Subprograms

In Text: Chapter 9

Outline

- Definitions
- Referencing environments
- Parameter passing modes and mechanisms
- Advanced subprogram issues

Characteristics of Subprograms

- Fundamental characteristics:
  - A subprogram has a single entry point
  - The caller is suspended during execution of the called subprogram
  - Control always returns to the caller when the called subprogram's execution terminates

Actual/Formal Param Correspondence

- Two basic choices:
  - Positional
  - Keyword

```
Sort (List => A, Length => N);
```

- For Keyword association:
  - Advantage: order is irrelevant
  - Disadvantage: user must know the formal parameter's names

Default Parameter Values

- Example, in Ada:

```
procedure sort (list   : List_Type;
                length : Integer := 100);
   ...
sort (list => A);
```


Design Issues for Subprograms

- What parameter passing methods are provided?
- Are parameter types checked?
- Are local variables static or dynamic?
- What is the referencing environment of a passed subprogram?
- Are parameter types in passed subprograms checked?
- Can subprogram definitions be nested?
- Can subprograms be overloaded?
- Are subprograms allowed to be generic?
- Is separate/independent compilation supported?

Local Referencing Environments

- If local variables are stack-dynamic:
  - Advantages:
    - Support for recursion
    - Storage for locals is shared among some subprograms
  - Disadvantages:
    - Allocation/deallocation time
    - Indirect addressing
    - Subprograms cannot be history sensitive
- Static locals are the opposite

Local Variables in Example PLs

- FORTRAN 77 and 90—most are static, but can have either (SAVE forces static)
- C—both; default is stack dynamic, but variables declared to be static are not
- Pascal, Modula-2, and Ada—dynamic only

Parameters and Parameter Passing

- Semantic Models: in mode, out mode, inout mode
- Conceptual Models of Transfer:
  - Physically move a value
  - Move an access path
- Implementation Models:
  - Pass-by-value
  - Pass-by-result
  - Pass-by-value-result
  - Pass-by-reference
  - Pass-by-name

Pass-By-Value

- in mode
- Either by physical move or access path
- Disadvantages of access path method:
  - Must write-protect in the called subprogram
  - Accesses cost more (indirect addressing)
- Disadvantages of physical move:
  - Requires more storage
  - Cost of the moves

Pass-By-Result

- out mode
- Local's value is passed back to the caller
- Physical move is usually used
- Disadvantages:
  - If value is moved, time and space
  - In both cases, order dependence may be a problem

```
procedure sub1(y: int, z: int);
     ...
sub1(x, x);
```

- Value of x in the caller depends on order of assignments at the return

Pass-By-Value-Result

- inout mode
- Physical move, both ways
- Also called pass-by-copy
- Disadvantages:
  - Those of pass-by-result
  - Those of pass-by-value

Pass-By-Reference

- inout mode
- Pass an access path
- Also called pass-by-sharing
- Advantage: passing process is efficient
- Disadvantages:
  - Slower accesses
  - Can allow aliasing:
    - Actual parameter collisions: sub1(x, x);
    - Array element collisions: sub1(a[i], a[j]); /* if i = j */
    - Collision between formals and globals
- Root cause of all of these is: The called subprogram is provided wider access to nonlocals than is necessary
- Pass-by-value-result does not allow these aliases (but has other problems!)

Ex: value/result vs. reference

```
program foo;
var x : int;
    procedure p(y : int);
    begin
            y := y + 1;
            y := y * x;
    end;
begin
    x := 2;
    p(x);
    print(x)
end.
```

Here, y is an <u>alias</u> for x

	value/result	***reference***
	x y	**x y**
(entry to p)	2 2	2 2
(after y := y + 1)	2 3	3 3
(at p's return)	6 (6)*	9 (9)*

* Actually NOT available after the return

Pass-By-Name

- multiple modes
- By textual substitution
- Formals are bound to an access method at the time of the call, but actual binding to a value or address takes place at the time of a reference or assignment
- Purpose: flexibility of late binding
- Resulting semantics:
  - If actual is a scalar variable, it is pass-by-reference
  - If actual is a constant expression, it is pass-by-value
  - If actual is an array element, it is like nothing else
  - If actual is an expression with a reference to a variable that is also accessible in the program, it is also like nothing else

