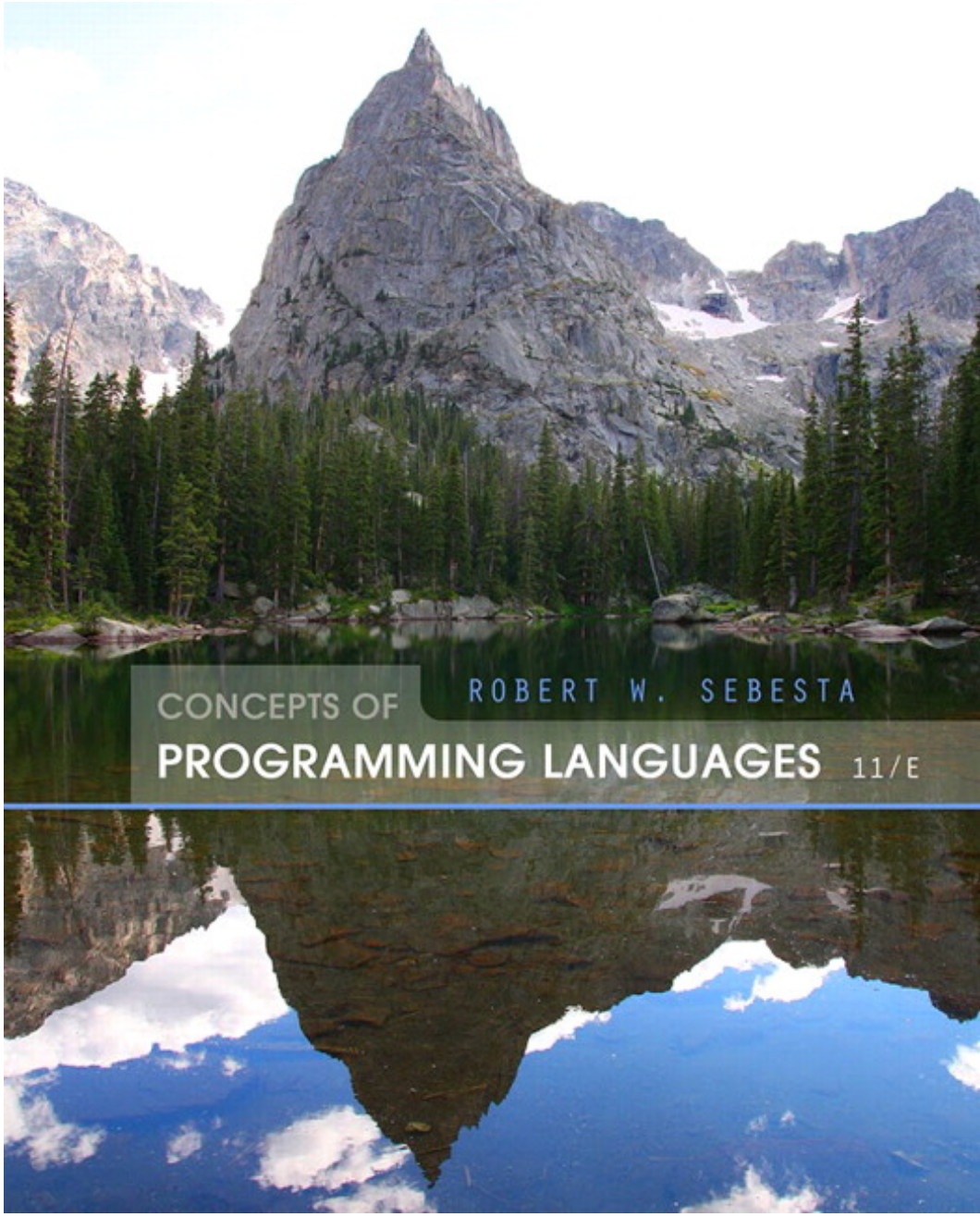
Chapter 8

Statement-Level Control Structures

*modified by Stephanie Schwartz



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Chapter 8 Topics

- Introduction
- Selection Statements
- Iterative Statements
- Unconditional Branching
- Guarded Commands
- Conclusions

Levels of Control Flow

- Within expressions (Chapter 7)
- Among program units (Chapter 9)
- Among program statements (this chapter)

