CSC 533: Organization of Programming Languages

Spring 2008

Control and subprogram implementation
- control structures
    conditionals, loops, branches, …
- subprograms (procedures/functions/subroutines)
    subprogram linkage, parameter passing, implementation, …

We will focus on C, C++, and Java as example languages

1

Conditionals & loops

early control structures were tied closely to machine architecture
e.g., FORTRAN arithmetic if: based on IBM 704 instruction

```
        IF (expression) 10, 20, 30
  10    code to execute if expression < 0
        GO TO 40
  20    code to execute if expression = 0
        GO TO 40
  30    code to execute if expression > 0
  40    . . .
```

later languages focused more on abstraction and machine independence

some languages provide counter-controlled loops
e.g., in Pascal:
```
for i := 1 to 100 do
begin
    . . .
end;
```
- counter-controlled loops tend to be more efficient than logic-controlled
- C/C++ and Java don't have counter-controlled loops (for is syntactic sugar for while)

2

Branching

unconditional branching (i.e., GOTO statement) is very dangerous

- leads to *spaghetti code*, raises tricky questions w.r.t. scope and lifetime
  what happens when you jump out of a function/block?
  what happens when you jump into a function/block?
  what happens when you jump into the middle of a control structure?

most languages that allow GOTO's restrict their use

- in C/C++, can't jump into another function
  can jump into a block, but not past declarations

```
void foo() {
    . . .
    goto label2;      // illegal: skips declaration of str
    . . .
  label1:
    string str;
    . . .
  label2:
    goto label1;      // legal: str's lifetime ends before branch
}
```

Branching (cont.)

why provide GOTO's at all?   (Java doesn't)

- backward compatibility
- some argue for its use in specific cases (e.g., jump out of deeply nested loops)

C/C++ and Java provide statements for more controlled loop branching

- *break:* causes termination of a loop

```
while (true) {
    num = input.nextInt();
    if (num < 0) break;
    sum += num;
}
```

- *continue:* causes control to pass to the loop test

```
while (inputKey != 'Q') {
    if (keyPressed()) {
        inputKey = GetInput();
        continue;
    }
    . . .
}
```

Procedural control

any implementation method for subprograms is based on the semantics of subprogram linkage (call & return)

in general, a subprogram call involves:

1. save execution status of the calling program unit
2. parameter passing
3. pass return address to subprogram
4. transfer control to subprogram

possibly: allocate local variables, provide access to non-locals

in general, a subprogram return involves:

1. if out-mode parameters or return value, pass back value(s)
2. deallocate parameters, local variables
3. restore non-local variable environment
4. transfer control to the calling program unit

5

Parameters

in most languages, parameters are *positional*

- Ada also provides *keyword* parameters:

```
AddEntry(dbase -> cds, new_entry -> mine);
```

advantage: don't have to remember parameter order
disadvantage: do have to remember parameter names

Ada and C/C++ allow for default values for parameters

C/C++ & Java allow for optional parameters (specify with …)

```
public static double average(double... values) {
    double sum = 0;
    for (double v : values) { sum += v; }
    return sum / values.length;
}

System.out.println( average(3.2, 3.6) );
System.out.println( average(1, 2, 4, 5, 8) );
```

- if multiple parameters, optional parameter must be rightmost   WHY?

6

3

Parameter passing

can be characterized by the direction of information flow

in mode:	pass by-value
out mode:	pass by-result
inout mode:	pass by-value-result, by-reference, by-name

by-value (in mode)
- parameter is treated as local variable, initialized to argument value

advantage: safe (function manipulates a copy of the argument)
disadvantage: time & space required for copying

used in ALGOL 60, ALGOL 68
default method in C++, Pascal, Modula-2
only method in C (and, technically, in Java)

7

Parameter passing (cont.)

by-result (out mode)
- parameter is treated as local variable, no initialization
- when function terminates, value of parameter is passed back to argument

potential problems: `ReadValues(x, x);`

`Update(list[GLOBAL]);`

by-value-result (inout mode)
- combination of by-value and by-result methods
- treated as local variable, initialized to argument, passed back when done

same potential problems as by-result

used in ALGOL-W, later versions of FORTRAN

8

4

Parameter passing (cont.)

