Control Flow

Chapter 6

Control Flow

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

Control Flow

- Sequencing:
  - major role in imperative languages
  - minor role in functional languages
- Recursion
  - major role in functional languages
  - less important in imperative languages (iteration)
- Logic programming
  - no control flow at all
  - programmer specifies a set of rules
  - the implementation finds the order to apply the rules

Expression Evaluation

- Expression: operands and operators
- Operator
  - function: $a + b$ means $+(a, b)$
  - Ada: `a+b` is short for `"+"(a,b)`
  - C++: `a+b` is short for `a.operator+(b)`
- Notation
  - *prefix* + a b or +(a, b) or (+ a b)
  - *infix* a + b
  - *postfix* a b +
- Infix: common notation; easy to work with
- Pre/Postfix: precedence/associativity not needed

Expression Evaluation

- Infix: binary operators:

```
a + b
```

- Prefix: unary operators, function calls (with parentheses)

```
-4, f(a, b)
```

- Scheme: prefix always – *Cambridge Polish* notation

```
(+ (* 1 2) 3)
(append x y my_list)
```

- Postfix: Pascal dereferencing `^`, C post in/decrement

```
a++, a--
```

- Ternary operators: C++ conditional operator '`?:`'

```
(a > b) ? a : b
```

Expression Evaluation

- Precedence, associativity
- Fortran example: `a + b * c ** d ** e / f`
- Precedence levels
- C, C++, Java, C#: too many levels to remember (15)
- Pascal: too few for good semantics

  `if A < B and C < D then …` means

  `if A < (B and C) < D then …`
- Fortran has 8 levels
- Ada has 6 (it puts *and* & *or* at same level)
- Associativity: usually left associative
  - Right associative; C: `a = b = c` means `a = (b = c)`
- **Lesson**: when unsure, use parentheses!

Expression Evaluation

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

Expression Evaluation

- *Side Effect*:
  - any effect other than returning a value to surrounding context
  - essential in imperative programming
    - computing by side effects
  - (pure) functional languages: no side effects
    - same value returned by an expression at any point in time
- *Value vs Reference*
  - `d = a` value of `a`
  - `a = b + c` location of `a`
  - *Value model:* a variable is a named container for a value
    - C, Pascal, Ada
  - *Reference model*: a variable is a named reference to a value
    - Scheme, Lisp, Python, Clu

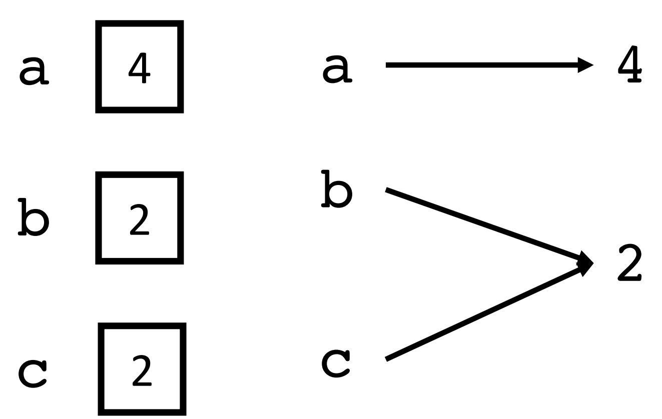
Expression Evaluation

- Example:

```
b := 2
c := b
a := b + c
```

- Pascal (value model):
  - any variable can contain value 2
- Clu (reference model):
  - there is only one 2

- value model
- reference model



Expression Evaluation

- Value vs Reference
- Java: in-between
  - built-in types – value model
  - user-defined types – reference model
  - drawback: built-in types cannot be passed when user-defined is expected – wrapping is used (boxing)
- C#: user can choose
  - `class` – reference
  - `struct` – value
- Important to distinguish between variables referring to:
  - the same object or
  - different objects whose values happen to be equal
  - Scheme, Lisp provide several notions of "equality"

Subroutines: Parameter Passing

- Call by *value*: pass the value
  - C, C++, Pascal, Java, C#
- Call by *reference*: pass the address
  - Fortran, C++, C (pointers)
- Call by *sharing*:
  - Java, C#, Python, Scheme
- Call by *name*: direct substitution; evaluated each time it is needed
  - Algol 60, Simula
- Call by *need*: call by name with memoization
  - Haskell, R

Short-circuiting

- Short-circuiting

  ```
  (a < b) && (c < d)
  ```

  - if `a` > `b` then the second part does not matter
- *Short-circuit evaluation*: evaluate only what is needed
  - *Lazy evaluation*
  - can save time:

    ```
    if (unlikely_cond && expensive_cond) ...
    ```
- Semantics change:
  - Avoiding out-of-bounds indices:

    ```
    if (i >= 0 && i < MAX && A[i] > foo) ...
    ```
  - Avoiding division by zero:

