **A(2)**, and **A(3)**, the programmer must ensure that the statement **go to A(I)** is not executed when the value of **I** is not 1, 2 or 3. The following statements, emulating the functions of a simple calculator, demonstrate the use of subscripted labels:

```

        define OPCODE as an integer variable
        read OPERAND1, OPERAND2, OPCODE
        go to OP.LABEL(OPCODE)
'OP.LABEL(1)'let RESULT = OPERAND1 + OPERAND2
        go to PRINT
'OP.LABEL(2)'let RESULT = OPERAND1 - OPERAND2
        go to PRINT
'OP.LABEL(3)'let RESULT = OPERAND1 * OPERAND2
        go to PRINT
'OP.LABEL(4)'let RESULT = OPERAND1 / OPERAND2
        go to PRINT
'PRINT'  print 1 line with RESULT thus
        RESULT IS: *****.*****

```

The **read** statement accepts two numeric operands and an integer value in the range 1 to 4 indicating the operations addition, subtraction, multiplication, and division. This integer code is used as a label subscript to select the appropriate transfer. The maximum subscript value allowed is arbitrarily limited to 3000. As an internal table (dimensioned by the largest subscript value used) must be generated, the use of widely ranging subscripts can lead to inefficiencies.

When the number of possible transfers is small, and the indexing values can be chosen to be contiguous from 1, an alternative construct may be useful. The possible transfer labels may be listed, in order, within a **go to** statement. If **label1**, **label2**, **label3**, ..., **labeln** represent statement labels, and **E** represents an arithmetic expression, a statement of the form:

```
go to label1 or label2 or ... or labeln per E
```

evaluates **e** (rounding if it is **real** valued) and transfers program control to **label1** if **E=1**, to **label2** if **E=2**, ..., to **labeln** if **E=n**. That is, control is transferred to the label in the first label position, or the second label position, or the  $n^{\text{th}}$  label position, according to the computed value of the expression **E**. Again, illegal transfers, where **E** lies outside the range 1 to **n**, cause abnormal program termination in most SIMSCRIPT II.5 implementations. Any label names defined within the program may be included in the list, and any name may be repeated in more than one position. The label names in the list must be separated by the word **or**, or by a comma. The word **to** is optional. Typical computed **go to** statements are:

```

go to ACCOUNT.ONE or ACCOUNT.TWO per CUSTOMER
go to READ.AGAIN, WINDUP, CONTINUE or HALT per
INSTRUCTION

```

Two or more distinct label names may be used to identify the same statement. They are called equivalent labels. The use of equivalent labels, together with the computed **go to** statement, may be useful during program development, when the logical paths in the program have been identified, but not all segments have been fully coded. The **go to** statement may list all the segment labels. A number of these may reference the same statement. The use of a computed **go to** is shown in the following example, which is an alternative to the previous example. It can be seen that several

additional functions are planned, but not yet developed. The code for these may be added in the appropriate places without modifying the **go to** statement.

```

        go to ADD,SUB,MULT,DIV,EXP,SIN,COS,TAN,LOG per OPCODE
'ADD'let RESULT = OPERAND1 + OPERAND2
        go to PRINT
'SUB'let RESULT = OPERAND1 - OPERAND2
        go to PRINT
'MULT'let RESULT = OPERAND1 * OPERAND2
        go to PRINT
'DIV'let RESULT = OPERAND1 / OPERAND2
        go to PRINT
'PRINT'print 1 line with RESULT thus
        RESULT IS : *****.*****
        go to NEXT
.
.
'EXP'
'SIN'
'COS'
'TAN'
'LOG'
        print 1 line thus
        THIS OPERATION NOT YET IMPLEMENTED
        go to NEXT

```

Although the above constructs provide great flexibility in directing control flow, they should be used carefully. Not all illegal transfers may be detected as such, possibly allowing undesired transfers with strange side effects. The relevant user's manual should be consulted to determine the degree to which transfers are checked in a particular implementation. Alternatively, the programmer may explicitly check the index value before it is used in the **go to** statement.

Under some circumstances, it may be desirable to write sections of a program in which control flow may be explicitly directed without the need to uniquely define statement labels. In order to make local changes in the flow of computation, several statements are provided.

The **jump ahead** statement transfers control to the first **here** statement that follows it. The **jump back** statement transfers control to the first **here** statement that precedes it. Several **jump** statements can refer to the same **here** statement, as in the following example:

```

read DATA
  if DATA > 10
    add DATA to DATA.GT.10
    jump ahead
  otherwise
    if DATA > 5
      add DATA to DATA.GT.5
      jump ahead
    otherwise
      add DATA to DATA.LS.5
here

```

The usefulness of this label-free capability becomes particularly apparent when coupled with the text substitution feature of SIMSCRIPT II.5. Consider the following example of a program written for interactive terminal execution:

```

preamble
  normally mode is integer
  substitute these 7 lines for INPUT
here  if mode is not integer
      print 1 line thus
      PLEASE USE NUMERIC VALUE
      skip 1 field
      jump back
    otherwise
      read
      .
      .
end

main
  input LAMBDA
  .
  .
  input MU
  .
  .

```

Each substitution for **input** contains a label-free jump when the program text is fully expanded.

## 6.4 Attribute Definitions: Packing and Equivalence

It has been assumed thus far that all data values are stored individually in separate and distinct computer locations. Occasionally, to minimize storage space requirements, it may be desirable to share storage locations between more than one variable. This may be done in two ways: If the ranges of values of the variables are limited in magnitude, a single location may be divided between several variables. If certain variables are known to be of importance only at nonconcurrent times during

program execution, they may share a common location. Locations in computer memory are commonly referred to as "words". The size of each, usually a measure of the size in binary digit positions, is termed the "wordlength."

When a word is divided between more than one data value, the values are said to be packed in the word. When a data location is so defined that it may be referenced by different names, the names are said to be equivalent. SIMSCRIPT II.5 offers facilities for packing **integer** and **alpha** data and for equivalencing any attribute values, with some restrictions.

Subscripted system attributes, and attributes of temporary and permanent entities, can be packed and equivalenced. Unsubscripted system attributes can only be equivalenced. This is one reason for defining certain values as system attributes, rather than as global variables, which can be neither packed nor equivalenced.

The SIMSCRIPT II.5 system uses programmer-specified packing factors to store and retrieve data values. The fact that data are packed is reflected in a program's preamble but not in its executable statements. A programmer operates at all times on a logical level, for example, **AGE (PERSON)**; and the SIMSCRIPT II.5 system determines how **AGE (PERSON)** is physically represented. Owing to inherent differences between computer systems, it is impossible to implement all forms of packing and equivalencing in an identical manner on all SIMSCRIPT II.5 implementations. Use of these features, therefore, may adversely affect the portability of programs between different systems. In general, with the decreasing limitations on memory capacity apparent on most systems, it is expected that such system-dependent usage may be avoided.

Attribute packing is specified by attaching a packing factor enclosed in parentheses to an attribute name. Three types of packing are available: field, bit, and intrapacking. Field and bit packing apply to all subscripted attributes. Intrapacking applies only to subscripted system attributes and to attributes of permanent entities.

Using field and bit packing, data fields can be laid out within computer words. The field-packing notation (1/2), for example, specifies that the attribute value to which it is attached is to occupy the first half of a computer word. The bit-packing notation (1-16) specifies that bits 1 through 16 are to be used to store an attribute value. Because computers differ in word size and in instructions available to access parts of words, it is impossible to specify all the possible field- and bit-packing factors available in different SIMSCRIPT II.5 implementations. Table 6-1 shows the packing factors available on typical 32-bit word-length machines. Consult the appropriate SIMSCRIPT II.5 user's manual to determine the packing supported on a particular machine.

Attribute names are processed as they appear in **every** statements. Normally, they are allocated successive words within an entity structure. Attribute equivalence may be specified by enclosing a list of attribute names within parentheses. All attributes within parentheses are assigned to the same word. If two such attributes have the same packing factors, their names are synonyms. Overlapping packing factors can also be specified. Attributes enclosed in equivalencing parentheses must appear in a list without the separators **a**, **an**, or **the**. The parenthesized list must, however, be preceded

by one of these words. The following examples illustrate the use of field- and bit-packing factors for attributes of temporary entities.

**Table 6-1. Field and Bit-Packing Factors for Common 32-Bit Machines**

Field-Packing Factor	Attribute Value Placement
1/2	first half of computer word
2/2	second half of computer word
1/4	first quarter of computer word
2/4	second quarter of computer word
3/4	third quarter of computer word
4/4	fourth quarter of computer word
Bit-Packing Factor	Attribute Value Placement bits n through m inclusive
n-m	$1 \leq n \leq 32$ $1 \leq m \leq 32$ $n \leq m$

temporary entities

1. Declaration:

every PERSON has an AGE and a NAME

Entity structure:

AGE
NAME

2. Declaration:

every PERSON has an ( AGE(1/2) and NAME(2/2) )

Entity structure:

AGE	NAME
-----	------



## 3. Declaration:

every PERSON has an AGE(1/4), a NAME and a SEX(1/4)

Entity structure:

AGE	unused
NAME	
SEX	unused

## 4. Declaration (assuming 32-bit word):

every PERSON has an ( AGE(1-8) and NAME(9-32) )

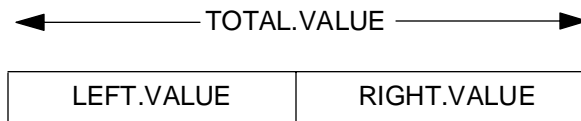
Entity structure:

bit positions	1	9	32
	AGE		NAME

## 5. Declaration:

every PART has a (LEFT.VALUE(1/2), RIGHT.VALUE(1/2),  
TOTAL.VALUE)

Entity structure:



## 6. Declaration:

every PERSON has an ( AGE(1/4), NAME(2/4),  
WEIGHT(17-32)) and owns a FAMILY

Entity structure:

1	9	17	32
AGE		NAME	WEIGHT
F.FAMILY			
L.FAMILY			
N.FAMILY			

## 7. Declaration:

```
every PERSON has an AGE(1/4), owns a FAMILY, has a
(NAME(2/4) and WEIGHT (2/2))
```

Entity structure:

AGE		
	NAME	WEIGHT
F.FAMILY		
L.FAMILY		
N.FAMILY		

Field and bit packing of **integer** attributes of permanent entities and subscripted system attributes places two or more attributes in each element of the same array. The declaration:

```
permanent entities
every HOUSE has an ( ADDRESS(1/2), and ZIP(2/2) )
```

places similarly indexed values of **ADDRESS** and **ZIP** in the same location.

This preamble declaration allows the executable statement **create every HOUSE(5)** to allocate storage as shown in figure 6-10.