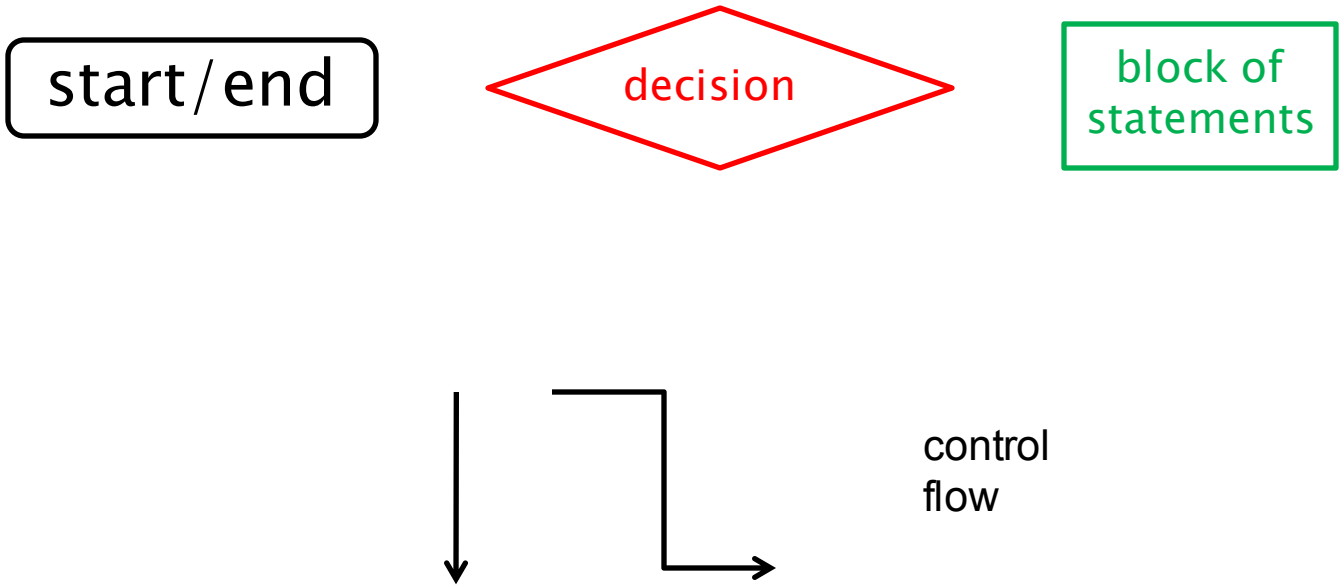
Control Statements: Evolution

- FORTRAN I control statements were based directly on IBM 704 hardware
- Much research and argument in the 1960s about the issue
  - One important result: It was proven that all algorithms represented by flowcharts can be coded with only two-way selection and pretest logical loops

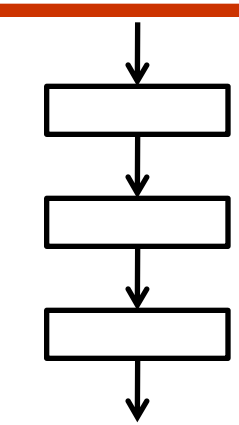
Control Structure

- 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?

