



# Theory of Programming Languages

---

## Statement-Level Control Structures

Sajid Anwer

Department of Computer Science,  
FAST-NUCES, CFD Campus



## Chapter Outline

---

- Introduction
- Selection Statements
- Iterative Statements
- Unconditional Branching

## Introduction - Control Structure

---

- A *control structure* is a control statement and the statements whose execution it controls
- *Readability* is the main concern related to control structures.
- Design question
  - » Should a control structure have *multiple entries*?

## Selection Statements

---

- A *selection statement* provides the means of choosing between two or more paths of execution
  
- Two general categories:
  - » Two-way selectors
  
  - » Multiple-way selectors

## Two-Way Selection Statements

---

- General form:

```
if control_expression
    then clause
    else clause
```

- Design Issues:

- » What is the form and type of the control expression?
- » How are the **then** and **else** clauses specified?
- » How should the meaning of *nested selectors* be specified?



## The Control Expression

---

- If the *then* reserved word or some other syntactic marker is not used to introduce the *then* clause, the control expression is placed in parentheses
- In C89, C99, Python, and C++, the control expression can *be arithmetic*
- In most other languages, the control expression must be *Boolean*

## Clause Form

---

- In many contemporary languages, the then and else clauses can be *single statements or compound statements*
- In Perl, all clauses must be delimited by braces (they must be compound)
- In Fortran 95, Ada, Python, and Ruby, clauses are statement sequences
- Python uses *indentation* to define clauses

```
if x > y :  
    x = y  
    print "x was greater than y"
```

## Nesting Selectors

---

- Java example

```
if (sum == 0)
    if (count == 0)
        result = 0;
else result = 1;
```

- Which **if** gets the **else**?
- Java's static semantics rule: **else** matches with the nearest previous **if**



## Nesting Selectors (continued)

---

- To force an alternative semantics, compound statements may be used:

```
if (sum == 0) {  
    if (count == 0)  
        result = 0;  
}  
  
else result = 1;
```

- The above solution is used in C, C++, and C#

## Nesting Selectors (continued)

---

- Statement sequences as clauses: Ruby

```
if sum == 0 then  
    if count == 0 then  
        result = 0  
    else  
        result = 1  
    end  
end
```

## Nesting Selectors (continued)

---

- Python

```
if sum == 0 :  
    if count == 0 :  
        result = 0  
    else :  
        result = 1
```

## Selector Expressions

---

- In ML, F#, and LISP, the selector is an expression

```
let y =  
    if x > 0 then x  
    else 2 * x
```

- If the *if* expression *returns* a value, there *must* be an *else* clause (the expression could produce output, rather than a value), *why?*

## Multiple-Way Selection Statements

---

- Allow the selection of *one of any number* of statements or statement groups
- Design Issues:
  1. What is the form and type of the control expression?
  2. How are the selectable segments specified?
  3. Is execution flow through the structure restricted to include just a single selectable segment?
  4. How are *case values* specified?
  5. What is done about *unrepresented expression* values?

## Multiple-Way Selection: Examples

---

- C, C++, Java, and JavaScript

```
switch (expression) {  
    case const_expr1: stmt1;  
    ...  
    case const_exprn: stmtn;  
    [default: stmtn+1]  
}
```

## Multiple-Way Selection: Examples

---

- Design choices for C's **switch** statement
  1. Selectable segments can be statement sequences, blocks, or compound statements
  2. Any number of segments can be executed in one execution of the construct (*there is **no implicit branch** at the end of selectable segments*).
  3. **default** clause is for unrepresented values (if there is no **default**, the whole statement does nothing)



## Multiple-Way Selection: Examples

---

- C#
  - » Differs from C in that it has a static semantics rule that disallows the implicit execution of more than one segment
  - » Each selectable segment must end with an unconditional branch (**goto** or **break**)
  - » Also, in C# the control expression and the case constants can be strings



## Implementing Multiple Selectors

---

- Approaches:
  - » Multiple conditional branches
  - » Store case values in a table and use a linear search of the table
  - » When there are more than ten cases, a hash table of case values can be used
  - » If the number of cases is small and more than half of the whole range of case values are represented, an array whose indices are the case values and whose values are the case labels can be used

## Multiple-Way Selection Using `if`

---

- Multiple Selectors can appear as direct extensions to two-way selectors, using else-if clauses, for example in Python:

```
if count < 10 :  
    bag1 = True  
elif count < 100 :  
    bag2 = True  
elif count < 1000 :  
    bag3 = True
```

## Multiple-Way Selection Using `if`

---

- The Python example can be written as a Ruby **case**

**case**

**when** count < 10 **then** bag1 = **true**

**when** count < 100 **then** bag2 = **true**

**when** count < 1000 **then** bag3 = **true**

**end**



## Iterative Statements

---

- The *repeated execution* of a statement or compound statement is accomplished either by iteration or recursion
- General design issues for iteration control statements:
  1. How is iteration controlled?
  2. Where is the control mechanism in the loop?



