CSC 533: Programming Languages

Spring 2015

Subprogram implementation

- subprograms (procedures/functions/subroutines)
- subprogram linkage
- parameter passing
- run-time stack

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

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

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?

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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)

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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

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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)
{
    x++;
    y++;
}
```

```
int a = 5;
IncrementBoth(a, a);
```

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

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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

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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!

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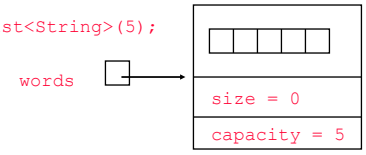
Parameters in Java

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

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

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

```
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

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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?

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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

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Run-time stack

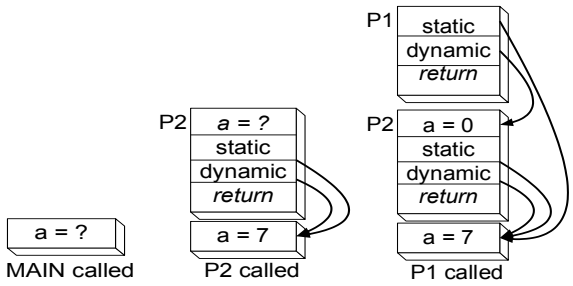
when a subroutine is called, an instance of its activation record is pushed

```
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

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Run-time stack (cont.)

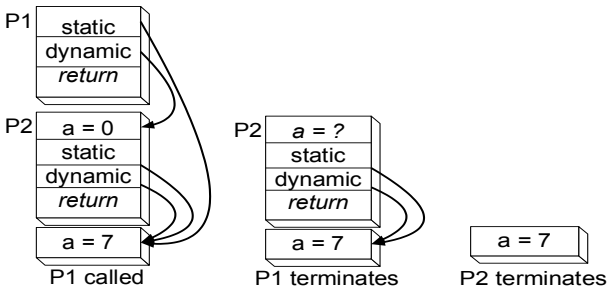
when a subroutine terminates, its activation record is popped (LIFO behavior)

```
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

Run-time stack (cont.)

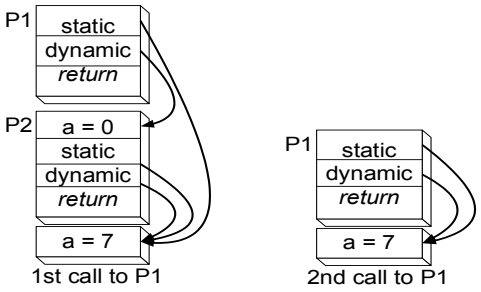
note: the same subroutine may be called from different points in the program

```
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}
```



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

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}
```

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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

- 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?

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