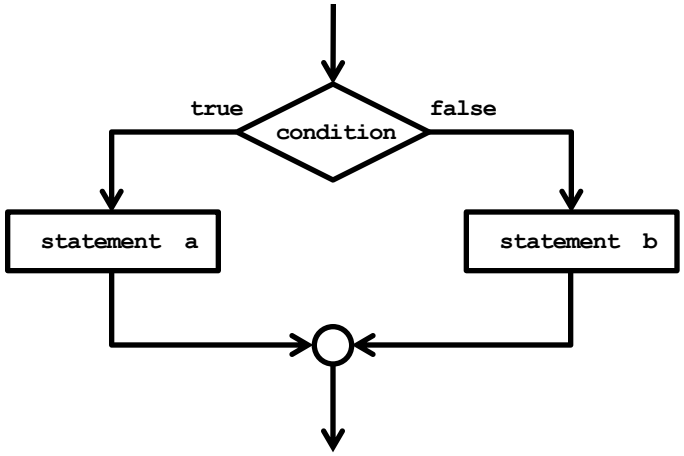
Flowchart Elements



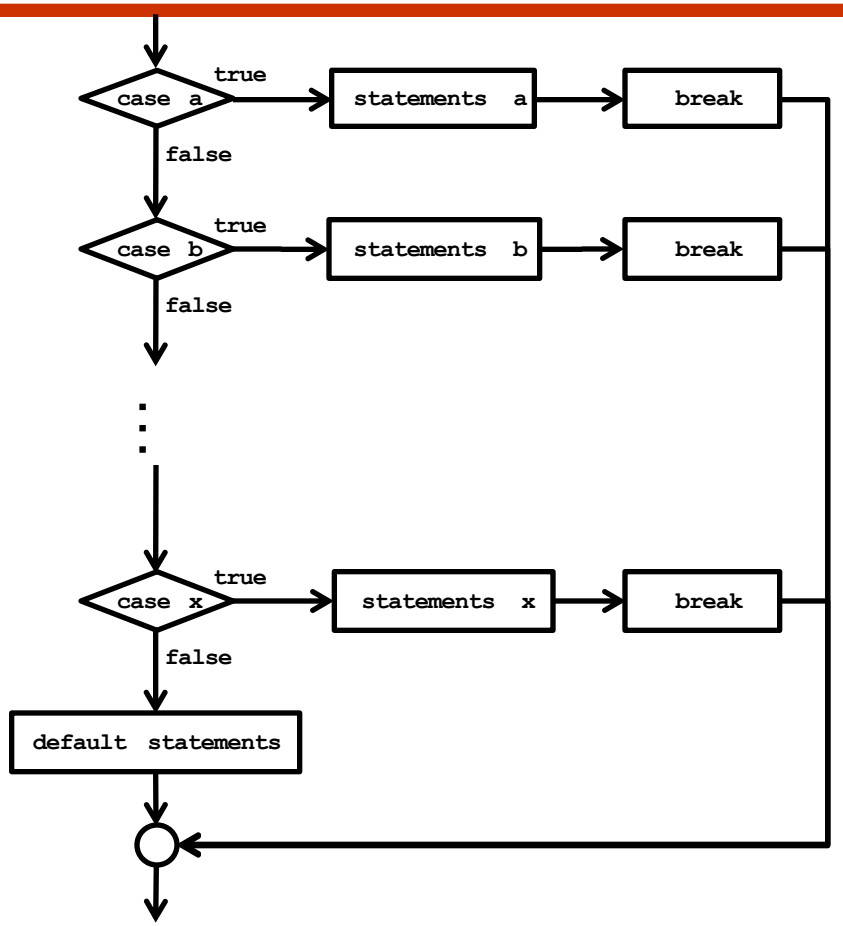
Sequence and Selection



Sequence



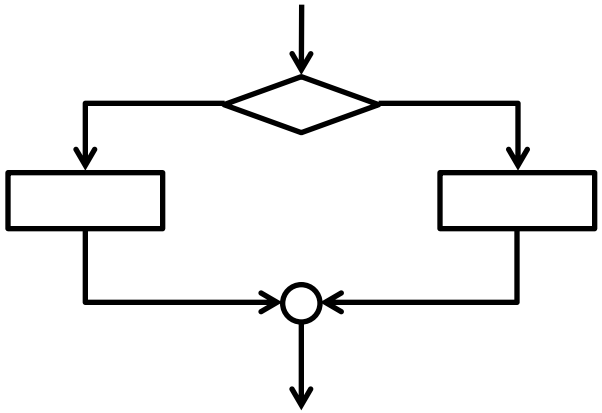
Selection (if/else)

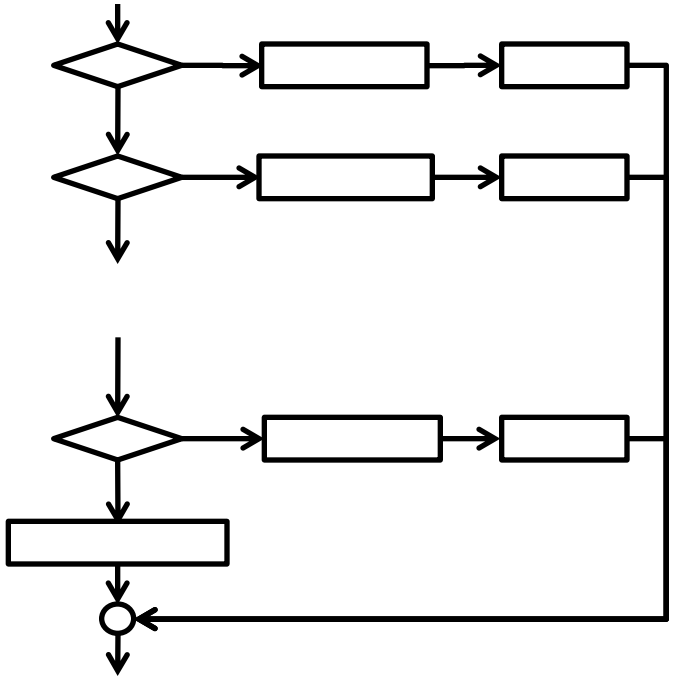


Selection (multi-way)

Selection Statements

- Alternatives between two or more execution paths
  1. **Two-way** selectors
  2. **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 languages such as Ada, Java, Ruby, and C#, the control expression must be Boolean

Two-Way Selection: Fortran

- FORTRAN
  - `IF (<boolean_expr>) <statement>`
- Problem
  - only a single statement can be selected
  - `GOTO` must be used to select more, e.g.