## Counter-Controlled Loops

---

- A counting iterative statement has a loop variable, and a means of specifying the *initial* and *terminal*, and *stepsize* values
- Design Issues:
  1. What are the *type and scope* of the loop variable?
  2. Should it be legal for the loop variable or loop parameters to be changed in the loop body, and if so, *does the change affect loop control?*
  3. Should the loop parameters be evaluated only once, or once for every iteration?

## Counter-Controlled Loops: Examples

---

- C-based languages

`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*
- Design choices:
  - » There is no *explicit* loop variable
  - » *Everything* can be changed in the loop
  - » The first expression is evaluated once, but the other two are evaluated with each iteration
  - » - It is legal to branch into the body of a for loop in C

## Counter-Controlled Loops: Examples

---

- C++ differs from C in two ways:
  1. The control expression can also be Boolean
  2. The initial expression can include variable definitions (scope is from the definition to the end of the loop body)
  
- Java and C#
  - » Differs from C++ in that the control expression must be Boolean

## Counter-Controlled Loops: Examples

---

- Ada

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

- Design choices:

- Type of the loop variable is that of the discrete range (A discrete range is a sub-range of an integer or enumeration type).
- Loop variable does not exist outside the loop
- The loop variable cannot be changed in the loop, but the discrete range can; it does not affect loop control
- The discrete range is evaluated just once
  - » Cannot branch into the loop body



## Counter-Controlled Loops: Examples

---

- Python

`for` loop\_variable `in` object:

- loop body

[`else`:

- else clause]

- » The object is often a range, which is either a list of values in brackets (`[2, 4, 6]`), or a call to the range function (`range(5)`, which returns 0, 1, 2, 3, 4
- » The loop variable takes on the values specified in the given range, one for each iteration

## Logically-Controlled Loops

- Repetition control is based on a Boolean expression
- Design issues:
  - » Pretest or posttest?
  - » Should the logically controlled loop be a special case of the counting loop statement or a separate statement?

## Logically-Controlled Loops: Examples

---

- C and C++ have both pretest and posttest forms, in which the control expression can be arithmetic:  

<b>while</b> (control_expr)	<b>do</b>
loop body	loop body
	<b>while</b> (control_expr)

  - In both C and C++ it is legal to branch into the body of a logically-controlled loop
- Java is like C and C++, except the control expression must be Boolean (and the body can only be entered at the beginning -- *Java has no goto*)

## User-Located Loop Control Mechanisms

---

- Sometimes it is convenient for the programmers to decide a *location for loop control* (other than top or bottom of the loop)
- Simple design for single loops (e.g., **break**)
- Design issues for nested loops
  1. Should the conditional be part of the exit?
  2. Should control be transferable out of more than one loop?

## User-Located Loop Control Mechanisms

---

- C , C++, Python, Ruby, and C# have *unconditional unlabeled* exits (**break**)
- Java and Perl have unconditional labeled exits (**break** in Java, **last** in Perl)
- C, C++, and Python have an unlabeled control statement, **continue**, that *skips the remainder of the current iteration*, but does not exit the loop
- Java and Perl have *labeled versions* of **continue**

## Iteration Based on Data Structures

---

- The number of elements in a data structure controls loop iteration
- Control mechanism is a call to an *iterator* function that returns the next element in some chosen order, if there is one; else loop is terminate
- C's **for** can be used to build a user-defined iterator:  

```
for (p=root; p!=NULL; traverse(p) ) {  
    . . .  
}
```

## Iteration Based on Data Structures (continued)

---

- PHP

- `current` points at one element of the array
- `next` moves `current` to the next element
- `reset` moves `current` to the first element

- Java 5.0 (uses **`for`**, although it is called `foreach`)

For arrays and any other class that implements the `Iterable` interface, e.g., `ArrayList`

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

## Iteration Based on Data Structures (continued)

---

- C# and F# (and the other .NET languages) have generic library classes, like Java 5.0 (for arrays, lists, stacks, and queues). Can iterate over these with the `foreach` statement.
- User-defined collections can implement the `IEnumerator` interface and also use `foreach`.

```
List<String> names = new List<String>();  
names.Add("Bob");  
names.Add("Carol");  
names.Add("Ted");  
foreach (Strings name in names)  
    Console.WriteLine ("Name: {0}", name);
```





## Unconditional Branching

---

- Transfers execution control to a specified place in the program
- Represented one of the most heated debates in 1960's and 1970's
- Major concern: Readability
- Some languages do not support `goto` statement (e.g., Java)
- C# offers `goto` statement (can be used in `switch` statements)
- Loop exit statements are restricted and somewhat camouflaged `goto`'s