ADDRESS(1)	ZIP(1)	element 1
ADDRESS(2)	ZIP(2)	element 2
ADDRESS(3)	ZIP(3)	element 3
ADDRESS(4)	ZIP(4)	element 4
ADDRESS(5)	ZIP(5)	element 5

**Figure 6-10. Entity Storage**

More than one set of attributes, of course, may be packed in a single **every** statement; for example:

```
every SHIP has a ( TONNAGE(1/2), CAPACITY(2/2) ),
a ( DESTINATION(1/2), HOME.PORT(2/2) )
```

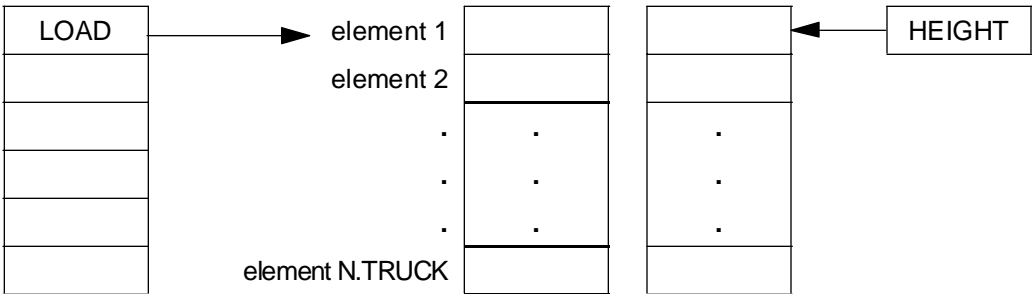
This statement pairs the attributes **TONNAGE** and **CAPACITY** and the attributes **DESTINATION** and **HOME.PORT** within the elements of two attribute arrays. Some additional examples follow.

```
normally mode is integer
permanent entities
```

1. Declaration:

every TRUCK has a LOAD and a HEIGHT

Attribute arrays:

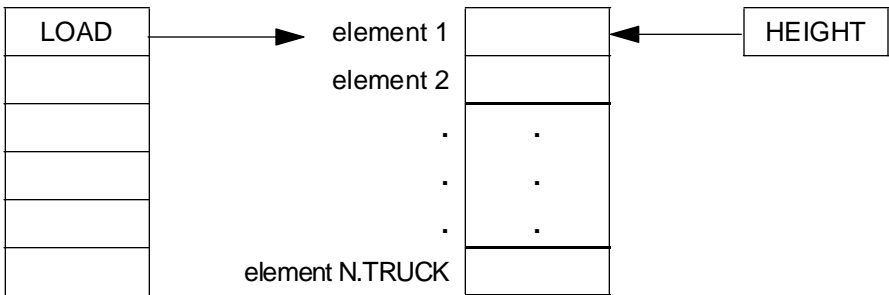


LOAD and HEIGHT are separate arrays.

2. Declaration:

every TRUCK has a ( LOAD, WEIGHT )

Attribute arrays:

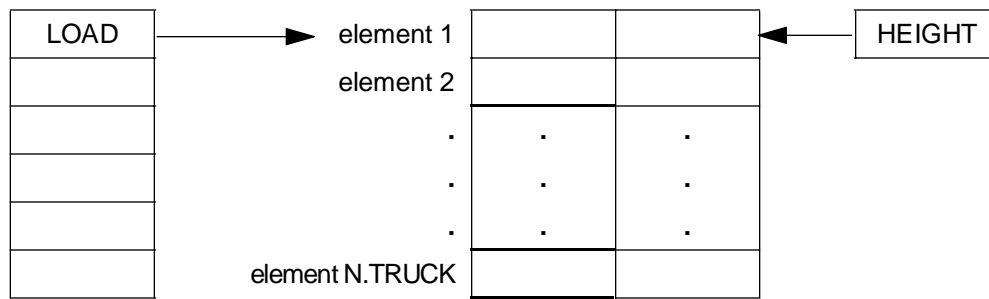


LOAD and WEIGHT refer to the same data array.

3. Declaration:

every TRUCK has a ( LOAD(1/2), HEIGHT(2/2) )

Attribute arrays:



LOAD is stored in the left, and HEIGHT in the right half of each element within the data array.

System attributes:

(1) Declaration:

normally dimension is 0  
the system has a HIGH and a LOW

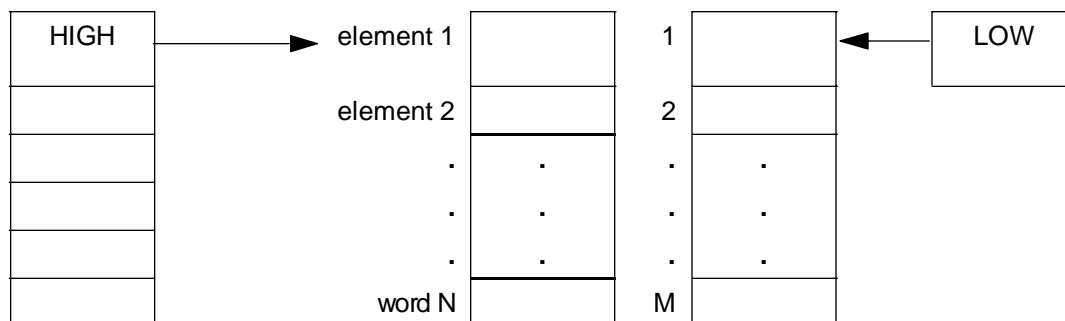
Attributes:



(2) Declaration:

normally dimension is 1  
the system has a HIGH and a LOW

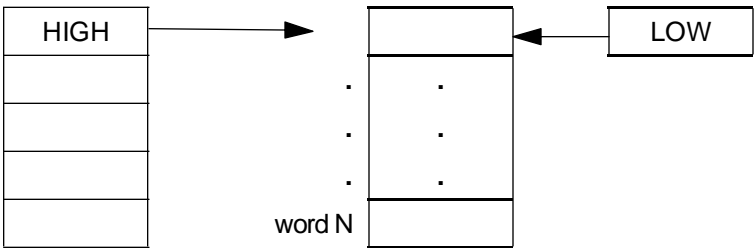
Attributes:



(3) Declaration:

normally mode is integer, dimension is 1  
the system has a ( HIGH, LOW )

Attributes:

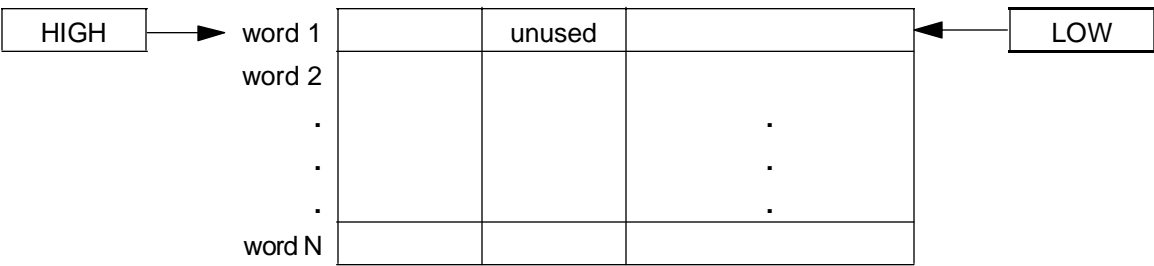


**HIGH** and **LOW** are synonyms. Both are pointers to the same attribute array. This is an array because the background dimensionality is set to 1.

(4) Declaration:

```
normally mode is integer, dimension is 1
the system has a ( HIGH(1/4), LOW(2/2) )
```

Attributes:



The elements of the attribute arrays are packed in the same locations as of a shared data array. The second quarter of each data word is unused.

Intrapacking is used to compress array storage of subscripted system attributes and attributes of permanent entities. The intrapacking notation **(\* / 2)** specifies that two distinct element values are to be packed in each storage location. That is, the array in which the elements are stored is compressed. For example, the declarations:

```
normally dimension is 1
the system has a LIST(* / 2)
```

and the statement **reserve LIST(\*)** as 10 specifies and allocates storage to **LIST** as shown in figure 6-11.

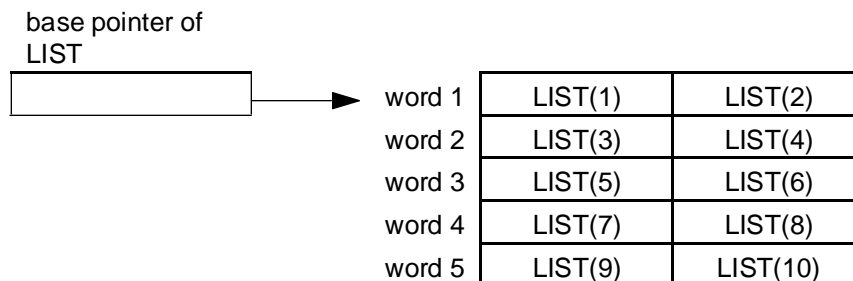


Figure 6-11. Array Storage

When a system attribute is multidimensional, packing takes place at the data-storage level only; the array pointer words are unpacked. Thus the statements:

```
normally dimension is 2
the system has a LIST(* / 2)
```

and

```
reserve LIST(*, *) as 3 by 4
```

specify and allocate storage to **LIST** as shown in figure 6-12.

As with field and bit packing, intrapacking specifications depend on computer implementation. Table 6-2 shows permissible intrapacking factors for common 32-bit wordlength machines. Other implementations have their permissible factors specified in the implementation manuals.

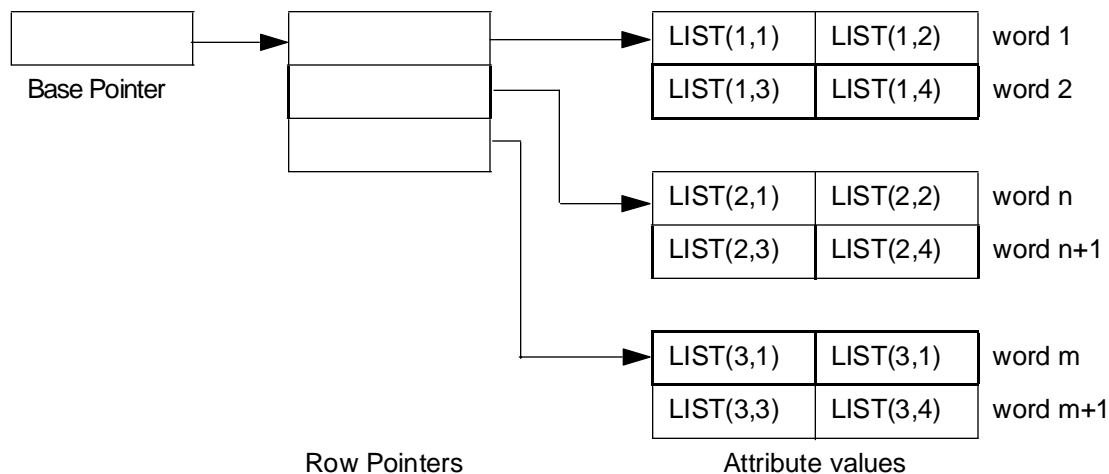


Figure 6-12. Array Storage

**Table 6-2. Intrapacking Factors for Common 32-Bit Machines**

Intrapacking Factor	Attribute Value Placement
(*/2)	2 values per word
(*/4)	4 values per word

Attributes are usually assigned locations within the entity structure in order of their appearance in an **every** statement, taking any explicit equivalencing and packing into account. It is also possible, however, to specify exactly where an attribute is to be placed within a temporary entity structure by following its declaration with the clause **in word *i***, where *i* is an integer constant, as in examples 1. and 2. below.

1. Declaration:

```
temporary entities
every PERSON owns a FAMILY, has an AGE in word 1,
and has a HEIGHT
```

Entity structure:

word 1	AGE
word 2	HEIGHT
word 3	F.FAMILY
word 4	L.FAMILY
word 5	N.FAMILY

It may be seen that **AGE** now occupies the first location.

2. Declaration:

```
every PERSON has an (AGE(1/4),SEX(2/4),HEIGHT(2/2))
in word 1 and a DEBT in word 2
```

Entity structure:

word 1	AGE	SEX	HEIGHT
word 2	DEBT		

This can provide a second method of equivalencing attributes: If two attributes are explicitly assigned to the same word number within an entity structure, they are equivalenced. Care should be taken that this is not done inadvertently. Some implementations insist that such equivalencing be recognized by enclosing the attribute names in parentheses, as is done when explicitly equivalencing an attribute group. In addition, there are certain restrictions on equivalencing attributes of different modes. In general, for example, **text** mode variables may not be equivalenced with other modes because of the way **text** is implemented through pointer values. Any inconsistent usage of these pointers could give rise to serious errors.

Attributes of permanent entities and system attributes are not assigned to words, but a similar effect is achieved by using the clause **in array i**, where *i* is an integer constant. This array may be thought of as comprising the structure of **the system** entity.