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

  - `GOTO`s must also be used for the else clause
  - Negative logic is bad for readability
- These problems were solved in FORTRAN 77
- Most later languages
  - allow compound statements to be selected
  - support else clause

Clause Form

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

```
if x > y :
  x = y
  print "case 1"
```

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 `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#
- Perl requires that all then and else clauses to be compound

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

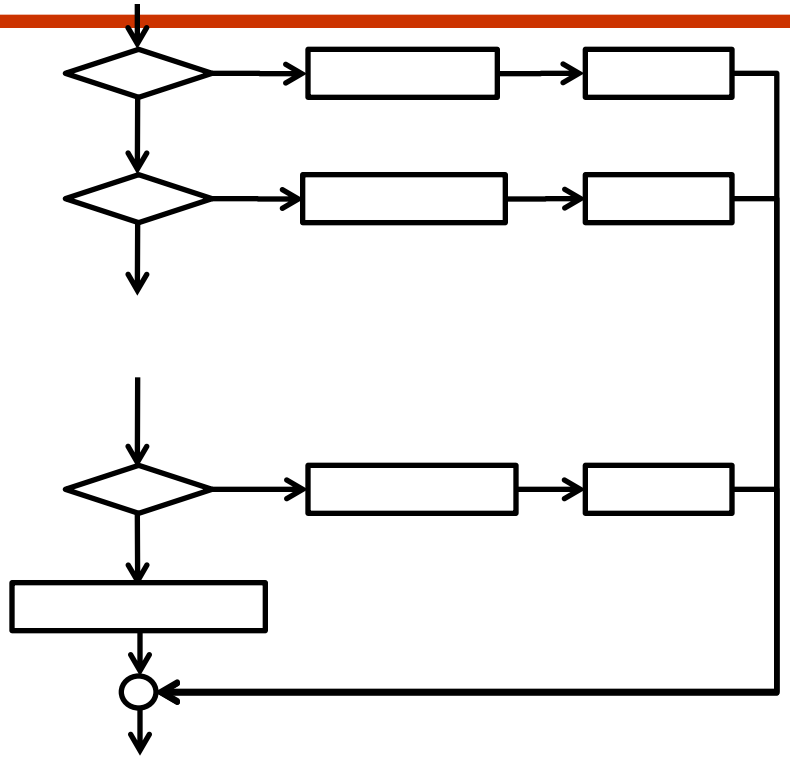
```
if sum == 0 :
   if count == 0 :
      result = 0
   else :
      result = 1
```

Functional vs Imperative Languages

- In functional languages, the selector is not a statement, it is an *expression*
- This means it returns a value (like assignment statements in some languages)
- Why?

Multiple-Way Selection Statements

- Select among one of many statements



- Design issues:
  1. **Form** and **type** of the control expressions
  2. How are the **selectable segments** specified?
  3. Will only a **single segment** be executed or does control continue checking other control expressions?
  4. What happens if no control expressions occurs?

Multiple-Way Selection: Examples

- C, C++, and Java

```
switch (expression) {
      case const_expr_1: stmt_1;
      …
      case const_expr_n: stmt_n;
      [default: stmt_n+1]
}
```

Multiple-Way Selection: Examples

- Design choices for C's **`switch`** statement
  1. Control expression can be only an integer type
  2. Selectable segments can be statement sequences, blocks, or compound statements
  3. Any number of segments can be executed in one execution of the construct (there is no implicit branch at the end of selectable segments)
  4. **`default`** clause is for unrepresented values (if there is no **`default`**, the whole statement does nothing)
  5. Virtually no restrictions on placement of case expressions

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

C# Switch Statement

```
switch (value) {
  case -1: Negatives++; break;
  case 0: Zeros++; goto case 1;
  case 1: Positives++;
  default:
     Console.WriteLine("error! \n");
}
```

