Programming Languages
Lecture09 – Control Flow

SUNG KYUN KWAN
UNIVERSITY

남 범 석

bnam@skku.edu

Control Flow

- Basic paradigms for control flow
  - Sequencing
  - Selection
  - Iteration
  - Procedural Abstraction
  - Recursion
  - Concurrency
  - Exception handling and speculation
  - Non-determinacy

Expression Evaluation

- Infix, prefix operators
  - Prefix notation does not incur ambiguity
  - Infix notation leads to ambiguity without parentheses
- Precedence, associativity
  - C has 15 levels – too many to remember
  - Pascal has 3 levels – too few for good semantics
  - Fortran has 8 levels
  - Ada has 6 levels
- Lesson
  - When unsure, use parentheses!

Precedence for Infix Notations

Fortran	Pascal	C	Ada
		++, -- (post-inc., dec.)	
**	not	++, -- (pre-inc., dec.), +, - (unary), &, * (address, contents of), !, ~ (logical, bit-wise not)	abs (absolute value), not, **
*, /	*, /, div, mod, and	* (binary), /, % (modulo division)	*, /, mod, rem
+, - (unary and binary)	+, - (unary and binary), or	+, - (binary)	+, - (unary)
		<<, >> (left and right bit shift)	+, - (binary), & (concatenation)
.eq., .ne., .lt., .le., .gt., .ge. (comparisons)	<, <=, >, >=, =, <>, IN	<, <=, >, >= (inequality tests)	=, /= , <, <=, >, >=
.not.		==, != (equality tests)	
		& (bit-wise and)	
		^ (bit-wise exclusive or)	
		| (bit-wise inclusive or)	
.and.		&& (logical and)	and, or, xor (logical operators)
.or.		|| (logical or)	
.eqv., .neqv. (logical comparisons)		?: (if...then...else)	
		=, +=, -=, *=, /=, %=, >>=, <<=, &=, ^=, |= (assignment)	
		, (sequencing)	

Figure 6.1 Operator precedence levels in Fortran, Pascal, C, and Ada. The operators at the top of the figure group most tightly.

Short-Circuiting

- Q: What will be printed?

```
int main()
{
    int x=0;
    if(0 && (x=1)==1){
        x++;
    }
    printf("x=%d\n", d);
}
```

Short-Circuiting

- Evaluating partial boolean expressions, not all
  - Consider (a < b) && (b < c)
    - If a >= b there is no point evaluating whether b < c
    - because (a < b) && (b < c) is automatically false
  - Other similar situations

```
if (b != 0 && a/b == c) ...
if (*p && p->foo) ...
if (f || messy()) ...
```

- Short-circuiting improves the performance

```
if (p != NULL && p->key != val)
        insert(p->next, val);
```

  - What if short-circuiting is not provided as in Pascal?

Value vs. Location

- Assignment statement

```
d = a;
a = b + c;
```

value of a, r-value

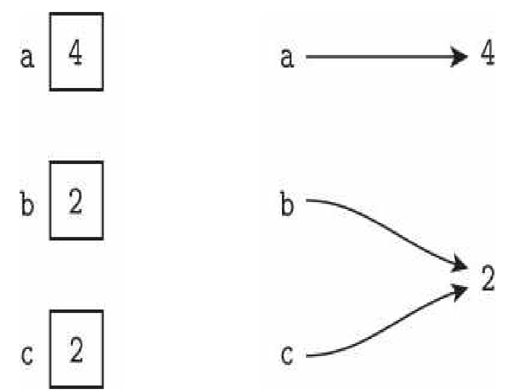
location of a, l-value

- Value model
  - Expression can be either l-value or r-value
  - Not all expressions can be an l-value (e.g. 2+3 = a)

- Reference model
  - Every variable is an l-value
  - When a variable is used for r-value, it must be dereferenced to obtain the value. (It is done implicitly and automatically.)

Value Model vs. Reference Model

- Variables as values vs. variables as references
  - Value-oriented languages
    - C, Pascal, Ada
  - Reference-oriented languages
    - Most functional languages (Lisp, Scheme, ML)
    - Clu, Smalltalk
  - Java deliberately in-between
    - Built-in (primitive) types are values
      e.g. byte, char, int, float, boolean, …
    - User-defined types are references to objects
      e.g. all classes including Integer, Double, String, etc



Value model Reference model

Expression- vs. Statement-Oriented

- Expression-oriented languages:
  - No separate notion of expression and statement
  - Functional languages (Lisp, Scheme, ML), Algol-68

Algol68

```
a := if  b < c then d else e;
a := begin f(b), g(c) end

g(d);
2 + 3;
```

Statements in other languages can be used as expressions (the value of last statement is used)

Expressions are used and the results are thrown away

- Statement-oriented languages:
  - Most imperative languages

- C is kind a halfway in-between
  - Allows expression to appear instead of statement

```
if (a==b) { … }
if (a=b) { … }
```

Side Effects

- Side effect is a permanent state change by a function
  - Often discussed in the context of functions
  - Some noticeable effect of call other than return value

- In a more general sense, assignment statements provide the ultimate example of side effects
  - They change the value of a variable
  - Side effects are fundamental to the whole von Neumann model of computing
  - In (pure) functional, logic, and dataflow languages, there are no such changes (single-assignment languages)
  - But side effect can be nice for some functions e.g. rand()

