Chapter 8

Statement-Level Control Structures

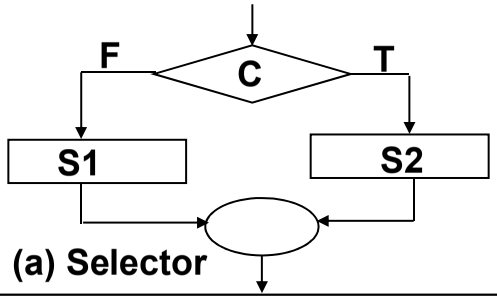
8.1 Introduction
8.2 *Selection* Statements
8.3 *Iterative* Statements
8.4 Unconditional *Branching*
8.5 *Guarded Commands*

The flow of control, or execution sequence, in a program can be examined at several levels.
- *flow of control within expressions : -> operator precedence and associativity*
- *flow of control among statements : -> statement-level control structures*
- *flow of control among unit : -> procedure invocation*

We have the theoretical result that only sequence, selection, and pretest logical loops are absolutely required to express computations

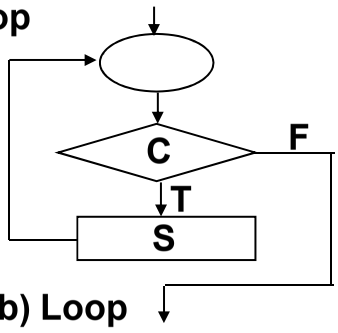
8.1 Introduction

- Computations in imperative languages
  - evaluating expressions and assigning resulting values to variables
    - ⇔ choosing among alternative control flow paths
    - ⇔ causing the repeated execution of certain collection of statements
- The control statements of early FORTRAN
  - directly related to machine language instructions
- It was proven that all algorithms that can be expressed by flowcharts can be coded in a programming language with only two control statements ;
  - one for choosing between two control paths
  - one for logically controlled iterations
- *Writability* is enhanced by a large number of control statements
  - How much should a language be expanded to increase its writability, at the expense of its simplicity and size ?
- *Flow graph* of two-way selector and a logically controlled loop



(a) Selector

Single-Entry
Single-Exit



(b) Loop

• Compound Statements

– In Algol 60,

⇔ *compound statement* : a collection of statements to be abstracted to a single statement

```
begin
    statement-1 ;
    statement-2 ;
    ......
end
```

⇔ *block* : compound statement + *data declarations*

```
begin
     integer index, count ;
    statement-1 ;
    statement-2 ;
    ......
end
```

– Pascal follows ALGOL 60's design for compound statements, but does not allow block

– The C language uses the braces to delimit both compound statements and blocks

– Design Issues

A *control structure* is a control statement and the statements whose execution it controls

⇔ *Can the control structure have multiple entries ?*

⇒ It is now generally believed that multiple entries add little to the flexibility of control structures, relative to the decrease in readability caused by increased complexity

7.3 Selection Statement

– It provides the means of choosing between two or more execution paths in a program

⇔ *two-way selection*, *n-way selection* (multiple selection)

(1) Two-Way Selection Statements

• Design Issues

– *What is the form and type of the expression that controls the selection ?*

⇔ In most of the languages : Boolean expression

⇔ In C : arithmetic expression

– *Can a single statement, a sequence of statements, or compound statement be selected ?*

– *How should the meaning of selectors nested in then clauses of other selectors be specified ?*

⇔ by syntax, or by semantic rule

- **Single-Way Selectors**
  - All imperative languages include a sing-way selector, in most cases as *a subform of a two way selector*. Two exceptions are BASIC and FORTRAN
  - In FORTRAN (a logical IF),
    - ⇔ *IF (Boolean expression) statement*
      - ⇒ The selector control expression is *boolean type*, and only *a single statement is selectable*
      - ⇒ Nesting is not allowed
      - ⇒ promotes the use of goto statement
      - ⇒ *very simple and highly inflexible*
  - The *compound statement* provides the selection construct with a simple mechanism for conditionally executing groups of statements. In ALGOL 60,

```
if (Boolean expression) then
     begin
        statement-1 ;
        statement-2
        ....
        statement-n
    end
```

