Control Structures

In Text: Chapter 8

Outline

- Control structures
- Selection
  - One-way
  - Two-way
  - Multi-way
- Iteration
  - Counter-controlled
  - Logically-controlled
- Gotos
- Guarded statements

Levels of Control Flow

- Within expressions
- Among program statements
- Among program units

Control Structures

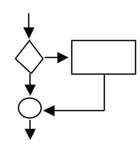
- A **control structure** is a control statement and the statements whose execution it controls
- Overall Design Question:
  - What control statements should a language have, beyond selection and pretest logical loops?
- Single entry/single exit are highly desirable
  - a lesson learned from structured programming

Selection Statements

- Design Issues:
  - What is the form and type of the control expression?
  - What is the selectable segment form?
    - single statement, statement sequence, compound statement
  - How should the meaning of nested selectors be specified?

Single-Way Selection

- One-way "if" statement
- FORTRAN IF:



```
IF (boolean_expr) statement
```

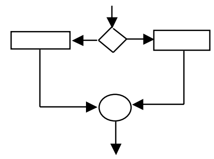
- Problem: can select only a single statement; to select more, a goto must be used

```
IF (.NOT. condition) GOTO 20
     ...
     ...
20 CONTINUE
```

Two-Way Selection

- "if-then-else" statement
- ALGOL 60 if:

```
if (boolean_expr) then
    statement
else
    statement
```



- The statements could be single or **compound**
  - `begin…end`
  - A **block** is a compound statement that can define a new scope (with local variables)

Nested Selectors

- Pascal:

```
if ... then
    if ... then
        ...
    else ...
```

- Which "then" gets the "else"?
- Pascal's rule: else goes with the nearest then

Disallowing Direct Nesting

- ALGOL 60's solution—disallows direct nesting

```
if ... then
  begin
    if ... then
      ...
    else
        ...
  end
```

```
if ... then
    begin
      if ... then
        ...
      end
else
     ...
```


Closing Reserved Words

- FORTRAN 77, Ada, Modula-2 solution—closing special words
- In Ada:

```
if ... then
  if ... then
    ...
  else
    ...
  end if
end if
```

```
if ... then
    if ... then
      …
    end if
else
     ...
end if
```

- Advantage: flexibility and readability
- Modula-2 uses END for all control structures
  - This results in poor readability

Multiple Selection Constructs

- Design Issues:
  - What is the form and type of the control expression?
  - What segments are selectable (single, compound, sequential)?
  - Is the entire construct encapsulated?
  - Is execution flow through the structure restricted to include just a single selectable segment?
  - What about unrepresented expression values?

Early Multiple Selectors:

- FORTRAN arithmetic IF (a three-way selector)

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

  - Disadvantages:
    - Not encapsulated
      - ➔ selectable segments could be anywhere
- FORTRAN computed GOTO

```
GO TO (L1, L2, ..., Ln), exp
```

goes to first label if exp=1, second if exp=2, etc.

if exp < 1 or exp > n, no effect

must still jump out of segment

Modern Multiple Selectors

- Pascal case
  - from Hoare's contribution to ALGOL W

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


Case: Pascal Design Choices

- Expression is any ordinal type
  - int, boolean, char, enum
- Segments can be single or compound
- Construct is encapsulated
- Only one segment can be executed per execution of the construct
- In Wirth's Pascal, result of an unrepresented control expression value is undefined
- Many dialects now have otherwise or else clause

C/C++ Switch

```
switch (expression)  {
    constant_expression_1 : statement_1;
    ...
    constant_expression_n : statement_n;
    [default: statement_n+1]
}
```

- Design Choices (for switch):
  - Control expression can be only an integer type
  - Selectable segments can be statement sequences or blocks
  - Construct is encapsulated
  - Any number of segments can be executed in one execution of the construct (reliability vs. flexibility)
  - Default clause for unrepresented values

Case: Ada Design Choices

```
 case expression is
      when constant_list_1 => statement_1;
      ...
      when constant_list_n => statement_n;
  end
```

- Similar to Pascal, except …
- Constant lists can include:

  Subranges: 10..15

  Multiple choices: 1..5 | 7 | 15..20
- Lists of constants must be exhaustive (more reliable)
- Often accomplished with others clause

Multi-Way If Statements

- Multiple selectors can appear as direct extensions to two-way selectors, using else-if clauses
  - ALGOL 68, FORTRAN 77, Modula-2, Ada
- Ada:

```
if ... then
    ...
elsif ... then
    ...
elsif ... then
    ...
else ...
end if
```

- Far more readable than deeply nested if's
- Allows a boolean gate on every selectable group

Iterative Statements

- The repeated execution of a statement or compound statement is accomplished either by iteration or recursion
- Here we look at iteration, because recursion is unit-level control
- General design issues for iteration control statements:
  - How is iteration controlled?
  - Where is the control mechanism in the loop?
- Two common strategies: counter-controlled, and logically-controlled

Counter-Controlled Loops

- Design Issues:
- What is the **type** (ordinal vs. real) and **scope** of the loop variable?
- What is the value of the loop variable at loop termination?
- Should it be legal for the loop variable or loop parameters to be changed in the loop body?
- If so, does the change affect loop control?
- Should the loop parameters be evaluated only once, or once for every iteration?

