

CSC 324: Principles of Programming Languages

Procedural Language Design Issues

Readings: Mitchell 7.1-7.3
Recommended Reference: Sethi Chapter 5 (on hold in library)

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Components of a Procedure

1. Name
2. Formal parameters, optionally with types
 - **parameter** (formal parameter)
Local variable whose value is received from caller
 - **argument** (actual parameter)
The info passed from caller to callee
3. Body, which is a syntactic construct in the language:
 - Block, i.e., declarations and statements
 - Expression
 - Conjunction of terms
4. Optional result, optionally with a type

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Procedural Language Design Issues

Procedures: A Control Abstraction

- A block of code that can be called (imperative)
- A lambda expression (functional)
- A horn clause (logic programming)

Procedures modularize program structure

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Procedure Implementation Issues

The general notion of a procedure leaves a number of points unspecified:

- How to pass parameters when the procedure is called
- How to maintain local state and control information
- How to access non-local names within a procedure body

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Parameter Passing

Matching arguments with parameters:

1. Positional association:

- Arguments are associated with parameters left to right

2. Keyword association:

- Arguments are given tags, eg:
procedure plot (x,y: real; penup:
boolean)
...
plot(0.0, 0.0, penup=>true)
plot(penup=>true, x=>0.0, y=>0.0)

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Parameter Passing

3. Optional arguments:

- E.g., C printf(...)
- Extra arguments are packaged into some structure
- Passed to special parameter

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Passing Modes

How to treat arguments

(pass-by-x/call-by-x):

1. Pass by value

(Java, C, C++, Pascal, Ada, Scheme, Algol68)

2. Pass by result

(Ada)

3. Pass by value-result

(some Fortrans, Ada)

4. Pass by reference

(Java objects, C++ with &, some Fortrans, Pascal with var, COBOL)

5. Pass by name

(Algol 60)

Example for Passing Modes

```
{ c : array[1..10] of integer;  
  m,n integer;  
  procedure r ( i , j : integer ) begin  
    i := i + 1;  
    j := j + 2  
  end r;  
  ...  
  m := 2;  
  n := 3;  
  r(m,n);           // call 1  
  write m, n ;     // print 1  
  
  m := 2;  
  c[1] := 1;  
  c[2] := 4;  
  c[3] := 8;  
  r(m,c[m]);           // call 2  
  write m,c[1],c[2],c[3]; // print 2  
}
```

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Pass by Value

- Initial values of parameters copied from current values of arguments
- Final values of parameters are “lost” at return time (like local variables).
- Example:

```
at call 1: i = 2 j = 3
print 1:
at call 2: i = 2 j = 4
print 2:
```
- Benefit: Arguments protected from changes in procedure.
- Problem: Requires copying of values: costs time and space, especially for large aggregates.

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Pass by Result (Example)

Suppose proc `r` initializes `i` and `j` to 0:

- `call 1`:
 - final values of `i` and `j`:
 - `m` and `n` are set to:
- `print 1`:
- `call 2`: more problematic
 - final values of `i` and `j`:
 - which element of `c` is modified, `c[1]` or `c[2]`?
- `print 2`:
 - If `c[1]` is modified:
 - If `c[2]` is modified:

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Pass by Result

- No initial values of parameters
 - Final values of parameters are copied back to arguments
 - Example: does not work, as written
- ⇒ For **output** values only. Used to indicate that a parameter is intended solely for returning a result.

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Problems with Pass by Result

- Requires copying of values: costs time and space, especially for large aggregates. (Cf. Call by value.)
- What if the argument is not a variable?
E.g., `r(1, 2)`;
- What if a variable is used twice in the argument list?
E.g., `r(m, m)`;
- What about calculations to determine locations of arguments?
E.g., which `c[m]`?

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Pass by Value-Result

- Initial values of parameters copied from current values of arguments
- Final values of parameters copied back to arguments

⇒ Combines functionality of pass by value and pass by result for **same** parameter.

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Further Specifying Pass by Result

With pass by result or pass by value-result, order of assignments and address computations is important.

Options:

1. Perform return address computations at call time:
On second return:
m set to 3; c[2] set to 6
print 2:

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Pass by Value-Result (Example)

- call 1:
 - initial: i = j =
 - final: i = j =
 - return: m and n set to:
- print 1:
- call 2:
 - initial: i = j =
 - final: i = j =
 - return: which element of c is modified, c[2] or c[3]?
- print 2:
 - if c[2] is modified:
 - if c[3] is modified:

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Further Specifying Pass by Result (cont'd)

2. Perform return address computations at return time:
 - (a) Before any assignments:
On second return: same as above, but might not be if procedure has side-effects
 - (b) Just before that assignment, in order:
On second return:
m set to 3; c[3] set to 6
print 2:

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Pass by Reference (Example)

Pass by Reference

- Formal parameters are pointers to the actual parameters (arguments).
- Address computations are performed at procedure call.
- Changes to the formal parameters are thus changes to the actual parameters.

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- call 1:
 - initial: i = j =
 - final: i = j =
 - return: m, n are:
- print 1:
- call 2:
 - initial: i = j =
 - final: i = j =
 - return: m, c[2] are:
- print 2:

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Pass by Reference

- Benefit: No copying for variables
- Problem: allow redefinition of expressions and constants?
- Problem: Leads to **aliasing**
 - two or more visible names for same location
 - can cause side effects not visible from code itself

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Aliasing

```
{ y : integer ;  
  procedure p ( x : integer ) begin  
    x := x + 1;  
    x := x + y  
  end p;  
  ...  
  y := 2;  
  p(y);  
  write y  
}
```

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Aliasing

Pass by Reference:

- The identifiers `x` and `y` refer to the same location in call of `p`.
- Result of “`write y`”?

Pass by Value-Result:

- The identifiers `x` and `y` refer to different locations in call of `p`.
- Result of “`write y`”?

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```
{ i, j, k : integer ;  
  procedure q ( a, b : integer ) begin  
    a := i * b;  
    b := i * b;  
  end q;  
  ...  
  i := 2; j := 3; k := 4;  
  q(i,j);  
  q(k,k);  
}
```

- First call has global-formal aliases:
 - `a` and `i`
- Second call has formal-formal alias:
 - `a` and `b`

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Pass by Name (Example)

Pass by Name

- A “name” for the argument is passed in to procedure
- Like textual substitution of argument in procedure
- Thus address computations are done whenever parameter is used
- Like pass-by-reference for scalar parameters

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- Example:
 - call 1: `m, n` set to:
 - print 1:
 - call 2: `m, c[m]` set to:
 - print 2:
- Benefit: same as pass by reference
- Problems: Inefficient, requires a *thunk*:
 - essentially a little program is passed that represents the argument
 - evaluates argument in caller’s environment

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Summary of Parameter Passing Modes

- Pass by value
- Pass by result
- Pass by value-result
- Pass by reference
- Pass by name