    ```
    if (d == 0 || n/d < threshold) ...
    ```

Short-circuiting: example

- C list searching:

```
while (p && p->key != val)
    p = p -> next;
```

- Pascal does not have short circuit:

```
p := my_list;
still_searching := true;
while still_searching do
    if p = nil then
        still_searching := false
    else if p^.key = val then
        still_searching := false
    else p := p^.next;
```

- Sometimes side effects are desired
  - C has also non-short-circuit: `&`, `|`

Short-circuiting: implementation

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

- Without short circuit

```
    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 -- (L1 unused)
    goto L3
L2: else_clause
L3:
```

- With short circuit (*jump code*)

```
    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

- Arbitrary complexity of programs:
  - Iteration – `for, while, …`
  - Recursion
- Iterate over collections
  - Iterator objects:
    - C++, Java, Euclid
  - True iterators:
    - Python, C#, Ruby, Clu
  - First-class functions
    - Scheme, Smalltalk

Iteration

- Python – user-defined iterator

```
class PowTwo:
    def __init__(self, max = 0):
        self.max = max

    def __iter__(self):
        self.n = 0
        return self

    def __next__(self):
        if self.n < self.max:
            result = 2 ** self.n
            self.n += 1
            return result
        else:
            raise StopIteration
```

Iteration

- Python – user-defined iterator

```
a = PowTwo(3)
i = iter(a)
print(next(i))  # 1
print(next(i))  # 2
print(next(i))  # 4
print(next(i))  # raises StopIteration
```

True iterators

- Example – Python:

```
for i in range(first, last, step):
    ...
```

  - `range` – built-in iterator
  - use a call to a `yield` statement
  - like `return` but control goes back to iterator after each iteration
  - the iterator continues where it left off
- `yield` – separate thread of control
  - its own program counter
  - execution interleaved with that of the `for` loop

True iterators

- Python generator – much simpler

```
def PowTwoGen(max = 0):
    n = 0
    while n < max:
        yield 2 ** n
        n += 1

a = PowTwoGen(3)
print(next(a))  # 1
print(next(a))  # 2
print(next(a))  # 4
print(next(a))  # raises StopIteration
```

True iterators

- Python generator: can generate infinite stream

```
def all_even():
    n = 0
    while True:
        yield n
        n += 2
print(next(a))    # 0
print(next(a))    # 2
print(next(a))    # 4
print(next(a))    # 6
print(next(a))    # 8
print(next(a))    # 10
...
```

First-class functions

- Iteration with first-class functions

```
(define uptoby
  (lambda (low high step f)
    (if (<= low high)
        (begin
          (f low)
          (uptoby (+ low step) high step f))
        '())))
(let ((sum 0))
  (uptoby 1 100 2
          (lambda (i)
            (set! sum (+ sum i))))
  sum)                                  ; 2500
```

Recursion

- Recursion vs Iteration – efficiency
- naïve implementation of recursion is less efficient
  - time and space needed for subroutine calls
- the language can generate fast code for recursion
- *Tail recursion*
  - no computation after the recursive call
  - as fast as iteration

```
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);
}
```

Recursion

- Tail recursion
  - can be implemented without the stack allocations
  - a good compiler can recast the recursive function as:

```
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; }
}
```

Recursion

- Scheme
- Recursive summation

```
(define sum1
 (lambda (f low high)
 (if (= low high)
  (f low)                                ; then
  (+ (f low) (sum1 f (+ low 1) high))))) ; else
(sum1 + 1 10)          ; 55
```

Recursion

- Scheme
- Tail recursive summation

```
(define sum2
  (lambda (f low high st)
    (if (= low high)
        (+ st (f low))
        (sum2 f (+ low 1) high (+ st (f low))))))
(sum2 + 1 10 0)        ; 55
```

- Eliminate `st` (subtotal)

```
(define sum3
  (lambda (f low high)
    (sum2 f low high 0)))
```

Recursion

- Careless recursion can be very bad
- Exponential

```
def fib1(n):
    if n == 0 or n == 1:
        return 1
    return fib1(n-1) + fib1(n-2)
```

- Linear

```
def fib2(n):
    f1 = f2 = 1
    for i in range(n-1):
        f1, f2 = f2, f1 + f2
    return f2
```

Recursion

- Evaluation order (of subroutine arguments)
- *Applicative*: evaluate before passing
  - used by most languages
- *Normal-order*: pass unevaluated; evaluate when needed
  - *lazy evaluation*
  - short-circuit evaluation
  - macros
  - Scheme: used for infinite data structures
    - *lazy data structures*

Recursion

- Example: Scheme lazy (infinite) data structures
  - `delay` – a promise
  - `force` – forces evaluation

```
(define naturals
  (letrec ((next (lambda (n) (cons n (delay (next
(+ n 1)))))))
    (next 1)))
(define head car)
(define tail (lambda (stream) (force (cdr
stream))))

(head naturals)                => 1
(head (tail naturals))         => 2
(head (tail (tail naturals))) => 3
...
```