  - Most of the languages that followed ALGOL 60, including FORTRAN 77 and 90, provide single-way selectors that can select a compound statement or a sequence of statements

- **Two-Way Selectors**
  - It allows one of *two control paths to be selected*
  - In ALGOL 60,

```
if (Boolean expression)
    then (compound) statement
    else (compound) statement
```

- **Nesting Selectors**
  - ⇔ Ambiguousness in nested selectors

```
if (sum = 0) then
    if (count = 0)
        then result := 0
else result := 1
```

  - *In most imperative languages, the static semantics of the language* specify that the `else` clause is always paired with *the most recent unpaired* `then` clause
  - In ALGOL 60,
    - ⇔ an `if` statement is not allowed to be nested directly in a `then` clause
      - ⇒ must be placed in compound statement

```
if (sum = 0) then
   begin
      if (count = 0)
        then result := 0
        else result := 1
   end
```

```
if (sum = 0) then
     begin
        if (count = 0)
        then result := 0
     end
else result := 1
```

– If the last clause in an *if*, whether *then* or *else*, is not a compound, there is no syntactic entity to mark the end of the whole selection construct

⇔ use of *special word*

⇒ in Modula-2, *END*

⇒ in FORTRAN 77, *END IF*

⇔ In Modular-2

```
IF sum = 0
    THEN IF count = 0
            THEN result := 0
            ELSE result := 1
         END
END
```

```
IF sum = 0
    THEN IF count = 0
            THEN result := 0
         END
    ELSE result := 1
END
```

⇔ in Python

⇒ uses indentation to define clauses

```
>>> if 1 + 1 == 2:
...     print "foo"
...     print "bar"
...     x = 42

>>> if 1 + 1 == 2:
...     print "foo"; print "bar"; x = 42

>>> if 1 + 1 == 2: print "foo"; print "bar"; x = 42
```

Because blocks are denoted by indentation in Python, indentation is uniform in Python programs. And indentation is meaningful to us as readers.

```
>>> if foo:
...     if bar:
...         x = 42
... else:
...   print foo
```


(2) Multiple Selection Constructs

– It allows the selection of one of any number of statements or statement groups

– a generalization of a selector

- Design Issues
  - What is the form and type of the expression that controls the selection ?
  - Can a single statement, a sequence of statements, or a compound statement be selected ?
  - Should the entire construct be encapsulated in a syntactic structure ?
  - Should execution flow through the structure be restricted to include just a single selectable statement ?
  - How should unrepresented selector expression values be handled, if at all ?
- Early Multiple Selector
  - In FORTRAN,

```
GOTO integer_variable,(label-1,label-2,...,label-n)
```

```
GOTO (label-1,label-2,...,label-n),expression
```

```
IF (arithmetic expression) N1, N2, N3
```

3-way selector (arithmetic IF)

Multiple Entry (lack of encapsulation)

```
      IF (expression) 10,20,30
10    ....
      ....
      GO TO 40
20    ....
      ....
      GO TO 40
30    ....
      ....
40    ....
```

if it is omitted, error?

- **Modern Multiple Selector : *Case***
  - ***In ALGOL-W,***
    - ⇔ The structure is encapsulated, and provide a single selectable segment
    - ⇔ The executed statement is the one chosen by the value of the expression

```
case integer_expression of
   begin
      statement-1 ;
      .....
      statement-n
   end
```

  - ***In Pascal***,
    - ⇔ selectable segments are labeled
    - ⇔ the expression is of ordinal type (integer, Boolean, character, or enumeration type)
    - ⇔ Semantics : the expression is evaluated, and the value is compared with the constants in the constant lists
    - ⇔ the constant lists must be of the same types as the expression, and they must be *mutually exclusive*, but *need not to be exhaustive*

implicit branching

```
case expression of
    constant_list_1 : statement_1 ;
    ....
    constant_list_n : statement_n ;
end
```

mutually exclusive

```
case index of                          ANSI/IEEE
    1, 3 : begin                       Pascal Standard
             odd := odd + 1 ;
           end
    2, 4 : begin
             even = even + 1 ;
           end
   else writeln ("Error in case") ;
end
```