Multiple-Way Selection: Examples

- Ruby has two forms of case statements–we'll cover only one

```
leap = case
    when year % 400 == 0 then true
    when year % 100 == 0 then false
    else year % 4 == 0
    end
```

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
```

Scheme's Multiple Selector

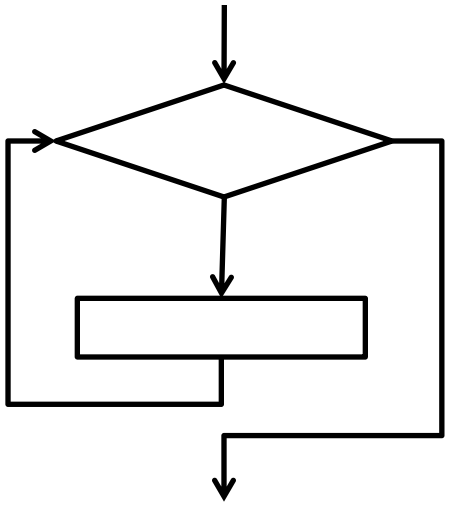
- General form of a call to COND:

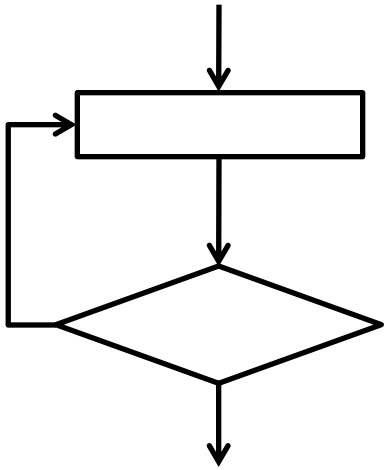
```
(COND
  (predicate1 expression1)
   …
  (predicaten expressionn)
  [(ELSE expressionn+1)]
)
```

  - The ELSE clause is optional; ELSE is a synonym for true
  - Each predicate-expression pair is a parameter
  - Semantics: The value of the evaluation of COND is the value of the expression associated with the first predicate expression that is true

Iterative Statements

- Repeated execution of a (compound) statement by iteration or recursion
  - Iteration is statement level
  - Recursion is unit-level control
    - next chapter





- Design issues
  1. **How** is iteration controlled ?
     - boolean expression or counter?
  2. **Where** is the control mechanism ?
     - pre or post?

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. What is the **value** of the loop variable **at loop termination?**
  3. Is it legal to change the loop variable or loop parameters in the loop body?
     - if so, does the change affect loop control?
  4. Should the **loop parameters** be evaluated **only once,** or 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
  - Less error-prone
    - but not completely, e.g.
      - `for (; b1 = b2;) {…} // b1, b2 boolean; b2 is true?!`

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

  - The else clause, which is optional, is executed if the loop terminates normally

Python for/else

```
found_obj = None
for obj in objects:
    if obj.key == search_key:
        found_obj = obj
        break
else:
    print 'No object found.'
```

** Can be helpful to read else as 'if not break'

Counter-Controlled Loops: Examples

- F#
  - Because counters require variables, and functional languages do not have variables, counter-controlled loops are simulated with recursive functions

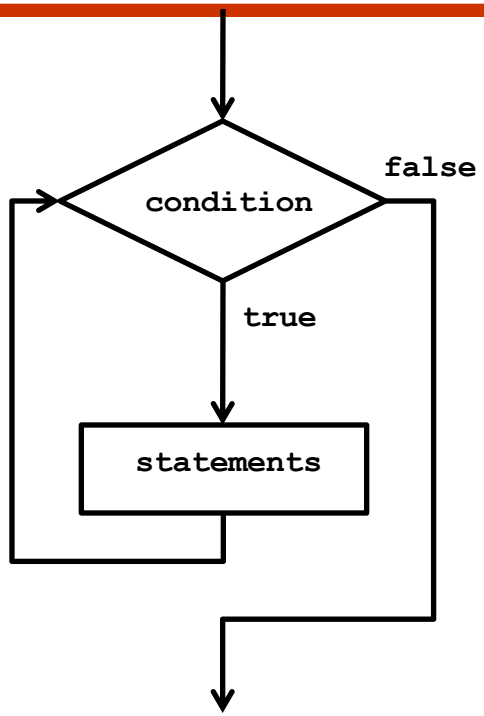
```
let rec forLoop loopBody reps =
  if reps <= 0 then ()
  else
    loopBody()
    forLoop loopBody, (reps - 1)
```

  - This defines the recursive function `forLoop` with the parameters `loopBody` (a function that defines the loop's body) and the number of repetitions
  - `()` means do nothing and return nothing

Iterative Statements: Logically-Controlled Loops

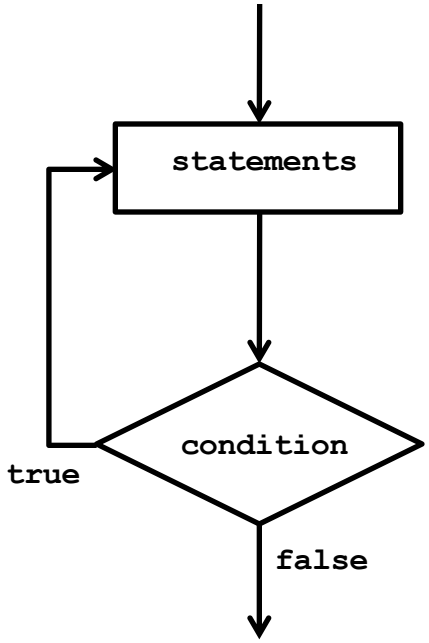
- Repetition control is based on a Boolean expression
- Design issues:
  - Pretest or posttest? Both? How many special forms?

Iteration/Repetition–Pre & Post Test



Pre-test repetition

(**while** <test> **do** <stuff>)



Post-test repetition

(**do** <stuff> **while** <test>)

Logically-Controlled Loops: Examples

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