Pass-By-Name Example 1

```
procedure sub1(x: int; y: int);
begin
    x := 1;
    y := 2;
    x := 2;
    y := 3;
end;

sub1(i, a[i]);
```

```
i    := 1;
a[i] := 2;
i    := 2;
a[i] := 3;
```

Pass-By-Name Example 2

- Assume k is a global variable

```
procedure sub2(x: int; y: int; z: int);
begin
    k := 1;
    y := x;
    k := 5;
    z := x;
end;

sub2(k+1, j, i);
```

```
k := 1;
j := k+1;
k := 5;
i := k+1;
```


Pass-by-Name (continued)

```
procedure p1;
var x:int;
begin
   x := 2;
   p2(x+1);
end;
```

```
procedure p2(y:int);
var x:int;
begin
   x := 5;
   glob := x + y  ===>
          x + (x + 1)  =>  p2.x + (p1.x + 1)
end;
```

Now: glob = 11 or 8?

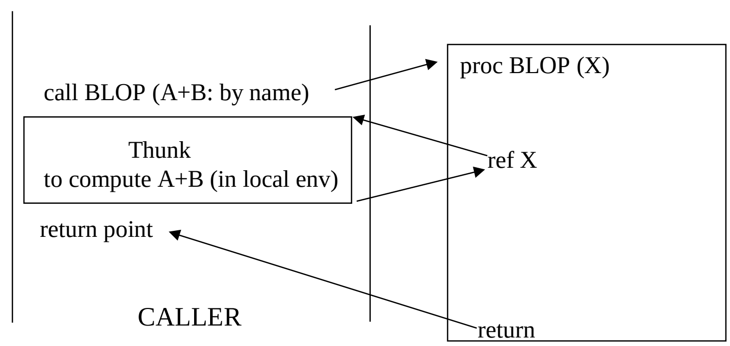
Disadvantages of Pass-By-Name

- Very inefficient references
- Too tricky; hard to read and understand

- re-evaluation of actuals
- need *thunk* = (code,env)
  - Special implementation issue

THUNKS (aka Jensen's Device)

- A Thunk is a parameterless* function, that exists in the calling program that evaluates the argument
- A parameter reference in the called program compiles as a call to the corresponding Thunk



Param Passing: Language Examples

- FORTRAN
  - Before 77, pass-by-reference
  - 77—scalar variables are often passed by value-result
- ALGOL 60
  - Pass-by-name is default; pass-by-value is optional
- ALGOL W: Pass-by-value-result
- C: Pass-by-value
- Pascal and Modula-2: Default is pass-by-value; pass-by-reference is optional

Param Passing: PL Examples (cont.)

- C++: Like C, but also allows reference type parameters, which provide the efficiency of pass-by-reference with in-mode semantics
- Ada
  - All three semantic modes are available
  - If out, it cannot be referenced
  - If in, it cannot be assigned
- Java
  - Like C++, except only references

Implementing Parameter Passing

- ALGOL 60 and most of its descendants use the run-time stack
- Value—copy it to the stack; references are indirect to the stack
- Result—same
- Reference—regardless of form, put the address in the stack
- Name:
  - Run-time resident code segments or subprograms evaluate the address of the parameter
  - Called for each reference to the formal
  - These are called thunks
  - Very expensive, compared to reference or value-result

Multidimensional Arrays as Params

- If a multidimensional array is passed to a subprogram and the subprogram is separately compiled, the compiler needs to know the declared size of that array to build the storage mapping function
- C and C++
  - Programmer is required to include the declared sizes of all but the first subscript in the actual parameter
  - This disallows writing flexible subprograms
  - Solution: pass a pointer to the array and the sizes of the dimensions as other parameters; the user must include the storage mapping function, which is in terms of the size parameters (See example, p. 351)

More Array Passing Designs

- Pascal
  - Not a problem (declared size is part of the array's type)
- Ada
  - Constrained arrays—like Pascal
  - Unconstrained arrays—declared size is part of the object declaration (See book example p. 351)
- Pre-90 FORTRAN
  - Formal parameter declarations for arrays can include passed parameters

```
SUBPROGRAM SUB(MATRIX, ROWS, COLS, RESULT)
 INTEGER ROWS, COLS
 REAL MATRIX (ROWS, COLS), RESULT
...
END
```


Design Considerations for Parameter Passing

- Efficiency
- One-way or two-way
- These two are in conflict with one another!
- Good programming => limited access to variables, which means one-way whenever possible
- Efficiency => pass by reference is fastest way to pass structures of significant size
- Also, functions should not allow reference parameters

Subprograms As Parameters: Issues

- Are parameter types checked?
  - Early Pascal and FORTRAN 77 do not
  - Later versions of Pascal, Modula-2, and FORTRAN 90 do
  - Ada does not allow subprogram parameters
  - C and C++—pass pointers to functions; parameters can be type checked

Subprogs as Params: Issues (cont.)