  - In C (*switch*)
    - ⇔ the control expression and constant expressions are ***integer type***
    - ⇔ It *does not provide implicit branches* at the end of those code segments (*reliable* vs. *flexible*)

```
switch (expression) {
    case constant_expression-1: statement-1 ;
    ....
    case constant_expression-N: statement-N ;
    default : statement-N+1 ;
}
```

```
switch (index) {
     case 1 :
     case 3 : odd += 1 ;          explicit
              break ;             branching
     case 2 :
     case 4 : even += 1 ;
              break ;
     default : printf("Error in switch");
}
```

  - In Python,

```
case
   when count < 10 then bag1 = true
   when count < 100 then bag2 = true
   when count < 1000 then bag3 = true
 end
```

8.3 Iterative Statements

- **Iterative Statement**
  - It is one that causes a statement or collection of statements to be executed zero, one, or more times
  - It is often accomplished in a functional language by *recursion* rather than by iterative constructs
  - The first iterative constructs in programming languages were directly related to arrays
  - Design Issues
    - ⇔ *How is the iteration controlled ?*
      - ⇒ logical, counting, or a combination of two
    - ⇔ *Where should the control mechanism appear in the loop ?*
      - ⇒ pretest, posttest, or user defined

(1) Counter-Controlled Loops

- Loop variable in which the count value is maintained
- Loop parameters
  - ⇔ initial, terminal, stepsize

```
      DO 30 I=1,100,2
      ….
30    CONTINUE
```

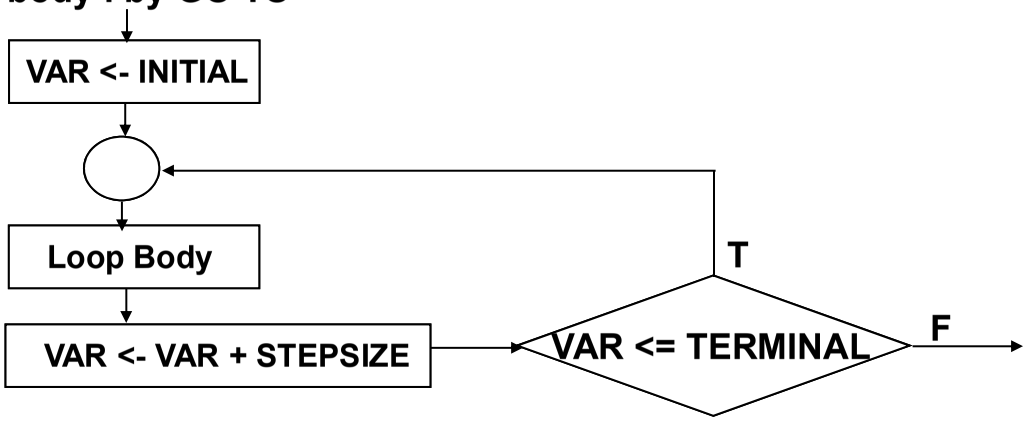
- Counter-controlled loops are often supported by machine instruction

- **Design Issues**
  - *What is the type and scope of the loop variable ?*
    - ⇔ integer, character, enumeration, floating types
  - *What value does the loop variable have at loop termination ?*
  - *Should it be legal for the loop variable or loop parameters to be changed in the loop, and if so, does the change affect loop control ?*
  - *Should the test for completion be at the top or the bottom of the loop ?*
  - *Should the loop parameters be evaluated only once, or once for every iteration ?*