In certain implementations, such explicit assignment, either for temporary or permanent entities, may be recognized by the compilation process, leading to efficiencies at program execution time. It may also affect the requirements for independent compilation of the routines in a program. Consult the appropriate user manual for implementing specific details of packing and equivalencing. Obviously, the use of these features may give rise to problems if a program is to be transported across different systems.

The results of packing, equivalence, and word and array specification are shown in table 6-3.

**Table 6-3. Attribute Specifications**

Specification	Assignment
No packing, equivalence, or word or array specification	Attributes assigned to separate words or arrays in the order of their appearance in preamble
Word or array specification	Attributes are assigned to specified words or array locations. Remaining attributes assigned as above.
Equivalence specification	Specified attributes assigned to the same word or array
Packing specification	Field and bit packing used to place more than one attribute within a computer word  Intrapacking used to compress storage for arrays

The **every** statement optionally permits detailed specification of the attributes of an entity. The use of packing factors, equivalence parentheses, and **word** and **array** clauses gives a programmer a good deal of control over the allocation of computer storage.



## 6.5 Attribute Definitions: Functions

When defined by statements of the form:

```
the system has an attribute name function
every entity name has an attribute name function
```

a system attribute or an attribute of a permanent or temporary entity is treated as a function and not as a variable. Any reference to such a function attribute is in effect a reference to a function routine with the same name. That is, a subprogram having the same name as the declared attribute must be included as one of the program routines. The routine must have the same number of arguments as the declared or implied dimensionality of the attribute, that is, no arguments for an unsubscripted system attribute, one argument for a temporary or permanent entity, two arguments for a two-dimensional system attribute, etc.

Function attributes, because they are computational procedures, have no storage space allocated to them. Declarations of attributes as functions interspersed between other attribute declarations have no effect, therefore, on storage allocation of attributes to arrays or entity records. To illustrate:

Declaration:

```
every AUTO has a FUEL FUNCTION, a CONSUMPTION.RATE,
a FUEL.CAPACITY and a DEPARTURE.TIME
```

Entity structure:

word 1	CONSUMPTION.RATE
word 2	FUEL.CAPACITY
word 3	DEPARTURE.TIME

Assume the function attribute, **FUEL**, is defined by the following routine:

```
routine FUEL(AUTO)
return with FUEL.CAPACITY(AUTO) -
    (TIME - DEPARTURE.TIME(AUTO)) *
    CONSUMPTION.RATE(AUTO)
end
```

Assuming that the value of the current time is maintained in a global variable, **TIME**, the amount of fuel currently remaining in a particular auto is calculated at each apparent attribute reference of the type:

```
let AMOUNT = FUEL(AUTO)
```

As the variable **TIME** changes, the reported value of **FUEL(AUTO)** changes.

Function attributes have a number of uses: they can be used, as above, to determine values of continuously changing quantities; to perform complex calculations; to provide optional attributes, described in a later example, and to perform monitoring and other operations. For example:

Declaration:

```
every CONSUMER has a CREDIT.RATING FUNCTION,
    a BANK.BALANCE, a DEBT.TOTAL,
    a MORTGAGE.PAYMENT, a NUMBER.OF.DEPENDENTS
and a SALARY
```

Function attribute definition:

```
routine CREDIT.RATING(CONSUMER)
    if SALARY(CONSUMER) - MORTGAGE.PAYMENT(CONSUMER) ....
        or ...more conditions....
        return with 0
    otherwise
        return with 1
end
```

Program statement:

```
if CREDIT.RATING(CUSTOMER) eq 0
    call ACTION1 giving CUSTOMER
else
    .
    .
```

## 6.6 Compound Entities Involving Temporary Entities

Compound entities composed exclusively of temporary entities, or of mixtures of permanent and temporary entities, look the same as "permanent" compound entities but function differently. The difference lies in the fact that all attributes of "mixed" or "temporary" compound entities are functions. They have no storage allocated to them. They cannot be created or destroyed, as can (and indeed must) the entities of which they are composed. A routine must be written for each compound attribute (including any set pointers) of this type that accepts the attribute indices as arguments and returns a single value as the attribute value (which may be a set pointer). Thus, the declaration:

```
every JOB,MAN has an INFLUENCE FUNCTION
```

where **JOB** and **MAN** are temporary entities, defines **INFLUENCE** as a function having the background mode. This function can be further defined, as in:

```
define INFLUENCE as a real FUNCTION
```

if necessary. When a statement such as:

```
let T = TIME * INFLUENCE(JOB,MAN)
```

is executed, the routine **INFLUENCE** is called with the arguments **JOB** and **MAN** — two pointer values identifying temporary entities. The routine then might perform the following as:

```
function INFLUENCE(I,J)
define I and J as integer values
if PRIORITY(I) > PM
    and STATUS(J) > 5M
    return with (STATUS((J)/5M) * (PRIORITY(I)/PM))
otherwise
    return with 1
end
```

returning the apparent attribute value.

## 6.7 Two Illustrations of Set Ranking by Function Attributes

As described in paragraph 4.8, sets are normally ranked on either the order in which entities are filed in them (**FIFO** and **LIFO**) or on the values of some attributes of their member entities. In the latter case, although cascading can be used to resolve ties, only simple single-attribute ranking comparisons can be made. Complex ranking comparisons can be devised using function attributes as ranking variables. Program 6-1 illustrates how a function attribute can be used to define a ranking variable that is the weighted average of several attribute values.

**Program 6-1.**


---

```

preamble
  temporary entities
    every JOB has a LABOR.COST, a MATERIAL.COST,
      an OVERHEAD, a PROFIT, a RANKING FUNCTION
      and belongs to a QUEUE
  permanent entities
    every MACHINE owns a QUEUE
  define QUEUE as a set ranked by high RANKING
end

main
  read N.MACHINE
  create every MACHINE
  until data is ended
  do
    create a JOB
    read LABOR.COST.., MATERIAL.COST.., OVERHEAD.., PROFIT..
      and MACHINE..
    file JOB in QUEUE(MACHINE)
    .
    .
    remove JOB from QUEUE(MACHINE)
    .
    .
  loop
  .
end

routine RANKING given JOB
  define JOB as an integer variable
  return with (LABOR.COST..*2 + MATERIAL.COST..*3
    + OVERHEAD.. + PROFIT..*4) / 10.0
end

```

---

The preamble defines **RANKING** as a function attribute of **JOB** and as the attribute by which jobs are to be ranked when they are filed in a **QUEUE** set owned by some **MACHINE**. The routine **RANKING** provides a procedure for computing a ranking value. The routine is invoked each time a **JOB** is filed. It is used to compute a ranking value for the **JOB** being filed, and for all the jobs against which this job's ranking value must be compared in order to insert it properly.

A somewhat more complex use of a function attribute is found in Program 6-2, which uses an attribute of the first member of a set owned by an entity as the ranking value for that entity's filing in another set.

**Program 6-2.**


---

```

preamble
temporary entities
    every JOB has a VALUE, a RANKING.FUNCTION, owns a
        ROUTING, and belongs to a QUEUE
    every PATH has an ORIGIN, a DESTINATION, a DISTANCE,
        and belongs to a ROUTING
permanent entities
    every MACHINE owns a QUEUE
define QUEUE as a set ranked by high RANKING
define ROUTING as a set ranked by low DISTANCE
define RANKING as an integer function
end

routine RANKING(J)
define J as an integer variable
return with ORIGIN(F.ROUTING(J))
end

```

---

**6.8 Using “Optional” Attributes**

In certain situations involving the processing of large amounts of data, the programmer may need to define entities with a large number of attributes, many of which, however, are constant. For example, in census data records the code n/a (not applicable) may appear in several places. When it is desired to conserve the amount of space allocated to individual entity records, function attributes may be used to define "optional attributes." These are actually represented by entities stored in a special set only if their values differ from specified default values. Thus, in the following example, if the optional attribute **RAPID.TRANSIT** is other than zero for a particular city, a record for it will appear in that city's optional attribute set. Otherwise, the value of **RAPID.TRANSIT** would be found in the default list (**DEFAULT(1)=0**).

The following declarations and programs show how to set up and use optional attributes.

## Declarations:

```

preamble
temporary entities
    every CITY has a NAME, a POPULATION, a STATE,
        an OPTIONAL FUNCTION, and owns an OPTIONSET
    every OPTION has a VALUE and a CODE and
        belongs to some OPTIONSET
    define NAME and STATE as text variables
    define WHICH as a variable
    define DEFAULT as a 1-dimensional array
    .
    .
end

```

## Function attribute definition:

```

function OPTIONAL(J)
define OPT and J as integer variables
for each OPT in OPTIONSET(J),
    with CODE(OPT) = WHICH,
    find the first case
    if found,
        return with VALUE(OPT)
    otherwise
        return with DEFAULT(WHICH)
end

```

## Program initialization to set up optional attribute structure:

```

main
    .
    .
    read N
    reserve DEFAULT(*) as N
    read DEFAULT "LIST OF DEFAULT VALUES"
    .
    .
    create a CITY
    until mode is alpha,
    do
        create an OPTION
        read CODE and VALUE
        file OPTION in OPTIONSET
    loop
    .
    .
end

```

Program statements that employ optional attributes:

```
let WHICH = 1 ``INDICATING THE FIRST OPTIONAL ATTRIBUTE
let X = OPTIONAL(CITY)
```

If an entity **CITY** has an entity filed in its **OPTIONS** set with a **CODE** value of **1**, **X** is set to the **VALUE** of the entity. If an entity **CITY** has no such entity filed in **OPTIONS**, **X** is set to **DEFAULT(1)**.

The program can be made even more straightforward if functions are used to define the optional attributes themselves. If **RAPID.TRANSIT** is an optional attribute of **CITY**, it can be defined and used by the following statements:

```
define RAPID.TRANSIT as an integer function
routine RAPID.TRANSIT(CITY)
  define CITY as an integer variable
  let WHICH = 1
  return with OPTIONAL(CITY)
end
```

The diagram in figure 6-13 shows the record structures for a temporary entity of the type **CITY** that has several "normal attributes" and several "optional attributes."

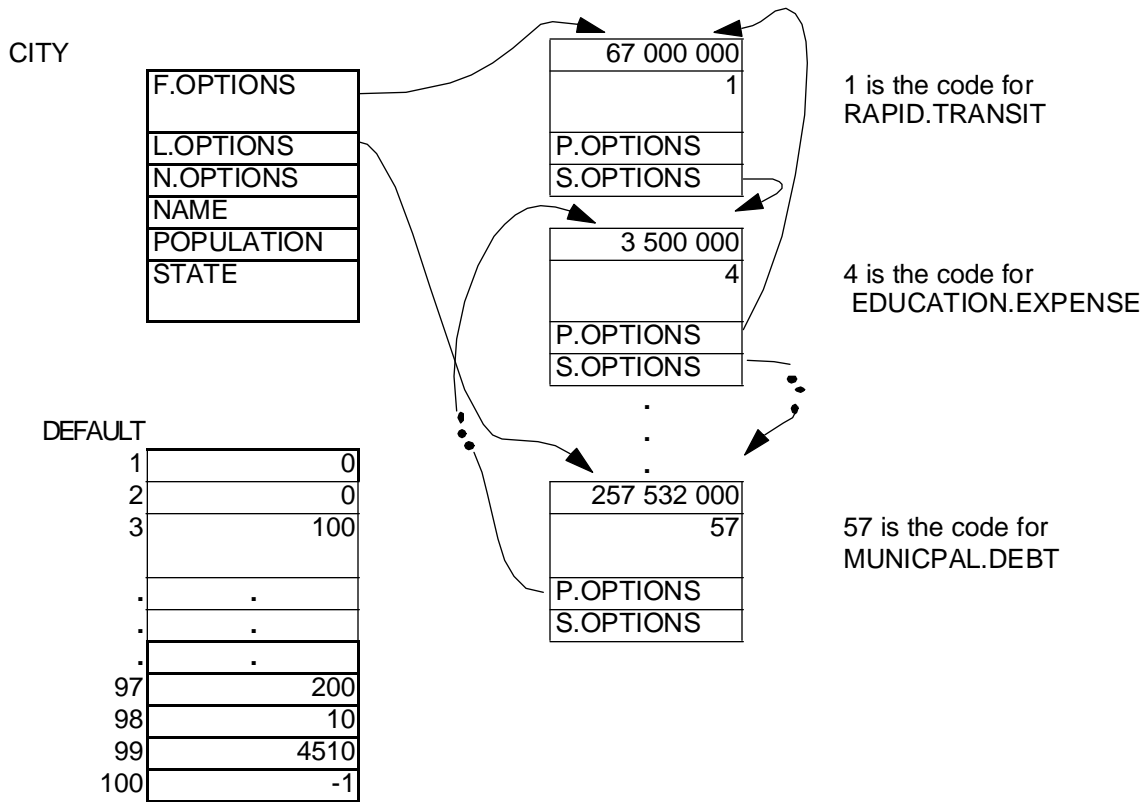


Figure 6-13. Record Structure

## 6.9 Deletion of Set Routines

Certain routines are automatically generated for each defined set during the processing of a program preamble. Sets declared as **FIFO** (explicitly or implicitly), **LIFO**, or **ranked** require different routines to perform their filing and removing operations. Each generated routine is tailored to individual program specifications reflecting such operations as set attribute deletions and cascaded set rankings.