by-reference (inout mode)

- instead of passing a value, pass an access path (i.e., reference to argument)

advantage: time and space efficient

disadvantage: slower access to values (must dereference), alias confusion

```
void IncrementBoth(int & x, int & y)          int a = 5;
{                                             IncrementBoth(a, a);
    x++;
    y++;
}
```

requires care in implementation: arguments must be l-values (i.e., variables)

used in early FORTRAN
can specify in C++, Pascal, Modula-2
Java objects look like by-reference

9

Parameter passing (cont.)

by-name (inout mode)

- argument is textually substituted for parameter
- form of the argument dictates behavior

    if argument is a: variable → by-reference
                                constant → by-value
                                array element or expression → ???

```
real procedure SUM(real ADDER, int INDEX, int LENGTH);
begin
    real TEMPSUM := 0;
    for INDEX := 1 step 1 until LENGTH do
        TEMPSUM := TEMPSUM + ADDER;
    SUM := TEMPSUM;
end;
```

```
SUM(X, I, 100)                 →        100 * X
SUM(A[I], I, 100)              →        A[1] + . . . + A[100]
SUM[A[I]*A[I], I, 100)         →        A[1]² + . . . + A[100]²
```

- flexible but tricky – used in ALGOL 60, replaced with by-reference in ALGOL 68

10

Parameters in Ada

in Ada, programmer specifies parameter mode

- implementation method is determined by the compiler

in	→	by-value
out	→	by-result
inout	→	by-value-result (for non-structured types)
	→	by-value-result *or* by-reference (for structured types)

- choice of inout method for structured types is implementation dependent

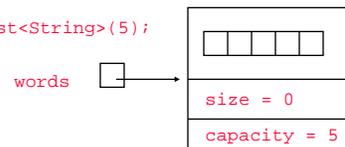 *DANGER:* `IncrementBoth(a, a)` yields different results for each method!

Parameters in Java

parameter passing is by-value, but looks like by-reference for objects

- recall, Java objects are implemented as pointers to dynamic data

```java
public void messWith(ArrayList<String> lst)
{
    lst.add("okay");
    . . .
    lst = new ArrayList();
}


ArrayList<String> words = new ArrayList<String>(5);
messWith(words);
```

when pass an object, by-value makes a copy (here, copies the pointer)
    pointer copy provides access to data fields, can change
    but, can't move the original

Polymorphism

in C/C++ & Java, can have different functions/methods with the same name
- overloaded functions/methods must have different parameters to distinguish

```
public double doStuff(String str) { … }

public double doStuff(int x) { … }    // OK since param type is different

public int doStuff(String str) { … }  // not OK, since only return differs
```

in C++, can overload operators for new classes

```
bool Date::operator==(const Date & d1, const Date & d2) {
    return (d1.day == d2.day &&
            d1.month == d2.month &&
            d1.year == d2.year);
}
```

- overloaded operators are NOT allowed in Java   RISKS?

13

Implementing subprograms

- some info about a subprogram is independent of invocation
  - e.g., constants, instructions
  - ➔ can store in static code segment

- some info is dependent upon the particular invocation
  - e.g., return value, parameters, local variables (?)
  - ➔ must store an *activation record* for each invocation

  - local variables may be allocated when subprogram is called, or wait until declarations are reached (stack-dynamic)