- **The FORTRAN IV DO**

```
      DO 30 I=1,100,2
      ….
30    CONTINUE
```

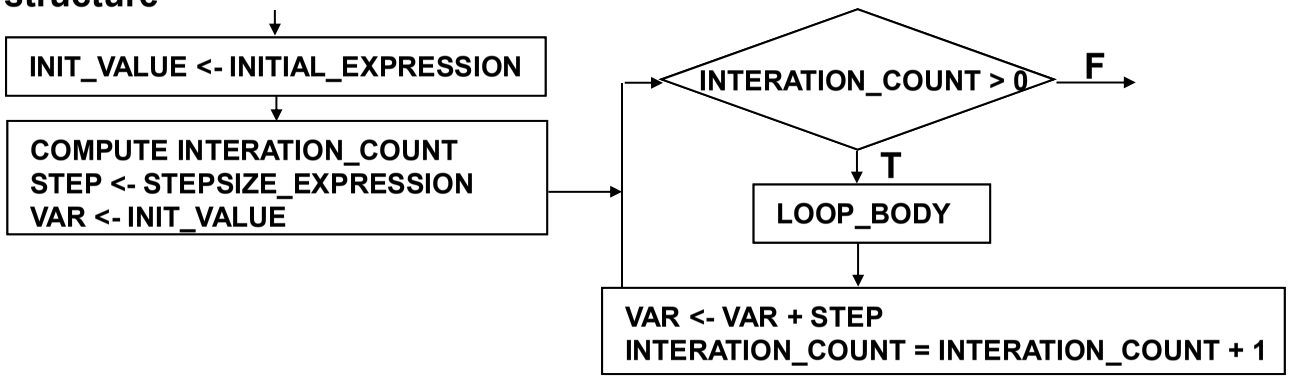
  - posttest
  - the initial, termination, and stepsize parameters are restricted to unsigned integer constants, or simple integer variable with positive values
  - the value of loop variable is
    - ⇔ *undefined* upon normal loop termination
    - ⇔ *its most recently assigned value* up abnormal termination
  - the loop variable and loop parameters *can not be changed in the loop body*, so there is no reason to evaluate the loop parameters more than once
  - extended loop body : by GO TO



- **The Do statement of FORTRAN 77 and FORTRAN 90**

```
Do label variable = initial, terminal [,stepsize]
```

  - pretest
  - the loop variable can be integer, real, or double-precision type
  - the loop parameters are allowed to be <u>expressions</u> and can have positive and negative values
  - the loop is controlled by *iteration count*, not the loop parameters, so even if the parameters are changed in the loop, which is legal, those change can not affect loop control
    - ⇔ the iteration count is an *internal variable* that is inaccessible to the user code
  - DO construct can be entered only through the DO statement - sing-entry structure



- **The C `for` statement**
  - **a pretest counting loop structure**

Evaluate only once — *Evaluate before each execution of body* — *Evaluate after each execution of body*

```
for (expression-1; expression-2; expression-3)
    statement
```

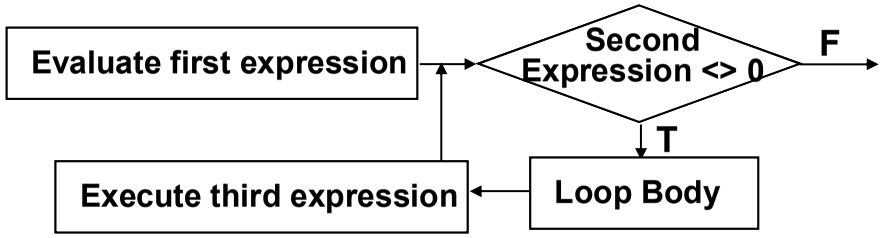
  - **If the value of the second expression is *zero*, the for is terminated; otherwise, the loop statements are executed**

```
for (index = 0 ; index <= 10; index++)
        sum = sum + list[index] ;
```

  - **All of the expressions of C's *for* are optional**

```
for (sum = 0.0, count = 0 ;
     count <= 10 && sum < 1000.0;
     sum = sum + count++) ;
```

- there is no explicit loop variable
- all involved variables can be changed in the loop body



