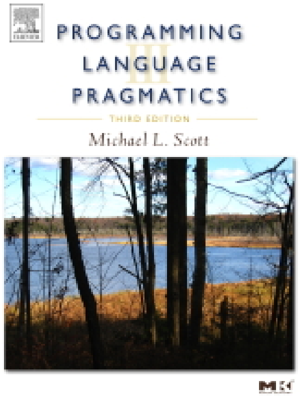
Control Flow

UNIVERSIDADE DA CORUÑA

GRAO EN ENXEÑERÍA INFORMÁTICA
DESEÑO DAS LINGUAXES DE PROGRAMACIÓN

Based on Chapter 6 of:
Michael L. Scott, *Programming Language Pragmatics*,
Morgan Kaufmann, 2008.



Control Flow

- Basic paradigms for control flow:
  - Sequencing
  - Selection
  - Iteration
  - Procedural Abstraction
  - Recursion
  - Concurrency
  - Exception Handling and Speculation
  - Nondeterminacy

Expression Evaluation

- Infix, prefix operators
- Precedence, associativity (see Figure 6.1)
  - C has 15 levels - too many to remember
  - Pascal has 3 levels - too few for good semantics
  - Fortran has 8
  - Ada has 6
    - Ada puts *and* & *or* at same level
  - **Lesson**: when unsure, use parentheses!

Expression Evaluation

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 operator s at the top of the figure group most tightly.

Expression Evaluation

- Ordering of operand evaluation (generally none)
- Application of arithmetic identities
  - distinguish between commutativity, and (assumed to be safe)
  - associativity (known to be dangerous)

  `(a + b) + c` works if `a~=maxint` and `b~=minint` and `c<0`

  `a + (b + c)` does not
  - inviolability of parentheses

Expression Evaluation

- Short-circuiting
  - 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()) ...
```

Expression Evaluation

- Variables as values vs. variables as references
  - value-oriented languages
    - C, Pascal, Ada
  - reference-oriented languages
    - most functional languages (Lisp, Scheme, ML)
    - Clu, Smalltalk
  - Algol-68 kinda halfway in-between
  - Java deliberately in-between
    - built-in types are values
    - user-defined types are objects -- references

Expression Evaluation

- Expression-oriented vs. statement-oriented languages
  - expression-oriented:
    - functional languages (Lisp, Scheme, ML)
    - Algol-68
  - statement-oriented:
    - most imperative languages
  - C kinda halfway in-between (distinguishes)
    - allows expression to appear instead of statement

Expression Evaluation

- Orthogonality
  - Features that can be used in any combination
    - Meaning is consistent

```
if (if b != 0 then a/b == c else false) then ...
if (if f then true else messy()) then ...
```

- Initialization
  - Pascal has no initialization facility (assign)
- Aggregates
  - Compile-time constant values of user-defined composite types

Expression Evaluation

- Assignment
  - statement (or expression) executed for its side effect
  - assignment operators (+=, -=, etc)
    - handy
    - avoid redundant work (or need for optimization)
    - perform side effects exactly once
  - C --, ++
    - postfix form

Expression Evaluation

- Side Effects
  - often discussed in the context of functions
  - a side effect is some permanent state change caused by execution of function
    - some noticable 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

Expression Evaluation

- SIDE EFFECTS ARE FUNDAMENTAL TO THE WHOLE VON NEUMANN MODEL OF COMPUTING

- In (pure) functional, logic, and dataflow languages, there are no such changes
  - These languages are called SINGLE-ASSIGNMENT languages

Expression Evaluation

- Several languages outlaw side effects for functions
  - easier to prove things about programs
  - closer to Mathematical intuition
  - easier to optimize
  - (often) easier to understand
- But side effects can be nice
  - consider rand()

Expression Evaluation

- Side effects are a particular problem if they affect state used in other parts of the expression in which a function call appears
  - It's nice not to specify an order, because it makes it easier to optimize
  - Fortran says it's OK to have side effects
    - they aren't allowed to change other parts of the expression containing the function call
    - Unfortunately, compilers can't check this completely, and most don't at all

Sequencing

- Sequencing
  - specifies a linear ordering on statements
    - one statement follows another
  - very imperative, Von-Neuman

Selection

- Selection
  - sequential if statements

```
if ... then ... else
if ... then ... elsif ... else
(cond
      (C1) (E1)
      (C2) (E2)
      ...
      (Cn) (En)
            (T)  (Et)
)
```

Selection

- Selection
  - Fortran computed gotos
  - jump code
    - for selection and logically-controlled loops
    - no point in computing a Boolean value into a register, then testing it
    - instead of passing register containing Boolean out of expression as a synthesized attribute, pass inherited attributes INTO expression indicating where to jump to if true, and where to jump to if false

Selection

- Jump is especially useful in the presence of short-circuiting
- **Example** (section 6.4.1 of book):

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

Selection

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

```
        r1 := A                  -- load
        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:
```

Selection

- Code generated w/ short-circuiting (C)

```
        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:
```

Iteration

- Enumeration-controlled
  - Pascal or Fortran-style for loops
    - scope of control variable
    - changes to bounds within loop
    - changes to loop variable within loop
    - value after the loop

Recursion

- Recursion
  - equally powerful to iteration
  - mechanical transformations back and forth
  - often more intuitive (sometimes less)
  - *naïve* implementation less efficient
    - no special syntax required
    - fundamental to functional languages like Scheme

Recursion

- Tail recursion
  - No computation follows recursive call

```
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);
}
```