- What is the correct referencing environment for a subprogram that was sent as a parameter?
  - Possibilities:
    - It is that of the subprogram that called it (shallow binding)
    - It is that of the subprogram that declared it (deep binding)
    - It is that of the subprogram that passed it (ad hoc binding, never been used)
  - For static-scoped languages, deep binding is most natural
  - For dynamic-scoped languages, shallow binding is most natural

Procedure and Function Arguments

```
program p123();
procedure p1(p);
/* p is a procedure parameter */
var x: int;
begin {p1}
    x := 1;
/* the passed procedure is invoked */
    p(); ed
end; {p1}
```

```
procedure p2();
var x : int;
    /* Note: p3 not normally visible to p1 */
    procedure p3();
    begin {p3}
            /* X must be the x in p2,
            not the x in p1! */
            print (x)
    end; {p3}
begin {p2}
    x := 2;
    p1(p3)
end {p2}
```

```
begin {main}    p2();    end. {p123}
```

Note: This requires *thunks* for static scoping ("deep binding").

Overloading

- An **overloaded subprogram** is one that has the same name as another subprogram in the same referencing environment
- C++ and Ada have overloaded subprograms built-in, and users can write their own overloaded subprograms
- Signature used to determine which overloaded subprogram is being referenced
  - Parameter number
  - Parameter types
  - Return value

Generic Subprograms

- A **generic** or polymorphic subprogram is one that takes parameters of different types on different activations
- Overloaded subprograms provide **ad hoc polymorphism**
- A subprogram that takes a generic parameter that is used in a type expression that describes the type of the parameters of the subprogram provides **parametric polymorphism**
- See Ada generic and C++ template examples in text

Functions

Design Issues:

- Are side effects allowed?
  - Two-way parameters (Ada does not allow)
  - Nonlocal reference (all allow)
- What types of return values are allowed?
  - FORTRAN, Pascal, Modula-2: only simple types
  - C: any type except functions and arrays
  - Ada: any type (but subprograms are not types)
  - C++ and Java: like C, but also allow classes to be returned

Accessing Nonlocal Environments

- The **nonlocal variables** of a subprogram are those that are visible but not declared in the subprogram
- **Global variables** are those that may be visible in all of the subprograms of a program

Methods for Accessing Nonlocals

- FORTRAN COMMON
  - The only way in pre-90 FORTRANs to access nonlocal variables
  - Can be used to share data or share storage
- Static scoping—discussed in Chapter 4
- External declarations: C
  - Subprograms are not nested
  - Globals are created by external declarations (they are simply defined outside any function)
  - Access is by either implicit or explicit declaration
  - Declarations (not definitions) give types to externally defined variables (and say they are defined elsewhere)
- External modules: Ada and Modula-2: Sec Ch. 10
- Dynamic Scope: discussed in Ch. 4

User-Defined Overloaded Operators

- Nearly all programming languages have overloaded operators
- Users can further overload operators in C++ and Ada (not carried over into Java)
- Ada Example (where Vector_Type is an array of Integers):

```
function "*"(a, b : in Vector_Type) return Integer is
    sum : Integer := 0;
begin
    for index in a'range loop
        sum := sum + a(index) * b(index);
    end loop;
    return sum;
end "*";
```

- Are user-defined overloaded operators good or bad?

Coroutines

- A **coroutine** is a subprogram that has multiple entries and controls them itself
- Also called **symmetric control**
- A coroutine call is named a resume
- The first resume of a coroutine is to its beginning, but subsequent calls enter at the point just after the last executed statement in the coroutine
- Typically, coroutines repeatedly resume each other, possibly forever
- Coroutines provide quasiconcurrent execution of program units (the coroutines)
- Their execution is interleaved, but not overlapped