- **In Python,**

```
#!/usr/bin/python
for letter in 'Python':     # First Example
   print 'Current Letter :', letter
fruits = ['banana', 'apple',  'mango']
for fruit in fruits:        # Second Example
   print 'Current fruit :', fruit
print "Good bye!"
```

```
Current Letter : P
Current Letter : y
Current Letter : t
Current Letter : h
Current Letter : o
Current Letter : n
Current fruit : banana
Current fruit : apple
Current fruit : mango
Good bye!
```

```
#!/usr/bin/python
fruits = ['banana', 'apple',  'mango']
for index in range(len(fruits)):
   print 'Current fruit :', fruits[index]
print "Good bye!"
```

```
Current fruit : banana
Current fruit : apple
Current fruit : mango
Good bye!
```

```
#!/usr/bin/python
for num in range(10,20):  #to iterate between 10 to 20
   for i in range(2,num):
      if num%i == 0:      #to determine the first factor
         j=num/i          #to calculate the second factor
         print '%d equals %d * %d' % (num,i,j)
         break #to move to the next number, the #first FOR
   else:                  # else part of the loop
      print num, 'is a prime number'
```

```
10 equals 2 * 5
11 is a prime number
12 equals 2 * 6
13 is a prime number
14 equals 2 * 7
15 equals 3 * 5
16 equals 2 * 8
17 is a prime number
18 equals 2 * 9
19 is a prime number
```

- *the else statement is executed when the loop has exhausted iterating the list.*
- *The else clause, which is optional, is executed if the loop terminates normally*

(2) Logically controlled loops

– the repetition control is based on a Boolean expression

- Design Issues
  - Should the control be *pretest or posttest ?*
  - Should the logically controlled loop be a special form of counting loop or a separate statement ?
- Examples
  - Some imperative languages - for example, Pascal, Modula-2, and C - include both pretest and posttest logically controlled loops
  - In C,

pretest

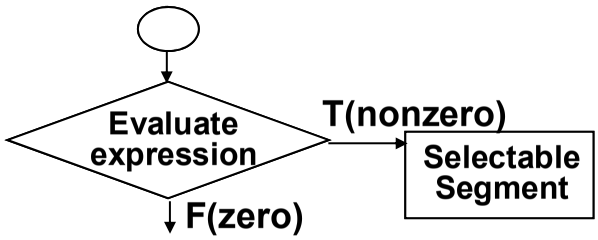
```
while (expression) statement
```

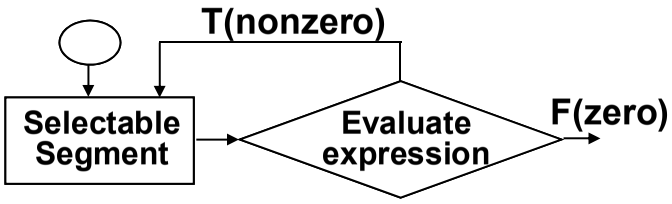
```
scanf ("%d", &indat) ;
while (indat >= 0) {
     sum = sum + indat ;
     scanf("%d", &indat) ;
}
```

posttest ← *body is execute at least once*

```
do statement while (expression)
```

```
do {
  indat = indat / 10;
  digits = digits + 1;
} while (indat>0);
```





(3) User-Located Loop Control Mechanisms

– a programmer chooses a location for loop control other than the top or bottom of the loop

- Design Issues
  - Should the conditional mechanism be an integral part of the exit ?
  - Should the mechanism be allowed to appear in a controlled loop or only in one without any other control ?
  - Should only one loop body exit, or can enclosing loops also be exited ?
- In Ada, *loop can be labeled*

```
OUTER_LOOP :
    for ROW in i..MAX_ROWS loop
INNER_LOOP :
        for COL in 1..MAX_COLS loop
             SUM := SUM + MAT(ROW, COL);
             exit OUTER_LOOP when SUM > 100.0
        end loop INNER_LOOP
    end loop OUTER_LOOP
```

infinite loop

```
loop
   ...
   SUM := SUM + INDEX ;
   exit when sum > = 1000;
   ...
end loop
```