Activation Record

local variables
parameters
static link
dynamic link
return address

14

Run-time stack

when a subroutine is called, an instance of its activation record is pushed
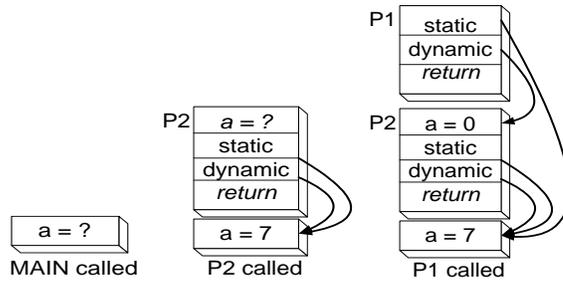
```
program MAIN;
  var a : integer;

  procedure P1;
  begin
    print a;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1;
  end; {of P2}

  begin
      a := 7;
      P2;
  end. {of MAIN}
```


when accessing a non-local variable
- follow static links for static scoping
- follow dynamic links for dynamic scoping

15

Run-time stack (cont.)

when a subroutine terminates, its activation record is popped (LIFO behavior)

```
program MAIN;
  var a : integer;

  procedure P1;
  begin
    print a;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1;
  end; {of P2}

  begin
      a := 7;
      P2;
  end. {of MAIN}
```
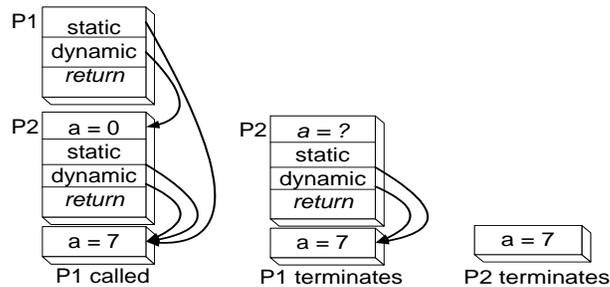

when the last activation record is popped,
control returns to the operating system
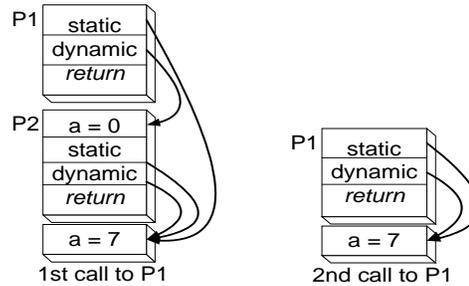
16

Run-time stack (cont.)

note: the same subroutine may be called from different points in the program

```
program MAIN;
  var a : integer;

  procedure P1;
  begin
    print a;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1;
  end; {of P2}

  begin
      a := 7;
      P2;
      P1;
  end. {of MAIN}
```


P1
| static |
| dynamic |
| *return* |

P2
| a = 0 |
| static |
| dynamic |
| *return* |

| a = 7 |
1st call to P1

P1
| static |
| dynamic |
| *return* |

| a = 7 |
2nd call to P1

➔ using dynamic scoping, the same variable in a subroutine may refer to a different addresses at different times

17

In-class exercise

run-time stack?

output using static scoping?

output using dynamic scoping?

```
program MAIN;
  var a : integer;

  procedure P1(x : integer);
    procedure P3;
    begin
      print x, a;
    end; {of P3}
  begin
    P3;
  end; {of P1}

  procedure P2;
  var a : integer;
  begin
      a := 0;
      P1(a+1);
  end; {of P2}

  begin
      a := 7;
      P1(10);
      P2;
  end. {of MAIN}
```

18

9

Optimizing scoping

naïve implementation:
- if variable is not local, follow chain of static/dynamic links until found

in reality, can implement static scoping more efficiently (displays)
- block nesting is known at compile-time, so can determine number of links that must be traversed to reach desired variable
- can also determine the offset within the activation record for that variable

➔ can build separate data structure that provides immediate access

can't predetermine # links or offset for dynamic scoping
- subroutine may be called from different points in the same program

- can't even perform type checking statically   WHY NOT?

19

Monday: TEST 1

types of questions:
- factual knowledge: TRUE/FALSE
- conceptual understanding: short answer, discussion
- synthesis and application: parse trees, heap trace, scoping rules, …

the test will include extra points (Mistakes Happen!)
- e.g., 52 or 53 points, but graded on a scale of 50

study advice:
- review online lecture notes (if not mentioned in class, won't be on test)
- review text
- reference other sources for examples, different perspectives
- look over quizzes

20