The most generally defined set, an unranked one declared as either **FIFO** or **LIFO**, has seven routines generated for it. Four are for filing and three for removing. The routines are named and their functions stated in table 6-4.

**Table 6-4. Set Manipulation Routines**

Routine	Generated Name	Function
File first	<i>T.set</i>	Files an entity first or ranked
File last	<i>U.set</i>	Files an entity last
File before	<i>V.set</i>	Files an entity before a specified entity
File after	<i>W.set</i>	Files an entity after a specified entity
Remove first	<i>X.set</i>	Removes the first entity
Remove last	<i>Y.set</i>	Removes the last entity
Remove specific	<i>Z.set</i>	Removes a specified entity

A set declared by the statement:

```
define QUEUE as a FIFO set
```

thus has seven routines, **T.QUEUE**, **U.QUEUE**, ..., **Z.QUEUE** generated for it.

Ranked sets, by their definition, do not permit filing first, last, or before or after a specific entity without attention to the specified set ranking. Hence, ranked sets generate four routines, there being only one file routine.

In addition, certain set operations are impossible if specific set attributes are not present. For instance, "filing before" is impossible in a **LIFO** set if the predecessor attribute has been deleted.

Table 6-5 shows the set attributes that must be present for the indicated set operations to be performed. Because all set attributes are not required for all set operations, table 6-5 can be used to determine which attributes to delete in order to save memory space. For example, if a program only files and removes first, the set attributes **L** and **P** can be deleted without penalty. If they are not deleted, the generated programs keep track of and update them anyway.



The generation of specific set routines can also be suppressed to conserve memory space when their associated operations are not used in a program. To do so, a list of the set operation codes, shown in table 6-5, is attached to a **define set** statement in the following form:

```
,without set operation code list routines
```

The comma is optional. A typical program might contain the statement:

```
define QUEUE as a FIFO set without P and N
  attributes and without FB, FA and RS routines
```

**Table 6-5. Set Operation-Set Attribute Relationships**

Set Operation Mnemonic	Set Name Prefix	Required Set Attribute
FF	T.	F,S
FL	U.	F,L,S
FB	V.	F,S,P
FA	W.	F,S
RF	X.	F,S
RL	Y.	F,L,S,P
RS	Z.	F,S,P

In unusual cases, where the programmer wants to use set-type statements but wants to provide his own set operation routines, all seven routines can be deleted. The codes **F** and **R** delete the four file and three remove routines, respectively. A complete range of set specifications is thus possible. Mere mention of a set name in **every** statements calls for all three set attributes for the owner and member entities and all seven set routines. Additional definition in a **define set** statement can selectively delete set attributes and set routines. The extreme statement:

```
define set as a set without F,L,P,S,M and N
  attributes without F and R routines
```

removes all mechanisms that make set operations possible.

## 6.10 Left-Handed Functions

Functions are normally used in a "right-handed" manner. That is, they are referenced as on the right-hand side of an assignment operator, where they return a single value computed from a number of given arguments. An example of a right-handed SIMSCRIPT II.5 function is the use of

**substr.f** to provide a copy of an embedded character string from a specified position within a source **text** string.

Defining a function as "left-handed" indicates that it receives a value, rather than computing one. SIMSCRIPT II.5 also allows the function **substr.f** to be used in a left-handed manner. The statement:

```
let substr.f(String,1,3) = "ABC"
```

replaces the first three character positions in the **text** variable **String**. The **substr.f** function appears to receive, rather than return, a value.

Any function can be defined to be used in both a right- and a left-handed manner. To compute a value, the right-handed version of the function is called. When a reference is made in a left-handed manner, that is, to store a value, the left-handed version is called.

No new concepts or statements are involved in the definition of right-handed functions, for all the functions dealt with thus far have been right-handed. All of the by-now-familiar declarative forms:

```
function name given argument
function name (argument list)
```

indicate that the statements that follow, up to the statement **end**, define a computational process, hence, a right-handed function. In programs that use both right-and left-handed functions, the word **right** may be put before **function**, but this is optional.

A left-handed function is headed by one of the forms of the **routine** statement shown above, preceded by the word **left**, as in:

```
left function ACCESS given I and J
```

and

```
left function ALLOCATE
```

In addition to the usual mechanism for transmitting input argument values to a function when it is called, a left-handed function must have a way of receiving a right-hand-side value. A special statement of the form:

```
enter with variable
```

must be the first executable statement in every left-handed function. It specifies that the value "computed on the right" and thus transmitted to the left-handed function is to be stored in the named variable, which can be local or global, unsubscripted, subscripted, or an attribute, for use within the function. From there on, a left-handed function functions exactly like any other function. It can store the value, perform computations with it, execute input-output statements, etc. Program 6-3 illustrates the definition and use of right- and left-handed functions.

The computations within the **main** routine seem to deal with simple subscripted variables. In fact, the surrounding functions and the preamble declarations define the data structures dealt with. In this sense, the program is independent of the structure used for storing and analyzing its data.

### Program 6-3.

---

```

preamble
  the system owns the DATASET
  temporary entities
    every SAMPLE has a VALUE,
    and belongs to the DATASET
  define X as a real function
  define VALUE as a real function
end

main
  read N
    for I = 1 to N,
      read X(I)
    for I = 1 to N-1,
      with X(I) less than 2 * X(I+1)
        compute M = avg, V = variance, K = number of X(I)**2
      list K,M,V
    stop
end

right function X(I)
  define I,J,S as integer variables
  if I greater than N.DATASET
    print 1 line with I thus
    MEMBER *** OF COLLECTION X DOES NOT EXIST
    stop
  otherwise
    let S = F.DATASET
    for J = 1 to I-1,
      let S = S.DATASET(S)
    return with VALUE(S)
end

left function X(I)
  define I,J,S as integer variables
  define A as a real variable
  enter with A
  if N.DATASET less than I-1,
    print 1 line with I,N.DATASET thus
    TRYING TO CHANGE THE ***TH OF ONLY *** VALUES
    stop
  otherwise

```

```

    if I eq N.DATASET+1
        create a SAMPLE called S
        file S last in DATASET
    else
        let S = F.DATASET
        for J = 1 to I-1,
            let S = S.DATASET(S)
    always
        let VALUE(S) = A
    return
end

```

---

### 6.11 Monitored Variables

Thus far, program names representing data values have had either memory locations or routines associated with them. Names defined as variables referred to values stored in computer words. Names defined as functions referred to values computed or stored by associated programs.

A new data type, a monitored variable, has both a storage location and a function routine associated with it. The statements required to define and use monitored variables parallel the statements required to define variables and functions and to implement left-handed functions.

Any variable, array, or attribute is defined as monitored by a statement of the form:

```
define name as a variable monitored on the left
```

or

```
define name as a variable monitored on the right
```

or

```
define name as a variable monitored on the right and left
```

The word **the** before **right** and **left** is optional.

Because monitored variables have data values as well as routines associated with them, mode and dimensionality declarations can also be included, as in:

```
define X as a real, 2-dimensional array monitored
    on left and right
```

Monitoring on the right and on the left is obtained through function routines similar to right- and left-handed functions. If a variable is declared as monitored on the right (or left), a right-handed (or left-handed) monitoring routine must be provided. A routine is able to perform a monitoring function by the inclusion of one new executable statement. The statement differs, depending on whether the routine is right- or left-handed.

The task of a right-handed function routine is to return a data value to a calling program. A typical right-handed function (not performing a monitoring task) is:

```
function EXAMPLE(I,J)
.
.
statements using I and J
.
.
return with expression
end
```

The function name (**EXAMPLE**) represents a subprogram name. The argument list transmits initial values for **I** and **J** from a calling program to **EXAMPLE**, and the **return with** statement returns a computed value to the calling program.

If **EXAMPLE** is declared as a monitored variable, its name refers to both data and a monitoring routine. **EXAMPLE(K,5)** is both a legitimate subscripted variable reference and a call on a routine with arguments **K** and **5**. The additional statement needed to convert a normal right-handed routine to a right-handed monitoring routine fetches the data value associated with the monitored variable name, and makes it accessible to a named variable within the routine. The statement is:

```
move to variable
```

The program:

```
function EXAMPLE(I,J)
  move to Q
.
.
statements using I,J, and Q
.
.
return with expression
end
```

starts out by assigning the value of **EXAMPLE(I,J)** to **Q**, which then can be used freely in the routine. The **move** statement variable can be local or global, unsubscripted or subscripted, an attribute, or even a left-handed function.

Except for defining **EXAMPLE** as being monitored, no other change is made in the rest of the program. **EXAMPLE** is reserved and used in the normal way; all data references are to **EXAMPLE(I,J)**, as though it were a simple subscripted variable.

Used for left-handed monitoring, the **move** statement must assign a value to the data cell associated with a monitored variable. The statement that does this is of the form:

```
move from arithmetic expression
```

The value of the arithmetic expression is stored in the variable referenced by the routine name and its arguments, if any. For example, **EXAMPLE(I,J)**. The form of a typical left-handed monitoring routine is:

```
left function EXAMPLE(I,J)
  enter with Q
  .
  .
  statements using I,Q
  .
  .
  move from expression
end
```

A value is transmitted to the function by the **enter** statement, computations are performed, and a value is assigned to the monitored variable by the **move** statement.

The following short programs use monitored variables in several different ways for data editing, where the monitored variable feature provides two important benefits: (1) It keeps the main body of the program clear of data-checking and message printing statements, making it easier to understand; and (2) Conversion of the program to remove the editing feature can be accomplished by changing only one preamble statement and discarding two routines, with the main body of the program text unchanged. However, the program must be recompiled.

This program first reads successive sets of data representing subscript values for a two-dimensional array and the associated data value. The subscripts are checked by the left-monitoring routine before values are assigned. Default values are computed for any unassigned values. The initialization data are delimited by a single non-numeric field, and followed by query data, requesting the value identified by two given subscripts. These subscripts are also checked, this time by the right-monitoring routine.