Sequencing

- Sequencing
  - Specifies a linear ordering on statements
    - One statement follows another
    - E.g.) begin

```
begin
        statement1;
        statement2;
        statement3;
end
```

- Selection
  - Same meaning as series of if-then-else statements

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

- Examples

<Modula-2 >

```
IF a = b THEN ...
ELSIF a = c THEN ...
ELSIF a = d THEN ...
ELSE ...
END
```

<Lisp>

```
(cond
        ((= A B) (Expr1))
        ((= A C) (Expr2))
        ((= A D) (Expr3))
        (T       (Exprt))
)
```

Selection Implementation

- Conditional branch instruction
  - For simple selections
- Jump code
  - For general selections and logically-controlled loops
  - Especially useful in the presence of short-circuiting

```
if ((A > B) and (C > D)) or (E <> F) then
    then_clause
else
    else_clause
```

Code for No Short-Circuiting

- Code generated w/o short-circuiting (Pascal)

```
((A > B) and (C > D)) or (E <> F)
```

```
        r1 := A
        r2 := B
        r1 := r1 > r2
        r2 := C
        r3 := D
        r2 := r2 > r3
        r1 := r1 & r2
        r2 := E
        r3 := F
        r2 := r2 ≠ r3
        r1 := r1 | r2
        if r1 = 0 goto L2
L1:     then_clause              -- label not actually used
        goto L3
L2:     else_clause
L3:
```

Code for Short-Circuiting

- Code generated w/ short-circuiting (C)

```
((A > B) and (C > D)) or (E <> F)
```

```
        r1 := A
        r2 := B
        if r1 <= r2 goto L4
        r1 := C
        r2 := D
        if r1 > r2 goto L1
L4:     r1 := E
        r2 := F
        if r1 = r2 goto L2
L1:     then_clause
        goto L3
L2:     else_clause
L3:
```

No need to compute the whole boolean value into a register and test it for conditional jump

Selection – case/switch

- Sequence of if-then-else (nested if-then-else) can be rewritten as case/switch

<Modula-2>

```
CASE ... OF
   1:     clause_A
|  2, 4: clause_B
|  3, 6: clause_C
   ELSE  clause_D
END
```

Jump Tables for case/switch

- (Linear) jump tables
  - Instead of sequential test, compute address to jump to

Jump table

```
T:   &L1                        -- case 1
     &L2                        -- case 2
     &L3                        -- case 3
     &L2                        -- case 4
     &L4                        -- case 5
     &L3                        -- case 6
L5:  r1 := ...                  -- calculate tested expr
     if r1 < 0 or r1 > 6 goto L4   -- ELSE case
     r2 := T[r1-1]             -- subtract off lower bound
     goto *r2
L6:  …
L1:  clause A
     goto L7
L2:  clause B
     goto L7
…
```

Alternative Implementations

- Linear jump table is fast for case/switch
  - Also space efficient, if overall set of cases are dense and does not contain a large ranges
  - May consume extraordinary space for large value ranges

- Alternatives
  - Sequential testing (nested ifs), O(n)
    - Good for small number of cases
  - Hashing, O(1)
    - Attractive for large label values
    - But space inefficient for large value ranges
  - Binary search , O(logn)
    - Accommodate ranges easily

Iteration

- Logically-controlled loops
  - Controlled by a boolean expression

```
while condition_expr
do
   ...
enddo
```

- Enumeration-controlled loops
  - i: index of the loop, loop variable
  - Controlled by index's initial value, its bound, and step size
  - Semantic complications
    - Loop enter/exit in other ways
      - E.g., break, continue
    - Scope of control variable
    - Changes to bounds within loop
    - Changes to loop variable within loop
    - Value after the loop

```
do i = 1, 10, 2
   ...
enddo
```

Recursion

- Recursion is equally powerful to iteration
  - Often more intuitive (sometimes less)
  - Naïve implementation is less efficient
    - If a recursive call is actually implemented with a subroutine call,
      it will allocate space for its function frame (local variables, bookkeeping information)
    - Compiler optimizations is required to generate excellent code for recursion (e.g., tail recursion)

Tail Recursion

- Tail recursion
  - A special kind of recursion where the recursive call is the very last thing in the function.
  - I.e., it's a function that does not do anything at all after recursion.
  - I.e., if no computation follows a recursive call, we call it tail recursion

- Tail recursion is desirable for optimization
  - Compiler can optimize it easily
  - The information to store for the previous function is only the return address, since nothing to compute after return
  - Otherwise, we may need to keep local variables for the remaining computation after recursive calls

Tail Recursion Elimination

```
int gcd (int a, int b) { /* assume a, b > 0 */
   if (a == b) return a;
   else if (a > b) return gcd (a - b,b);
   else return gcd (a, b – a);
}
```

Return multiple times at the end

```
int gcd (int a, int b) { /* assume a, b > 0 */
start:
   if (a == b) return a;
   else if (a > b) { a = a - b; goto start; }
   else { b = b – a; goto start; }
}
```

Return once at the end

Summary

- Expression
  - Evaluation order – commutativity, associativity

- Control flow
  - Sequencing
  - Selection
    - Short-circuiting, jump table, …
  - Iteration (loop)
    - Logically-controlled, enumeration-controlled
  - Recursion
    - Optimization for tail-recursion