```
while (control_expr)          do
    loop body                     loop body
                                  while (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`

Logically-Controlled Loops: Examples

- F#
  - As with counter-controlled loops, logically-controlled loops can be simulated with recursive functions

```
let rec whileLoop test body =
   if test() then
     body()
     whileLoop test body
   else ()
```

  - This defines the recursive function `whileLoop` with parameters `test` and `body`, both functions. `test` defines the control expression

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, Java, Perl and C# have unconditional unlabeled exits (`break`)
- Java, C# and Perl also have unconditional labeled exits (`break` in Java, `last` in Perl)
- C, C++, Java, Perl 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 also have labeled versions of `continue`

Java Labeled *break*

```
outerLoop:
    for (row = 0; row < numR; row++)
        for (col = 0; col < numC; col++){
            sum += mat[row][col];
            if (sum > 1000.0)
                break outerLoop;
        }
```

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);
```

Iteration Based on Data Structures (continued)

- Ruby *blocks* are sequences of code, delimited by either braces or **`do`** and **`end`**
  - Blocks can be used with methods to create iterators
  - Predefined iterator methods (`times`, `each`, `upto`):

```
3.times {puts "Hey!"}
list.each {|value| puts value}
```

(`list` is an array; `value` is a block parameter)

```
1.upto(5) {|x| print x, " "}
```

Iterators are implemented with blocks, which can also be defined by applications

Iteration Based on Data Structures (continued)

- Ruby blocks are attached methods calls; they can have parameters (in vertical bars); they are executed when the method executes a **`yield`** statement

```
def fibonacci(last)
  first, second = 1, 1
  while first <= last
    yield first
    first, second = second, first + second
  end
end
puts "Fibonacci numbers less than 100 are:"
fibonacci(100) {|num| print num, " "}
puts
```

  - Ruby has a **`for`** statement, but Ruby converts them to `upto` method calls

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

Guarded Commands

- Designed by Dijkstra
- Purpose: to support a new programming methodology that supported verification (correctness) during development
- Basis for two linguistic mechanisms for concurrent programming (in CSP)
- Basic Idea: if the order of evaluation is not important, the program should not specify one

Selection Guarded Command

- Form

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

- Semantics: when construct is reached,
  - Evaluate all Boolean expressions
  - If more than one are true, choose one non-deterministically
  - If none are true, it is a runtime error

Loop Guarded Command

- **Form**

  do <Boolean> -> <statement>

  [] <Boolean> -> <statement>

  ...

  [] <Boolean> -> <statement>

  od

- Semantics: for each iteration
  - Evaluate all Boolean expressions
  - If more than one are true, choose one non-deterministically; then start loop again
  - If none are true, exit loop

Guarded Commands: Rationale

- Connection between control statements and program verification is intimate
- Verification is impossible with `goto` statements
- Verification is possible with only selection and logical pretest loops
- Verification is relatively simple with only guarded commands

Conclusions

- Variety of statement-level structures
- Choice of control statements beyond selection and logical pretest loops is a trade-off between language size and writability
- Functional and logic programming languages use quite different control structures