**Program 6-4.**


---

```

preamble
  normally, mode is integer
  define DATA as a real, 2-dimensional array
    monitored on the right and the left
  define M and N as variables
end

main
  read N and M 'THE ARRAY BOUNDS
  reserve DATA(*) as N by M 'RESERVE THE ARRAY
  until mode is alpha,
    read I,J,DATA(I,J)
  for I = 1 to N,
    for J = 1 to M
      do      'ASSIGN DEFAULT VALUES
        if DATA(I,J) eq 0
          if J greater than I
            let DATA(I,J) = 1
          else
            let DATA(I,J) = -1
          always
        always
      loop
    skip one field 'THE ALPHA DELIMITER
  until mode is alpha
  do
    read I,J
    print 1 line with I,J,DATA(I,J) like this
    THE VALUE OF DATA(**,**) IS ****.**
  loop
  stop
end

function DATA(L,K)
  define VALUE as a real variable
  'THE FETCHING OF THE VALUE DATA(L,K) IS INHIBITED
  'UNTIL THE SUBSCRIPTS ARE VERIFIED
  if L less than 1
    or L greater than N
    or K less than 1
    or K greater than M
    print 1 line with L,K thus
    INVALID SUBSCRIPTS *** AND ***
    stop
  otherwise
    move to VALUE 'THE VALUE OF DATA(L,K) IS FETCHED
    return with VALUE
end

```

```
left routine DATA(L,K)
  define VALUE as a real variable
  enter with VALUE
  ''DON'T CHANGE THE VALUE OF DATA(L,K)
  ''IF SUBSCRIPTS ARE OUT OF BOUNDS
  if L less than 1
    or L greater than N
    or K less than 1
    or K greater than M
    print 1 line with L,K thus
  INVALID SUBSCRIPTS *** AND ***
  else
    move from VALUE''TO DATA(L,K)
  always
  return
end
```

---

### 2. Monitored variables used for data transformation:

#### **Program 6-5.**

---

```
preamble
  permanent entities
    every SERIES owns a GRAPH
  temporary entities
    every SAMPLE has an XVAL and a YVAL
    and belongs to a GRAPH
  define XVAL and YVAL as real variables
    monitored on the right
  define GRAPH as a set ranked by high YVAL,
    without M attribute,
    without FB,FA,FL and RS routines
  normally, mode is integer
end
```



```

main
  read N.SERIES
  create every SERIES
  for each SERIES,
  do
    read N
    also for I = 1 to N
    do
      create a SAMPLE
      read XVAL and YVAL
      file SAMPLE in GRAPH
    loop
  for each SERIES,
  call PLOT.GRAPH
stop
end

routine PLOT.GRAPH
  'ASSUME XVAL BETWEEN 0 AND 132
  'ASSUME YVAL BETWEEN 0 AND LINES.V-4
  start new page
  print 1 line with SERIES as follows
  PLOT OF SERIES NUMBER **
  for each I in GRAPH
    compute X as the maximum of XVAL(I)
  print 2 lines with X, YVAL(F.GRAPH) thus
  X RANGE IS 0 TO ***.*
  Y RANGE IS 0 TO **.*
  skip 1 output line
  for each I in GRAPH
  do
    if I ne F.GRAPH
      skip trunc.f(YVAL(I)) - trunc.f(YVAL(P.GRAPH(I)))
      output lines
    always
      write as B TRUNC.F(XVAL(I))+1,"*"
  loop
  return
end

'MONITOR ROUTINES CONVERT DATA VALUES BEFORE THEY ARE PLOTTED
'CONVERSION IS OUTSIDE THE PLOTTING ROUTINE
function XVAL(I)
  define V as a real variable
  move to V
  return with log.e.f(V) 'FOR EXAMPLE
end

function YVAL(I)
  define V as a real variable

```

```

    move to V
    return with V**2''FOR EXAMPLE
end

```

---

The monitoring routines deliver transformed values of the attributes to the plotting routine without changing their values in memory. As there are no left-handed monitoring routines, **XVAL** and **YVAL** are stored as they are read. To change the transformations, only the monitoring routines need be altered. **main** and **PLOT.GRAPH** stay the same.

## 6.12 Implementation Details for the TALLY Statement

The program preamble generates any required attributes and routines for each **tally** statement. A left-handed monitoring routine is always generated for each tallied variable. The number of generated attributes and other routines varies with the statistical quantities specified. Table 6-6 presents the cases in which additional routines and attributes are generated.

**Table 6-6. Tally Actions**

Statistical Quantity	Tally Action
number	Uses name in <b>tally</b> list. Attribute generated if <b>mean</b> , <b>variance</b> , <b>std.dev</b> , <b>mean.square</b> , <b>minimum</b> or <b>maximum</b> requested and <b>number</b> not requested.
sum	Uses name in <b>tally</b> list. Attribute generated if <b>mean</b> , <b>variance</b> or <b>std.dev</b> requested and <b>sum</b> not requested.
mean	<b>Function</b> with name in <b>tally</b> list generated.
sum.of.squares	Uses name in <b>tally</b> list. Attribute generated if <b>mean.square</b> , <b>variance</b> or <b>std.dev</b> requested and <b>sum.of.squares</b> not requested.
mean.square	Function with name in <b>tally</b> list generated.
variance	Function with name in <b>tally</b> list generated.
std.dev	Function with name in <b>tally</b> list generated.
maximum	Uses name in <b>tally</b> list.
mimimum	Uses name in <b>tally</b> list.

From these examples it can be seen that certain counters, defined as variables or as attributes, are required for the statistical computations. These counters are listed in table 6-7.

**Table 6-7. Counters Required for Tally Statements**

Statistic	Counters
number	$N$ , the number of samples
sum	$SX_i$ , the sum of sample values
sum.of.squares	$SX^2$ , the sum of squares of the sample values
mean	$SX_i$ , $N$
variance	$SX_i$ , $SX^2$ , $N$
std.dev	$SX_i$ , $SX^2$ , $N$
maximum	$M$ , the value of the largest sample and $N$
minimum	$M$ , the value of the smallest sample and $N$



# Appendix A. Format Conventions Used In Print Statements

---

## Value & Typical Formats

## Display Results

## Examples

### Integer

- |           |  |   |
|-----------|--|---|
| *         | (a) Print an integer value.  | Print 1 line with J thus<br>The value of J is***  |
| **<br>*** | (b) If the expression is not integer-valued, print a rounded integer value by adding + or - 0.5 to the value of the expression, depending on its sign, and truncating the result.                          | prints, for j = 3<br>The value of J is 3<br><br>or prints, for J = 9.7<br>The value of J is 10<br><br>or prints, for J = -97.6<br>The value of J is -98 |
|           | (c) Print as many digits as possible to the left, upto the next nonconsecutive * or textual character, treating the rightmost as the low-order position; if space not sufficient, use scientific notation. |   |
|           | (d) Only the position of the rightmost digit must be shown.  |   |

### Decimal

- |     |                            |   |
|-----|----------------------------|---|
| *.* | (a) Print a decimal value; | Print 1 line with X thus<br><br>The value of X is *.* |
|-----|----------------------------|---|

## Value & Typical Formats

## Display Results

## Examples

`**.*`

- (b) Treat the integer part as  
(c) and (d) above;

prints the line

The value of X is 3.25

`*.**`

`**.**`

`***.`

`.**`

- (c) Round the decimal part to the number of digits specified by asterisks to the right of the decimal point. An expression is rounded in the  $n^{\text{th}}$  decimal place by adding  $0.5 \times 10^{-n}$  and truncating at the  $n^{\text{th}}$  decimal place.

if  $x = 3.4545$ ; the conversion for printing is  $3.2495 + 0.005 = 3.245 \Rightarrow 3.25$ . The value of x, as stored in the computer is unchanged.

- (d) If trailing decimal digits are zero, print them.

If the format is `*.***`, 3.5 prints as 3.500

- (e) Print a rounded integer between 0 and 1

3.257 prints as 3. in the format `**.`

- (f) Print a fractional value between 0 and 1

**Frac.f**(3.257) prints as.257 in the format `.***`

## **Scientific**

`.....`

- (a) Print a number in the form decimal number E+XX

Using the format `.....`

the value 3726.257 is printed as 3.7E+03

at least 8 consecutive periods

- (b) the value of the computed expression is decimal number `*10**+XX`;

Using format `.....`

it would be printed as 3.7263E+03

- (c)  $0 \leq |\text{decimal number}| < 10$

<u>Value &amp; Typical Formats</u>	<u>Display Results</u>	<u>Examples</u>
<b>Text</b>		
*	(a) Print a text value	If <b>NAME</b> has the value <b>"JOHN"</b> ,
*****	(b) Print text characters, left-justified, up to the number of print positions.	Print 1 line with NAME thus  PUPIL'S NAME IS *****
	(c) If the value has fewer characters, complete the field with blanks.	prints: <b>PUPIL'S NAME IS JOHN</b>
<b>Alpha</b>		
*	(a) Print an alpha value, left-justified in the field.	If <b>CODE</b> has the value <b>"K"</b> ,  Print 1 line with CODE thus DESTINATION CODE IS **
****	(b) If the alpha variable represents more than one character, print as many as are indicated, using blanks to complete the field as required.	prints:  DESTINATION CODE IS K





## Appendix B. Functions and Routines

---

### B.1 Functions

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>abs.f</b>	e	Mode of e	Returns the absolute value of the expression.
<b>and.f</b>	$e_1, e_2$	Integer	Logical product of $e_1$ and $e_2$ .
<b>arccos.f</b>	e	Real	Computes the arc cosine of a real expression; $-1 > e > 1$ .
<b>arcsin.f</b>	e	Real	Computes the arc sine of a real expression, $-1 > e > 1$ .
<b>arctan.f</b>	$e_1, e_2$	Real	Computes the arc tangent of $e_1/e_2$ ; $(e_1, e_2) \neq (0,0)$ .
<b>atot.f</b>	e	Text	Converts an <b>alpha</b> expression to a <b>text</b> value.
<b>beta.f</b>	$e_1, e_2, e_3$	Real	Returns a random sample from a beta distribution. $e_1 = \text{power of } x, \text{ real}$ $e_2 = \text{power of } (1-x), \text{ real; } e_1 > 0$ $e_3 = \text{random number stream, integer}$

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>binomial.f</b>	$e_1, e_2, e_3$	Integer	<p>Returns a random sample from a binomial distribution.</p> <p><math>e_1</math> = number of trials, integer</p> <p><math>e_2</math> = probability of success, real</p> <p><math>e_3</math> = random number stream, integer</p>
<b>concat.f</b>	a,b...	Text	<p>Concatenates any number of <b>text</b> strings to produce a single <b>text</b> string.</p>
<b>cos.f</b>	e	Real	<p>Computes the cosine of a real expression given in radians.</p>
<b>date.f</b>	$e_1, e_2, e_3$	Real	<p>Converts a calendar date to cumulative simulation time, based on values given to <b>origin.r</b>.</p> <p><math>e_1</math> = month, integer</p> <p><math>e_2</math> = day, integer</p> <p><math>e_3</math> = year, integer</p>
<b>day.f</b>	e	Integer	<p>Converts simulation time to the day portion based on values given to <b>origin.r</b>.</p> <p>e = cumulative simulation time, real</p>
<b>dim.f</b>	$v(*)$	Integer	<p>Returns the number of elements pointed to by the pointer variable v, in the dimension of the array v.</p>

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>div.f</b>	$e_1, e_2$	Integer	Returns the truncated value of $(e_1/e_2)$ .  $e_1$ = dividend, integer  $e_2$ = divisor, integer;  $e \neq 0$
<b>efield.f</b>	none	Integer	Returns the ending column of the next data field to be read by a <b>read</b> free-form statement. May affect file position.
<b>erlang.f</b>	$e_1, e_2, e_3$	Real	Returns a sample value from an Erlang distribution.  $e_1$ = mean, real  $e_2$ = k, integer  $e_3$ = random number stream, integer
<b>exp.f</b>	e	Real	Computes <b>exp.c</b> to the $e^{\text{th}}$ power; e must be real.
<b>exponential.f</b>	$e_1, e_2$	Real	Returns a random sample from an exponential distribution.  $e_1$ = mean, real  $e_2$ = random number stream, integer
<b>fixed.f</b>	s,e	Text	Expands or truncates a <b>text</b> string to a given length.  s = string, text  e = length, integer
<b>frac.f</b>	e	Real	Returns the fractional portion of a real expression.