- In C,

skip the remaining loop body

```
while (sum < 1000) {
   getnext(value) ;
   if (value < 0) continue ;
   sum = sum + value ;
}
```

Multiple Exit

terminate the loop

```
while (sum < 1000) {
   getnext(value) ;
   if (value < 0) break ;
   sum = sum + value ;
}
```

(4) Iteration based on Data Structure

- Iteration based on data structure
  - The loops are controlled by the number of elements in a data structure, rather than counter or boolean expression
- Example
  - Java 5.0
    - ⇔ the enhanced version of `for` simplifies iteration through *the value in an array* or *the objects in a collection* that implements the `Iteratable` interface
    - ⇔ example
      - ⇒ if we had an `ArrayList` collection named `myList` of strings, the following statement would iterate through all of its elements, setting each to `myElement`

```
for (String myElement : myList) { ….}
```

  - C#

```
String[] StrList={"Bob", "Carol", "Ted", "lala"};
…
foreach (String name in strList)  …. ;
```


8.4 Unconditional Branching

- An *unconditional branch statement* transfers execution control to a specified place in the program

(1) Problems with Unconditional Branching

- The unconditional branch, or *goto*, is *the most powerful statement* for controlling the flow of execution of a program statements, but it is this very power that makes its use *dangerous*
  - readability is best when the execution order of the statements is nearly the same as the order in which they appear - this usually means *top to bottom*
  - a few languages have been designed without a goto, for example, Java
  - However, *most currently popular languages include a goto statement*
  - the languages that have eliminated the goto have provided additional control statements, usually in the form of loop and subprogram exits, to replace many of the typical application of the goto

(2) Label Forms

- **Label Forms**
  - In ALGOL 60 and C : use their identifier forms for labels
  - In FORTRAN and Pascal : use unsigned integer constants for labels
  - In PL/1 : allows the labels to be variables
- **Restrictions on Branches** → *most language restricts their usages*
  - In Pascal,
    - ⇔ Pascal labels must be declared as if they were variables, but they cannot be passed as parameters, stored, or modified
    - ⇔ a *goto* can never have as its target a statement in a compound statement of a control structure, unless execution of that compound statement has *already begun and has not yet terminated*

illegal

```
    while ... do  begin
       ...
100:   ...
       ...
    end
    while ... do begin
       ...
       goto 100 ;
       ...
       goto 200 ;
    end
    while ... do begin
       ...
200:   ...
    end
```

```
    while ... do begin
       ...
100:   ...
       ...
       while ... do begin
          ...
          goto 100 ;
          ...
       end ;
    end ;
```

legal

⇔ Pascal allows to branch to a a different procedure (error-propagation)

8.5 Guarded Commands (by Dijkstra 1975)

- **Dijkstra's selection construct**

```
if <Boolean expression> -> <statement>
[] <Boolean expression> -> <statement>
[] ....
[] <Boolean expression> -> <statement>
fi
```

  - all the Boolean expressions are evaluated each time the construct is reached during execution. If more than one expression is true, one of the corresponding statement is *nondeterminstically chosen* for execution. If none is true, *a run-time error* occurs that causes program termination
    - ⇔ It forces the programmer to consider and list all possibilities (*exhaustive listing*)
  - In Ada case statement,