FORTRAN DO Loops

- FORTRAN 77 and 90
- Syntax:

```
DO label var = start, finish [, stepsize]
```

- Stepsize can be any value but zero
- Parameters can be expressions
- Design choices:
  - Loop var can be INTEGER, REAL, or DOUBLE
  - Loop var always has its last value
  - Loop parameters are evaluated only once
  - The loop var cannot be changed in the loop, but the parameters can; because they are evaluated only once, it does not affect loop control

FORTRAN 90's Other DO

- Syntax:

```
[name:] DO variable = initial, terminal [, stepsize]
   ...
END DO [name]
```

- Loop var must be an INTEGER

ALGOL 60 For Loop

- Syntax:

```
for var := <list_of_stuff> do statement
```

- where <list_of_stuff> can have:
  - list of expressions
  - expression step expression until expression
  - expression while boolean_expression

```
for index := 1 step 2 until 50, 60, 70,
             80, index + 1 until 100 do
```

- (index = 1, 3, 5, 7, ..., 49, 60, 70, 80, 81, 82, ..., 100)

ALGOL 60 For Design Choices

- Control expression can be **int or real**; its scope is whatever it is declared to be
- Control var has its **last assigned value** after loop termination
- The loop var **cannot be changed** in the loop, but the parameters can, and when they are, it affects loop control
- Parameters are **evaluated with every iteration**, making it very complex and difficult to read

Pascal For Loop

- Syntax:

```
for var := initial (to | downto) final do
    statement
```

- Design Choices:
  - Loop var must be an ordinal type of usual scope
  - After normal termination, loop var is undefined
  - The loop var cannot be changed in the loop
  - The loop parameters can be changed, but they are evaluated just once, so it does not affect loop control

Ada For Loop

- Syntax:

```
for var in [reverse] discrete_range loop
     ...
end loop
```

- Design choices:
  - Type of the loop var is that of the discrete range (e.g., [1..100]); its scope is the loop body (it is implicitly declared)
  - The loop var does not exist outside the loop
  - The loop var cannot be changed in the loop, but the discrete range can; it does not affect loop control
  - The discrete range is evaluated just once

C For Loop

- Syntax:

```
for ([expr_1] ; [expr_2] ; [expr_3])
     statement
```

- The expressions can be whole statements, or even statement sequences, with the statements separated by commas
- The value of a multiple-statement expression is the value of the last statement in the expression
- If the second expression is absent, it is an infinite loop

C For Loop Design Choices

- There is no explicit loop variable
- Everything can be changed in the loop
- Pretest
- The first expression is evaluated once, but the other two are evaluated with each iteration
- This loop statement is the most flexible

C++ & Java For Loops

- Differs from C in two ways:
  - The control expression can also be Boolean
  - The initial expression can include variable definitions; scope is from the definition to the end of the body of the loop
- Java is the same, except the control expression must be Boolean

Logically-Controlled Loops

- Design Issues:
  - Pretest or post-test?
  - Should this be a special case of the counting loop statement, or a separate statement?

Logic Loops: Examples

- Pascal: separate pretest and posttest logical loop statements

  `while-do` and `repeat-until`
- C and C++: also have both

  `while - do` and `do - while`
- Java: like C, except the control expression must be Boolean (and the body can only be entered at the beginning—Java has no goto)
- Ada: a pretest version, but no post-test
- FORTRAN 77 and 90: have neither

User-Located Loop Controls

- Statements like `break` or `continue`
- Design issues:
  - Should the conditional be part of the exit?
  - Should the mechanism be allowed in logically- or counter-controlled loops?
  - Should control be transferable out of more than one loop?

User-Located Controls: Ada

- Can be conditional or unconditional; for any loop; any number of levels

```
for ... loop
  ...
  exit when ...
  ...
end loop;
```

```
LOOP1:
    while ... loop
        ...
LOOP2:
    for ... loop
        ...
        exit LOOP1 when ..
        ...
     end loop LOOP2;
        ...
     end loop LOOP1;
```

User-Loc. Controls: More Examples

- C, C++, Java:
  - Break: unconditional; for any loop or switch; one level only (except Java)
  - Continue: skips the remainder of this iteration, but does not exit the loop
- FORTRAN 90:
  - EXIT: Unconditional; for any loop, any number of levels
  - CYCLE: same as C's continue

Iteration Based on Data Structures

- Lets user specify range of values over which a loop iterates (CLU).
  - ```
    for (ptr = root; ptr == nul; traverse(ptr)) {
        ...
    }
    ```
  - ```
    for i in `ls *` do

    od
    ```

Unconditional Branching (GOTO)

- Problem: readability
- Some languages do not have them: e.g., Modula-2 and Java
- They require some kind of statement label
- Label forms:
  - Unsigned int constants:
    - Pascal (with colon),
    - FORTRAN (no colon)
  - Identifiers with colons: ALGOL 60, C, C++
  - Identifiers in << ... >>: Ada

Variables as labels: PL/I

- Can store a label value in a variable
- Can be assigned values and passed as parameters
- Highly flexible, but make programs impossible to read and difficult to implement

Guarded Commands (Dijkstra, 1975)

- Purpose: to support a new programming methodology
  - verification during program development
- Also useful for concurrency
- Two guarded forms:
  - Selection (guarded if)
  - Iteration (guarded while)

Guarded Selection

```
if <boolean> -> <statement>
[] <boolean> -> <statement>
     ...
[] <boolean> -> <statement>
fi
```

- Semantics: when this construct is reached,
  - Evaluate all boolean expressions
  - If more than one are true, choose one nondeterministically
  - If none are true, it is a runtime error
- Idea: if the order of evaluation is not important, the program should not specify one
- See book examples (p. 343)

Guarded Iteration

```
do <boolean> -> <statement>
[]  <boolean> -> <statement>
      ...
[]  <boolean> -> <statement>
od
```

- Semantics: For each iteration:
  - Evaluate all boolean expressions
  - If more than one are true, choose one nondeterministically; then start loop again
  - If none are true, exit loop
- See book example (p. 344)

Choice of Control Statements

- Beyond selection and logical pretest loops, choice is a trade-off between:
  - Language size
  - Readability
  - Writability