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>gamma.f</b>	$e_1, e_2, e_3$	Real	Returns a random sample from a gamma distribution.  $e_1$ = mean, real  $e_2$ = k, real  $e_3$ = random number stream, integer
<b>hour.f</b>	e	Integer	Converts event time to the hour portion.  e = cumulative event time, real
<b>int.f</b>	e	Integer	Returns the rounded integer portion of a real expression.
<b>istep.f</b>	v,e	Integer	Returns a random sample from a look-up table without interpolation.  v = variable that points to the look-up table.  e = random number stream, integer
<b>itoa.f</b>	e	Alpha	Converts an integer expression to an alphanumeric value (one digit only).
<b>itot.f</b>	e	Text	Converts an integer expression to a <b>text</b> value.
<b>length.f</b>	a	Integer	Returns the length of a <b>text</b> variable in characters.
<b>lin.f</b>	v,e	Real	Returns a random sample from a look-up table, using linear interpolation.  v = variable that points to the look-up table  e = random number stream, integer

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>line.f</b>	$e$	Integer	Yields the line number currently being executed.  $e$ = process notice pointer
<b>log.e.f</b>	$e$	Real	Computes the natural logarithm of a real expression; $e > 0$ .
<b>log.normal.f</b>	$e_1, e_2, e_3$	Real	Returns a random sample from a log normal distribution.  $e_1$ = mean, real  $e_2$ = standard deviation  $e_3$ = random number stream, integer
<b>log.10.f</b>	$e$	Real	Computes log of a real expression.
<b>lor.f</b>	$e_1, e_2$	Integer	Logical sum of $e_1$ and $e_2$ .
<b>lower.f</b>	$s$	Text	Converts letters in a <b>text</b> string to lower case.
<b>match.f</b>	$s_1, s_2, e$	Integer	Returns the location of a text substring with a <b>text</b> string or 0 if not found.  $s_1$ = source, text  $s_2$ = pattern to be matched, text  $e$ = number of characters of source to be skipped, integer
<b>max.f</b>	$e_1, e_2, \dots, e_n$	Real if any $e$ ;	Returns the value of the largest $e_i$ . real; if none, integer

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>min.f</b>	$e_1, e_2, \dots, e_n$	Real if any	Returns the value of smallest $e_i$ . $e_i$ ; real; if none, integer
<b>minute.f</b>	$e$	Integer	Converts event time to the minute portion.  $e$ = cumulative event time, real
<b>mod.f</b>	$e_1, e_2$	Real if either $e_i$ ;  real; if none,  integer	Computes a remainder as real; if none, integer  $e = \text{trunc.f } (e_1 / e_2) * e_2$ ;  $e_2 \neq 0$ .
<b>month.f</b>	$e$	Integer	Converts simulation time to month portion based on values given to <b>origin.r</b> .  $e$ = cumulative simulation time, real
<b>nday.f</b>	$e$	Integer	Converts event time to the day portion.  $e$ = cumulative event time, real
<b>normal.f</b>	$e_1, e_2, e_3$	Real	Returns a random sample from a normal distribution.  $e_1$ = mean, real  $e_2$ = standard deviation, real  $e_3$ = random number stream, integer
<b>out.f</b>	$e$	Alpha	Sets or returns the $e^{\text{th}}$ alphabetic character in the current output buffer; $e$ must yield an integer value; $e > 0$ ; both right and left-handed function.

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>poisson.f</b>	$e_1, e_2$	Integer	Returns a random sample from a Poisson distribution.  $e_1$ = mean, real  $e_2$ = random number stream, integer
<b>randi.f</b>	$e_1, e_2, e_3$	Integer	Returns a random sample uniformly distributed between a range of values.  $e_1$ = beginning value, integer  $e_2$ = ending value, integer  $e_3$ = random number stream, integer
<b>random.f</b>	$e$	Real	Returns a pseudorandom number between zero and one.  $e$ = random number stream, integer
<b>real.f</b>	$e$	Real	Converts an integer expression to a real value.
<b>repeat.f</b>	$s, e$	Text	Repeats a string $e$ times.  $s$ = string, text  $e$ = integer
<b>rstep.f</b>	$v, e$	Real	Returns a random sample from a look-up table.  $v$ = variable that points to the look-up table  $e$ = random number stream, integer
<b>sfield.f</b>	none	Integer	Returns the starting column of the next data field to be read by a <b>read</b> free-form statement. May affect file position.

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>shl.f</b>	$e_1, e_2$	Integer	Shift $e_1$ left $e_2$ positions. Vacated positions are filled with zeros.
<b>shr.f</b>	$e_1, e_2$	Integer	Shift $e_1$ right $e_2$ positions. Vacated positions are filled with zeros.
<b>sign.f</b>	$e$	Integer	Indicates the sign of a real expression.  1 if $e > 0$  0 if $e = 0$  -1 if $e < 0$
<b>sin.f</b>	$e$	Real	Computes the sine of a real expression given in radians.
<b>sqrt.f</b>	$e$	Real	Computes the square root of a real expression; $e > 0$ .
<b>substr.f</b>	$s, e_1, e_2$	Text	Sets or returns a substring of a text value; both a left-handed and right-handed function. In the left-handed usage, $s$ must be an unmonitored variable.  $s$ = string, text  $e_1$ = position, integer  $e_2$ = length, integer
<b>tan.f</b>	$e$	Real	Computes the tangent of a real expression given in radians.



Function		Function	
<u>Mnemonic</u>	<u>Arguments</u>	<u>Mode</u>	<u>Description</u>
<b>trang.f</b>	$e_1, e_2, e_3, e_4$	Real	<p>Returns a value from a triangular distribution.</p> <p><math>e_1</math> = distribution minimum, real</p> <p><math>e_2</math> = mean of distribution, real</p> <p><math>e_3</math> = distribution maximum, real</p> <p><math>e_4</math> = random number stream, integer</p>
<b>trim.f</b>	s,e	Text	<p>Trims leading and/or trailing blanks from a string.</p> <p>s = string, text</p> <p>e = flag, where</p> <p>-1 = trim leading blanks</p> <p>0 = trim leading and trailing blanks</p> <p>+1 = trim trailing blanks</p>
<b>trunc.f</b>	e	Integer	<p>Returns the truncated integer value of a real expression.</p>
<b>ttoa.f</b>	e	Alpha	<p>Converts first character of text expression to alpha.</p>
<b>uniform.f</b>	$e_1, e_2, e_3$	Real	<p>Returns a uniformly distributed random sample between a range of values.</p> <p><math>e_1</math> = beginning value, real</p> <p><math>e_2</math> = ending value, real</p> <p><math>e_3</math> = random number stream, integer</p>
<b>upper.f</b>	s	Text	<p>Converts letters in a text string to upper-case.</p>

Function <u>Mnemonic</u>	<u>Arguments</u>	Function <u>Mode</u>	<u>Description</u>
<b>weekday.f</b>	e	Integer	Converts event time to the weekday portion.  e = cumulative event time, real
<b>weibull.f</b>	$e_1, e_2, e_3$	Real	Returns a sample value from a Weibull distribution.  $e_1$ = scale parameter, real  $e_2$ = shape parameter, real  $e_3$ = random number stream, integer
<b>xor.f</b>	$e_1, e_2$	Integer	Logical difference of $e_1$ and $e_2$ .
<b>year.f</b>	e	Integer	Converts simulation time to the year portion based on values given to <b>origin.r</b> .  e = cumulative simulation time, real

## B.2 Routines

Routine <u>Mnemonic</u>	<u>Arguments</u>	<u>Description</u>
<b>date.r</b>	d,t	<p>Returns the current date and time in <b>text</b> mode. Format of the returned value is system-dependent.</p> <p>d = date, text</p> <p>t = time, text</p>
<b>origin.r</b>	m,d,y	<p>Establishes an origin time when the calendar format is used.</p> <p>m = month, integer</p> <p>d = day, integer</p> <p>y = year, integer</p>
<b>snap.r</b>	none	User-supplied routine called when an execution error is detected.
<b>time.r</b>	none	Controls simulation timing and selects events.



# Appendix C. SIMSCRIPT Reference Syntax

---

## C.1 Basic Constructs

The notation employed in describing SIMSCRIPT II.5 is an improved version of conventions used in several computer programming language descriptions. In the following pages:

1. Words in lower case **bold** letters denote required statement keywords, as well as optional words or phrases used either for clarity or used as an optional feature.
2. Primitives are shown in lower case *italics* and denote words for which values must be supplied, unless denoted as optional.
3. Metavariables, such as expressions, selection clauses (defined below), etc., are shown in lower case *italics* also. Again, actual expressions must be supplied.
4. A statement is a combination of keywords, primitives, and metavariables that follow a certain pattern called the syntax of the statement.
5. Brackets [ ] and braces { } denote choices. When brackets appear, a choice may be made from the options indicated. When braces appear, a choice must be made. The items available for selection appear within the brackets or braces separated from one another by a vertical bar |. When the choice can be repeated, a symbol (or symbols) that must separate the items in that list of choices is written immediately after the right-hand brace or bracket enclosed in angles. For example:

$$\{ A \mid B \} < , >$$

represents a sequence of any number of As and Bs separated by commas. For example,

$$A, A, B, A, B$$

whereas:

$$\{ A \} < , >$$

is equivalent to:

$$A [ , A ] [ , A ] \dots [ , A ]$$

6. The null separator  $< >$  is used to indicate that no symbol need separate the items in a list. An example of  $\{ A \mid B \} < >$  might be AABAB...A. The choice represented by  $\{ A \} < >$  is equivalent to  $A [ A ] [ A ] \dots [ A ]$ .
7. A list separator symbol can itself be complex, involving choices and repetitions, as in  $\{ A \mid B \} < \text{AND} \mid \text{OR} >$ . An instance might be:

$$A \text{ AND } B \text{ OR } B \text{ OR } A$$

8. Plural keywords ending in S such as **variables** or **lines**, can be written in singular form as **variable** or **line** when called for by the grammar of a statement.

## C.2 Primitives

**Integer:** Sequence of digits delimited by blanks, special characters, or an end of record.

**Name:** Any sequence of letters and digits containing at least one letter and delimited by blanks, special characters, or an end of record.

**Special names:** The syntax of special names is the same as name. However, each special name is required in the context specified.

Each of the following names must be defined in the program preamble before use in other contexts:

attribute name

event name

permanent entity name

process name

qualifier name

resource name

set name

temporary entity name

Routine name, while not necessarily defined in the preamble, must correspond to a user-defined routine.

**Word:**{ integer

| name

| number

| special character

| string

}

Words must be separated from each other by one or more blanks unless one of them is a special character. Periods (.) are ignored between words and at the end of statements.

Comments can be inserted between any two words in a program by enclosing them in quotation marks (") formed by two consecutive apostrophes. The right-hand set of quotes is not necessary if the comment is the last item on the line.