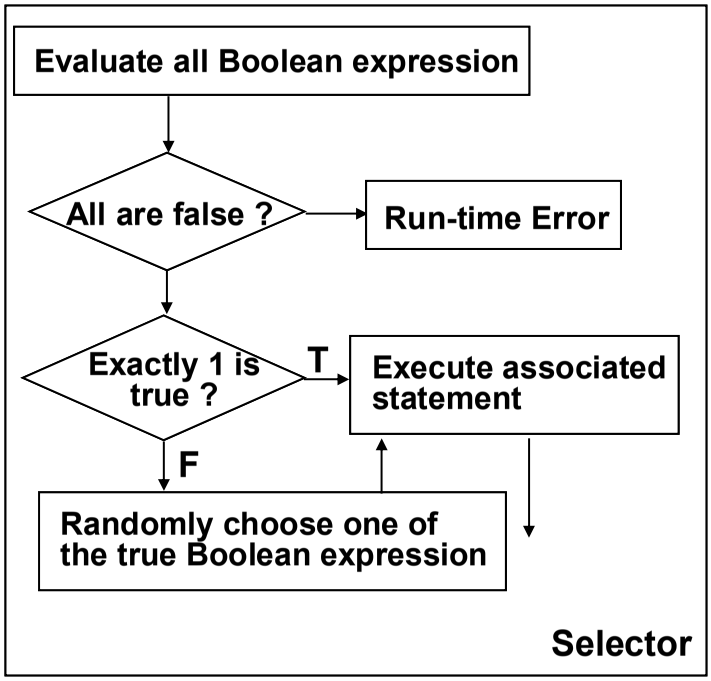
```
if i = 0 -> sum := sum + i
[] i > j -> sum := sum + j
[] j > i -> sum := sum + I
fi
```

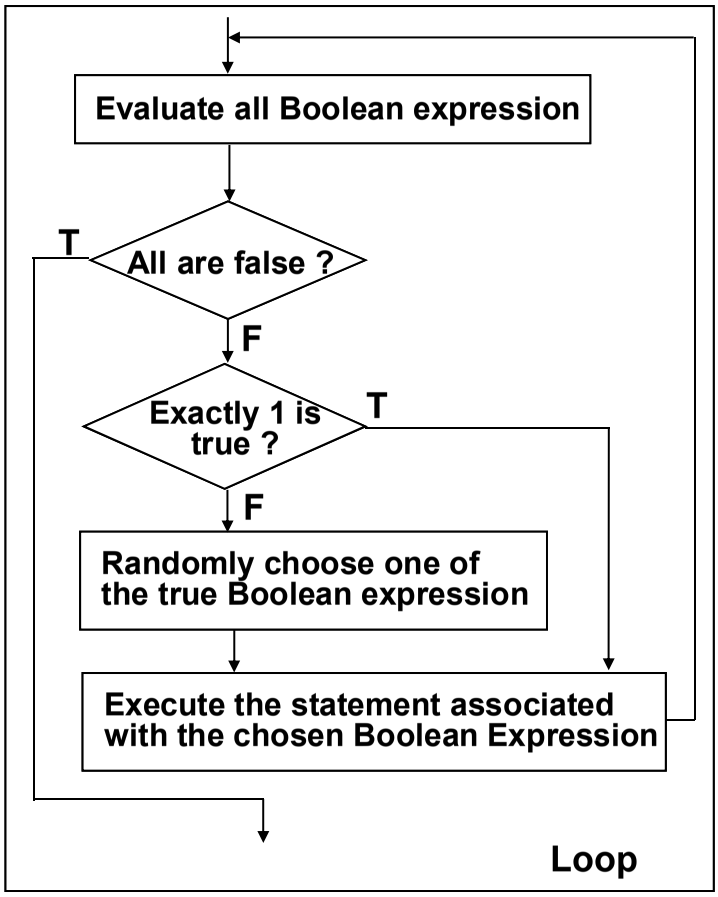
if (i=0) and (j=1) ?
if (i=j) and (i<>0) ?

- **Dijkstra's loop structure**

```
q1 := Q1; q2 := Q2; q3:= Q3; q4 := Q4;
do  q1 > q2 -> temp := q1; q1 := q2 ; q2 := temp ;
 [] q2 > q3 -> temp := q2; q2 := q3 ; q3 := temp ;
 [] q3 > q4 -> temp := q3; q3 := q4 ; q4 := temp ;
od
```

  - the concurrency control in the Ada languages


Evaluate all Boolean expression
All are false ?
Run-time Error
Exactly 1 is true ?
T
Execute associated statement
F
Randomly choose one of the true Boolean expression
Selector


Evaluate all Boolean expression
T
All are false ?
F
Exactly 1 is true ?
T
F
Randomly choose one of the true Boolean expression
Execute the statement associated with the chosen Boolean Expression
Loop