### C.3 Metavariables

In order to compress the syntax description of the statements, several commonly repeated expressions, or metavariables, are defined here rather than at each permissible usage.

arithmetic expression: = [ + | - ] { ( *expression* )

| *number*

| *subprogram constant*

| *string constant*

| [ \$ ] *variable*

} < + | - | \* | / | \*\* >

array reference: = ( [ *expression* ] < , > { \* } < , > )

comma: = { , | **and** | , **and** }

**for** phrase:

**for** { *name* { **back from** | = } *expression* **to** *expression* [ **by** *expression* ]

| { **each** | **all** | **every** }

{ *permanent entity name* | *resource name* [ **called** *variable* ]

| *name* [ { **from** | **after** } *expression* ]

{ **of** | **in** | **on** | **at** } *set name* [ *subscript* ]

[ **in reverse order** ]

}

}

} [ , ] [ *selection clause* | *termination clause* ] < >

format:

$\text{format}_1 = \{ B \text{ expression} \mid S \text{ expression} \mid / \}$

$\text{format}_2 = \{ \text{format}_1, \mid \text{integer A expression}$   
 $\mid \text{integer C expression}$   
 $\mid \text{integer I expression}$   
 $\mid \text{integer D ( expression, expression )}$   
 $\mid \text{integer E ( expression, expression )}$   
 $\mid \text{integer T expression} \mid \text{integer T}^*$   
 $\}$

logical expression:

$\{ \{ ( \text{logical expression} )$   
 $\mid \text{expression} \{ [ \text{is} ] \text{relational operator expression} \} < >$   
 $\mid \text{expression} [ \text{is} ] [ \text{not} ] \{ \text{positive} \mid \text{negative} \mid \text{zero} \}$   
 $\mid \text{mode} [ \text{is} ] [ \text{not} ] \{ \text{real} \mid \text{integer} \mid \text{alpha} \mid \text{text} \}$   
 $\mid \text{data} [ \text{is} ] [ \text{not} ] \text{ended}$   
 $\mid \text{card} [ \text{is} ] [ \text{not} ] \text{new}$   
 $\mid \text{page} [ \text{is} ] [ \text{not} ] \text{first}$   
 $\mid [ \text{the} \mid \text{this} ] \text{set name} [ \text{subscript} ] \text{is} [ \text{not} ] \text{empty}$   
 $\mid [ \text{the} \mid \text{this} ] \text{expression is} [ \text{not} ]$   
 $\quad \text{in} [ \text{a} \mid \text{an} \mid \text{the} \mid \text{some} ] \text{set name}$   
 $\mid \{ \text{event} \mid \text{process} \} \text{is} [ \text{not} ]$   
 $\quad \{ \text{internal} \mid \text{endogenous}$   
 $\quad \mid \text{external} \mid \text{exogenous}$   
 $\}$   
 $\} [ \text{is} ] \{ \text{true} \mid \text{false} \}$   
 $\} \{ \text{and} \mid \text{or} \}$



number: = { *integer* | *.integer* | *integer* [ *.integer* ] }

program label: = ' { *name* | *number* } '

relational operator:

{ { = | **eq** | **equals** | **equal to** }  
 | {  $\neg$  = |  $\triangleleft$  | **ne** | **not equal to** }  
 | { < | **ls** | **lt** | **less than** }  
 | { > | **gr** | **gt** | **greater than** }  
 | { < = | **le** | **not greater than** | **no greater than** }  
 | { > = | **ge** | **not less than** | **no less than** }  
 }

selection clause:

{ **with**  
 | [ **except** ] **when**  
 | **unless**  
 } *logical expression* [ , ]

string constant: = " { *name* | *number* | *blank* }  $\triangleleft$  "

special character: = { ( | ) | + | - | # | / | \* | \$ }

subscript: = ( { *expression* } < , > )

subprogram constant: = { ' *routine name* ' }

termination clause: = { **while** | **until** } *logical expression* [ , ]

variable: = *name* [ *subscript* | *array reference* ]

## C.4 The Statement Syntax

```
{ accumulate|tally }
{ name { = | as } [ the ] [ qualifier name ]
{ average | avg | mean
| sum
| number | num
| variance | var
| std.dev | std
| sum.of.squares | ssq
| mean.square | msq
| minimum | min
| maximum | max
}
| name ( { name | [ + | - ] number } to { name | [ + | - ] number }
      by { name | number } )
      { as | = } [ the ] [ qualifier name ] histogram
} < comma > of name
```

Specifies automatic data collection and analysis.

```
{ activate | cause | reactivate | schedule | reschedule }
{ a | an | the [ above ] | this }
{ process name | event name } [ called variable ]
[ { given | giving } { expression } < comma >
  | ( expression } < comma > )
]
```

```
{ at expression
  | now | next
  | { in | after } expression { units | days | hours | minutes }
}
```

Creates (for **a** or **an**) and places an event or process notice in the pending list in proper chronological order.

**add** *expression to variable*

Adds the value of expression to the value of the variable variable.

**after** - See **before**.

```
[ also ] { for | termination clause }
  [ for | termination clause | selection clause ] < >
  do [ this | the following ]
```

Logical phrases control the execution of statements that follow them. When more than one statement is to be controlled, the words **do** and **loop** must bracket the statements. Multiple control phrases terminating control on the same **loop** statement are preceded by the word **also**.

**always** - See **if**.

```
{ before | after }
{ { creating | destroying } < comma >
  [ a | an | the | any ] temporary entity name
| { filing | removing } < comma >
  [ in | from ] { a | an | the | any } set name
| { activating | causing | canceling | interrupting | scheduling } < comma >
[ a | an | the | any ] § process name | event name }
} call routine name
```

Specifies a call to the named routine whenever the indicated statement is executed. Inputs to the routine (automatically supplied) are:

	BEFORE	AFTER
<b>create</b>	not allowed	entity identifier
<b>destroy</b>	entity identifier	not allowed
<b>file</b>	entity identifier, subscripts	entity identifier, subscripts
<b>remove</b>	entity identifier, subscripts	entity identifier, subscripts
<b>activate</b>	entity identifier, time	entity identifier, time
<b>cause</b>	entity identifier, time	entity identifier, time
<b>schedule</b>	entity identifier, time	entity identifier, time
<b>cancel</b>	entity identifier	entity identifier
<b>interrupt</b>	entity identifier	entity identifier

#### **begin heading**

Marks the beginning of a heading section within a report section.

**begin report** [ **on a new page** ] [ **printing for** , **in groups of** *integer*  
[ **per page** ] ]

Marks the beginning of a report section with optional new page and column repetition features.

**break** { *event name* | *process name* } **ties** { **by** | **on** } [ **high** | **low** ]  
*attribute name* } < *comma* **then** >

Establishes the priority order within a process or event class in case of time-tie.

```
{ call | perform | now } routine name
[ { given | giving | the | this } { expression } < comma >
| ( { expression } < comma > ) [ yielding { variable } < comma > ]
```

Invokes a routine used as a procedure.

```
cancel [ the [ above ] | this ] event name [ called variable ]
```

Removes a scheduled event notice from the pending list.

**cause** - See **activate**.

```
close [unit|tape] expression
```

Exact syntax is implementation-specific.

**compute**

```
{ variable { = | as } [ the ]
    { average | avg | mean
    | sum
    | number | num
    | variance | var
    | std.dev | std
    | sum.of.squares | ssq
    | mean.square | msq
    | minimum | min
    | maximum | max
    | { minimum | min } ( variable )
    | { maximum | max } ( variable )
  }
```

} < comma > **of** *expression*

Must be controlled by a logical control phrase. Computes the indicated statistics of the expression expression after the **loop** statement if the control is over a **do...loop** block.

```
create { [ a | an ] { temporary entity name | process name | event name }
      [ called variable ]
      | { each | all | every } { { permanent entity name | resource name }
      [ ( expression ) ] } < comma >
    }
```

Obtains a block of words of the appropriate size for the named entity.

**cycle** | **next**

Returns control immediately to the top of a loop for testing and next iteration. Must be contained within a **do...loop** block.

```
define { set name } < comma > as [ a | an ] [ LIFO | FIFO ] set
[ ranked { by | on } [ high | low ] attribute name ]
    < comma then > ]
[ without § F | L | N | P | S | M } attributes ]
[ [ , ] without { FF | FL | FB | FA | F | RF | RL | RS | R } < comma > routines ]
```

Defines set ranking and optional deletion of owner and member attributes and processing routines.

```
define { routine name } < comma > as [ a | an ]
[ integer | alpha | real | double | text ]
[ releasable | fortran | nonsimscript ] { routine | function }
[ { given | giving | with } integer [ values | arguments ] ]
[ [ comma ] yielding integer [ values | arguments ] ]
```

Defines routines, their mode and the number of given/yielding arguments for consistency checking.

```

define { name } < comma > as [ a | an ]
[ [ integer | real | double | alpha | text | signed integer ]
  [ integer - { dim | dimensional } ]
  [ dummy | subprogram | stream { name | integer } ]
] < [ comma ] >
  { variable | array }
  [ monitored on { [ the ] { left | right } } < comma > ]

```

Defines the properties of global variables.

```

define { name } < comma > as [ a | an ]
[ [ integer | real | double | alpha | text ]
  [ integer - { dim | dimensional } ]
  [ subprogram ]
  [ saved | recursive ]
] < [ comma ] >
  { variable | array }

```

Defines the properties of local variables.

```

define word to mean { word } < >

```

Instructs the compiler to substitute the words following the keyword **mean** for the indicated word in all subsequent statements, before they are compiled. The sequence of words to be substituted is terminated by the first end of record following **mean**. The sequence of words in a **define to mean** statement cannot be empty.

```

destroy{ [ the | this ] { temporary entity name | process name
  | event name } [ called variable ]
  | each { permanent entity name | resource name } }

```

Releases the block of storage for the specified entity **name**.

**do** loop [ **this** | **the following** ]

Used with **loop** to delimit a group of statement controlled by one or more logical control phrases.

**else** - See **if**.

**end**

Marks the physical end of a program preamble, routine, report section, or heading section within a report section.

**enter with** *variable*

Used to transfer a right-hand expression to a local variable within a left-handed function.

**erase** { *name* }

Used to release storage used for **text** variables.

{ **event** | **upon** } [ **to** | **for** ] *event name*

[ { **given** | **giving** | **the** | **this** } { *name* } < *comma* >

| ( { *name* } < *comma* > ) ]

[ **saving the event notice** ]

Event routine heading. Unless **saved**, the associated event notice is automatically destroyed when the event routine is executed.

{**event notices** | **events** } [ { **include** | **are** } { *event name* } < *comma* > ]

Preamble statement marking the start of event declarations.



**every** { *entity name* } < *comma* > [ **may** | **can** ]  
 { **has** { **a** | **an** | **the** | **some** } *attribute name*  
     [ ( { *integer/integer* | *\*/integer* | *integer-integer* } ) ]  
     [ **in** { **array** | **word** } *integer* | **function** ]  
 | **owns** { { **a** | **an** | **the** | **some** } *set name* } < *comma* >  
 | **belongs to** { { **a** | **an** | **the** | **some** } *set name* } < *comma* >  
 | **has** { **a** | **an** | **the** | **some** } *attribute name*  
     **random** [ **step** | **linear** ] *variable*  
     [ **in** { **word** | **array** } *integer* ]  
 } < *comma* >

Entity-attribute-set structure declaration. Specifies optional attribute packing, equivalences, word assignments, and functions.

{ **external** | **exogenous** }  
 { **event** | **process** } **units are**  
 { *name* | *integer* } < *comma* >

Logical input devices from which external event/process data will be read.

{ **external** events | **exogenous** }  
 { **events** | **processes** } **are** { *event name* | *process name* } < *comma* >

Declares the names of the events and processes which can be triggered externally.

**file** [ **the** | **this** ] *expression*  
     [ **first** | **last** | { **before** | **after** } *expression* ]  
     **in** [ **the** | **this** ] *set name* [ *subscript* ]

Places an entity in a set.

**find { the first case**

```
| { variable = [ the ] [ first ] expression } < comma >
| [ , ]
| if { found | none } [ , ] ]
```

Must be controlled by a **for** phrase with a selection clause, but cannot be within a **do...loop** block. The option **if** statement directs control after the control phrase has been completed, depending upon the outcome of the **find**.

```
go [ to ] { 'program label [ ( expression ) ] '
| program label [ ( expression ) ]
| $ 'program label' | program label } < or > per expression
}
```

Transfers control to a labelled statement or one of several labelled statements in a list according to the integer value of the transfer expression *expression*.

```
if logical expression [ , ]
[ statement ] < >
[ else | otherwise ]
[ statement ] < >
{endif | always | regardless }
```

The **if** statement directs control to one of two possible groups of statements, depending on the outcome of logical expression. **if** statements may be nested to any complexity.

```
interrupt [ the | this | the above ] process name [ called variable ]
```

Removes a process from the pending list, computes the "time to go" ( **time.a** - **time.v** ) and stores it in **time.a** ( *process name* ) [ or **time.a** ( *variable* ) ].

**last column** { **is** | = } *integer*

Directs compiler to ignore columns beyond integer on subsequent input records.

**leave**

Transfers control to the statement immediately following the next **loop** statement.

**let** *variable* = *expression*

Assigns the value of expression to the variable *variable*. If variable is integer and expression is real, the result is rounded before storing.

**list** { *expression*

| **attributes of** { *entity* [ **called** *expression* ]

| **each** *entity*

[ { **from** | **after** } *expression* ]

[ { **in** | **of** | **at** | **on** } *set name* [*subscript* ] ]

[ **in reverse order** ]

[ , { *selection clause* | *termination clause* } < > ]

}

} < *comma* >

A free-form output statement that labels and displays values of expressions, and one- or two-dimensional attributes or arrays.

{ **loop**[ | **repeat** ]

Used with **do** to delimit a group of statements controlled by one or more logical control phrases.

### **main**

Marks the beginning of the main routine in a program. Execution commences at the first executable statement after **main**.

```
move { from expression  
      | to variable  
      }
```

Used only within a routine defined for a monitored variable to access or set the value of that variable.

NOTE: **move to** *left-monitored variable*

**move from** *right-monitored variable*

**next** - See **cycle**.

**normally** [ , ]

{ **mode** { **is** | = } { **integer** | **real** | **double** | **alpha** | **text** | **undefined** }

| **type** { **is** | = } { **saved** | **recursive** }

| { **dimension** | **dim** } { **is** | = } *integer*

} < *comma* >

Establishes background conditions for properties of variables and functions that are effective unless overridden by subsequent **define** declarations or, in the case of local arrays, first use.

**now** - See **call**.

**open** [**unit**] *expression* **for**

$\left\{ \begin{array}{l} \text{input} \\ \text{output} \end{array} \right\}$	$\left. \vphantom{\left\{ \begin{array}{l} \text{input} \\ \text{output} \end{array} \right\}} \right\} \text{comma}$	$\left[ \begin{array}{l} \text{name} = \text{expression} \\ \text{recordsize} = \text{expression} \\ \text{binary} \\ \text{noerror} \end{array} \right]$
---	---	---

Exact syntax is implementation-specific.

**otherwise** - See **if**.

**perform** - See **call**.

**permanent entities** [ **include** { *permanent entity name* } < *comma* > ]

Preamble statement marking the start of permanent entity declarations.

[ **new** | **old** | **very old** ] **preamble**

Marks the beginning of the program preamble.

**print** *integer* [ **double** ] **lines**

[ **with** { *expression* | **a group of** { *expression* }

< *comma* > **fields** } } < *comma* > ]

[ **suppressing from column** *integer* ]

{ **thus** | **like this** | **as follows** }

The *integer lines* following the **print** statement are format lines containing text and pictorial formats for the display of indicated expression values.

The phrases, **a group of** { *expression* } < *comma* > **fields** and **suppressing from column** *integer*, can only be used within report sections that have column repetition.

**priority order** is { *event name* | *process name* } < comma >

This preamble statement assigns a priority order to different classes of processes and events to be used to resolve time-ties in scheduling.

**process** [ **to** | **for** ] *process name*

[ { **given** | **giving** | **the** | **this** } { *name* } < comma >  
| ( { *name* } < comma > ) ]

Process routine heading declaration. The process name process must be declared in the preamble.

**processes** [ { **include** | **are** } { *process name* } < comma > ]

Preamble statement marking the start of process entity declarations.

**read** { { *variable* } < comma > [ **as** { [ **double** ] **binary**  
| [ ( *expression* ) ] { *format*<sub>2</sub> } < comma > } ]  
| **as** { *format*<sub>1</sub> } < comma >  
}  
[ **using** { **the buffer** | [ **tape** | **unit** ] *expression* } ]

Reads data, either formatted or free-form from a specified device or the previously established input device.

**regardless** - See **if**.

**release**{ *variable* } < comma >

Frees storage occupied by variables (either arrays or attributes of permanent entities or resources).

**relinquish** *expression* [ **units of** ] *resource name* [ ( *subscript* ) ]

Makes the specified number of units of the resource available for automatic reallocation.

**remove** [ **the** ]

{ { **first** | **last** } *variable*

| [ **this** | **above** ] *expression*

} **from** [ **the** | **this** ] *set name* [ *subscript* ]

Removes an entity from a set.

**repeat** - See **loop**.

**request** *expression* [ **units of** ] *resource* [ ( *subscript* ) ]

[ [ , ] **with priority** *expression* ]

Makes a request for the specified number of units of the resource. If not available, the requesting process is enqueued in **priority** order and suspended awaiting availability of the resource.

**reschedule** - See **activate**.

**reserve** { { *variable* } < *comma* > **as** { *expression* }

< **by** > [ **by** \* ] } < *comma* >

Allocates blocks of storage of the specified size to the variables. If **by** \* is specified only pointer space (for multi-dimensioned arrays) is allocated. Otherwise the data storage is also allocated.

**reset** [ **the** ] [ *qualifier name* ] < *comma* >

**totals of** { *variable* } < *comma* >

Initializes **accumulate** or **tally** counters associated with variable. If **totals** is not preceded by qualifier name(s), all counters of variable are (re)initialized. Otherwise, only those counters with the matching qualifiers are reset.

**resources**[ { **include** | **are** } { *resource name* } < *comma* > ]

Preamble statement marking the start of resource entity declarations.

**resume** [ **the** | **this** | **the above** ] *process name* [ **called** *variable* ]

Used to restore a previously interrupted process to the pending list with the remaining "time-to-go" taken from **time.a** (*process name*).

**resume substitution**

Used to reinstate the substitutions previously nullified by a **suppress substitution** statement.

**return** [ ( *expression* ) | **with** *expression* ]

Used in a procedure, this statement returns control to its calling program. Used in a function, this statement returns control and a value to its calling program.

**rewind** [ **tape** | **unit** ] *expression*

Rewinds an input/output device.



```
[ left | right ] { routine | function | subroutine }
[ to | for ] routine name
[ { given | giving | the | this } { name } < comma >
  | ( { name } < comma > )
[ yielding { name } < comma > ]
```

Routine heading declaration. The prefix **left** or **right** is for declaring monitoring routines. A routine used as a function has only **given** arguments.

**schedule** - See **activate**.

```
skip expression { fields
  | [ input | output ] { cards | lines | records }
}
```

Applies to the current input or current output unit. **Skip expression fields** applies only to the current input unit. If neither **input** nor **output** is specified, **cards** and **records** imply **input** and **lines** implies **output**.

```
start new { page
  | [ input | output ] { card | line | record }
}
```

Applied to the current input or output unit. If neither **input** nor **output** is specified, **card** and **record** imply **input**, and **line** implies **output**.

**start simulation**

Causes the timing routine (**time.r**) to begin selecting and executing events and/or processes.

**stop**

Halts program execution and returns control to the operating system.

**store** *expression* **in** *variable*

Assigns the value of expression to variable without regard to mode.

**substitute**{ **this** | **these** } *integer lines* **for** *word*

Instructs the compiler to substitute the next integer lines following "word" for each occurrence of "word" in all subsequent statements before they are compiled. Blank lines and lines containing only comments do not count in this statement.

**subtract** *expression* **from** *variable*

Subtracts the value of expression from the value of variable and stores the difference in variable.

**suppress substitution**

Used to nullify current substitutions (possibly in order to modify the substitutions).

**suspend** [ **process** ]

Used to place the current process in the passive state and return control immediately to the timing routine without destroying the current process.

**tally** - See **accumulate**.

**temporary entities**

Preamble statement marking the start of temporary entity declarations.

**the system** [ **may** | **can** ]

{ **has** { { **a** | **an** | **the** | **some** } *attribute name*

[ ( { *integer/integer* | *\*/integer* | *integer-integer* } ) ]

[ **in** { **array** | **word** } *integer* | **function** ]

} < *comma* >

| **owns** { { **a** | **an** | **the** | **some** } *set* } < *comma* >

| **has** { **a** | **an** | **the** | **some** } *attribute name*

**random** [ **step** | **linear** ] **variable**

[ **in** { **word** | **array** } *integer* ]

} < *comma* >

Specifies attributes of the system and sets owned by the system. Also specifies optional attribute packing, equivalences, word assignments, and functions.

[ **then** ] **if** - See **if**.

**trace** [ **using** [ **tape** | **unit** ] *expression* ]

Produces a backtrack of the current function and subroutine calls. **Trace** is executed automatically when SIMSCRIPT detects an error during execution. In this case, the standard listing device is used.

**upon** - See **event**.

$$\text{use}\{ \text{the buffer} \mid [\text{tape} \mid \text{unit}] \text{expression} \} \text{for} \{ \text{input} \mid \text{output} \}$$

Establishes the indicated input or output device as the current input or output unit. All subsequent input/output statements that do not specify their own devices in **using** phrases use these current units. Specifying **the buffer** causes reading or writing to an internal file.

$$\{ \text{wait} \mid \text{work} \} \textit{expression} \{ \text{units} \mid \text{days} \mid \text{hours} \mid \text{minutes} \}$$

Introduces a delay of expression time-units into a process.

**work** - See wait.

```

write { expression } < comma > { as { [ double ] binary
                                     | [ ( expression ) ] { format2 } < comma >
                                     }
      | as { format1 | * }
      }
[ using { the buffer | [ tape | unit ] expression }
]

```

Writes data to the specified device or the previously established output device according to the specified format.

## C.5 Preamble Statement Precedence Rules

The following statements may only appear in the program preamble (except where otherwise noted). No other statements may appear in the preamble.

Statement Type	Statement	Rules
1a	<b>normally</b>	Can appear anywhere in preamble.
1b	<b>define to mean</b>	
1c	<b>substitute</b>	
1d	<b>suppress substitution</b>	
1e	<b>resume substitution</b>	
1f	<b>last column</b>	
2a	<b>temporary entities</b>	A preamble may contain many types of 2a, 2b, 2c, 2d, and 2e statements.
2b	<b>permanent entities</b>	
2c	<b>event notices</b>	
2d	<b>processes</b>	
2e	<b>resources</b>	
3a	<b>every</b>	Many can follow a type 2 statement. An entity can appear in more than one <b>every</b> statement.
3b	<b>the system</b>	
4	<b>define</b> variable	No precedence relation if it defines a global variable. Must follow all Type 3a statements if it defines an attribute named in them. A variable, attribute, or function can appear in only one <b>define</b> statement.
5	<b>define</b> set	Must follow Type 3 statements which declare the <b>MEMBER</b> or <b>OWNER</b> entity.
No type 6-9 statement can precede any Type 2-3 statements.		
6a	<b>break ties</b>	One statement allowed for each process or event notice.
6b	<b>external events</b>	
6c	<b>external processes</b>	
6d	<b>external units</b>	
7	<b>priority</b>	Must follow all Type 2c, 2d, and Type 6b and 6c statements (and their <b>every</b> statements).
8a	<b>before</b>	One of each per entity/set action.

## Statement

Statement Type	Statement	Rules
	<b>after</b>	
9a	<b>accumulate</b>	One statement allowed for each attribute or unsubscripted global variable.
9b	<b>tally</b>	

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