CSCI 3336 Organization of Programming Languages

SUBPROGRAMS

Topics

- Introduction
- Fundamentals of Subprograms
- Design Issues for Subprograms
- Local Referencing Environments
- Parameter-Passing Methods
- Parameters That Are Subprograms
- Overloaded Subprograms
- Generic Subprograms
- Design Issues for Functions
- User-Defined Overloaded Operators
- Coroutines

Introduction

- Two fundamental abstraction facilities
  - Process abstraction
    - Emphasized from early days
  - Data abstraction
    - Emphasized in the1980s

Fundamentals of Subprograms

- Each subprogram has a single entry point (except the coroutines)
- The calling program is suspended during execution of the called subprogram
- Control always returns to the caller when the called subprogram's execution terminates

Basic Definitions

- A *subprogram definition* describes the interface to and the actions of the subprogram abstraction
  - In Python, function definitions are executable; in all other languages, they are non-executable
- A *subprogram call* is an explicit request that the subprogram be executed
- A *subprogram header* is the first part of the definition, including the name, the kind of subprogram, and the formal parameters
- The *parameter profile* (aka *signature*) of a subprogram is the number, order, and types of its parameters
- The *protocol* is a subprogram's parameter profile and, if it is a function, its return type

Basic Definitions (continued)

- Function declarations in C and C++ are often called *prototypes*
- A *subprogram declaration* provides the protocol, but not the body, of the subprogram
- A *formal parameter* is a dummy variable listed in the subprogram header and used in the subprogram
- An *actual parameter* represents a value or address used in the subprogram call statement

Actual/Formal Parameter Correspondence

- Positional
  - The binding of actual parameters to formal parameters is by position: the first actual parameter is bound to the first formal parameter and so forth
  - Safe and effective
- Keyword
  - The name of the formal parameter to which an actual parameter is to be bound is specified with the actual parameter
  - *Advantage*: Parameters can appear in any order, thereby avoiding parameter correspondence errors
  - *Disadvantage*: User must know the formal parameter's names

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Keyword paramaters– Example

- Python:

summer (length = my_length, list = my_array,
sum = my_sum)

  - Advantages: parameters can appear in any order
  - Disadvantages: user must know the names of formal parameters
- In addition to keyword parameters, Ada, Fortran 95, and Phyton allow positional parameters

summer (my_length, list = my_array, sum = my_sum)

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Formal Parameter Default Values

- In certain languages (e.g., C++, Python, Ruby, Ada, PHP), formal parameters can have default values (if no actual parameter is passed)
  - In C++, default parameters must appear last because parameters are positionally associated

Example:

```
float compute_pay (float income, float tax_rate, int exemptions = 1)
```

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Variable numbers of parameters

- C# methods can accept a variable number of parameters as long as they are of the same type—the corresponding formal parameter is an array preceded by `params`

```
public void DisplayList (params int[] list) {
      foreach (int next in list )
            Console.WriteLine("Next value {0}", next);
      }
}
```

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Variable numbers of parameters

- In Ruby, the actual parameters are sent as elements of a hash literal and the corresponding formal parameter is preceded by an asterisk.

```
list = [2, 4, 6, 8]
def tester (p1, p2, p3, *p4)
    …
end
…
tester ( 'first', mon=>72, tue=>68, wed=>59, *list)
```

- Inside tester, the values of its formal parameters are:

p1 is 'first', p2 is {mon=>72, tue=>68, wed=>59}
p3 is 2, and p4 is {4, 6, 8}

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Ruby Blocks

- Ruby includes a number of iterator functions, which are often used to process the elements of arrays
- Iterators are implemented with blocks
- Blocks are attached methods calls; they can have parameters (in vertical bars); they are executed when the method executes a `yield` statement

```
def fibonacci(last)
  first, second = 1, 1
  while first <= last
    yield first
    first, second = second, first + second
  end
end

puts "Fibonacci numbers less than 100 are:"
fibonacci(100) {|num| print num, " "}
puts

sum = 0
fibonacci(100) {|num| sum += num}
puts "Sum of the Fibonacci numbers less than 100 is: #{sum}"
```

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Procedures and Functions

- There are two categories of subprograms
  - *Procedures* are collection of statements that define parameterized computations
  - *Functions* structurally resemble procedures but are semantically modeled on mathematical functions
    - They are expected to produce no side effects
    - In practice, program functions have side effects

Design Issues for Subprograms

- Are local variables static or dynamic?
- Can subprogram definitions appear in other subprogram definitions?
- What parameter passing methods are provided?
- Are parameter types checked?
- If subprograms can be passed as parameters and subprograms can be nested, what is the referencing environment of a passed subprogram?
- Can subprograms be overloaded?
- Can subprogram be generic?

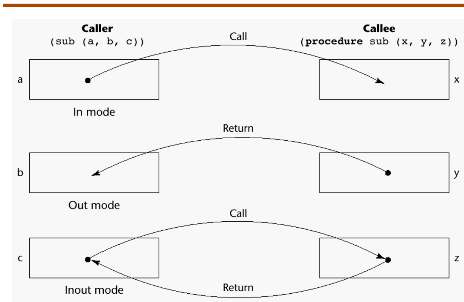
Local Referencing Environments

- Local variables can be stack-dynamic
  - Advantages
    - Support for recursion
    - Flexibility
    - Storage for locals is shared among some subprograms
  - Disadvantages
    - Cost in allocation/de-allocation, initialization time
    - No history-sensitive
- Local variables can be static
  - Advantages and disadvantages are the opposite of those for stack-dynamic local variables

Semantic Models of Parameter Passing

- In mode
- Out mode
- Inout mode

Models of Parameter Passing



Pass-by-Value (In Mode)

- The value of the actual parameter is used to initialize the corresponding formal parameter
  - Normally implemented by copying
  - *Disadvantages*: additional storage is required (stored twice) and the actual move can be costly (for large parameters)

Pass-by-Result (Out Mode)

- When a parameter is passed by result, no value is transmitted to the subprogram; the corresponding formal parameter acts as a local variable; its value is transmitted to caller's actual parameter when control is returned to the caller
  - Require extra storage location and copy operation

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Pass-by-Value-Result (inout Mode)

- A combination of pass-by-value and pass-by-result
- Sometimes called pass-by-copy
- Formal parameters have local storage
- Disadvantages:
  - Those of pass-by-result
  - Those of pass-by-value

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Pass-by-Reference (Inout Mode)

- Pass an access path
- Also called pass-by-sharing
- Advantage: Passing process is efficient (no copying and no duplicated storage)
- Disadvantages
  - Slower accesses (compared to pass-by-value) to formal parameters
  - Potentials for unwanted side effects (collisions)
  - Unwanted aliases (access broadened)

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Implementing Parameter-Passing Methods

- In most language parameter communication takes place thru the run-time stack
- Pass-by-reference are the simplest to implement; only an address is placed in the stack

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Parameter Passing Methods of Major Languages

- C
  - Pass-by-value
  - Pass-by-reference is achieved by using pointers as parameters
- C++
  - A special pointer type called reference type for pass-by-reference
- Java
  - All parameters are passed by value
  - Object parameters are passed by reference
- Ada
  - Three semantics modes of parameter transmission: `in`, `out`, `in out`; `in` is the default mode
  - Formal parameters declared `out` can be assigned but not referenced; those declared `in` can be referenced but not assigned; `in out` parameters can be referenced and assigned

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Parameter Passing Methods of Major Languages (continued)

- Fortran 95
  - Parameters can be declared to be in, out, or inout mode
- C#
  - Default method: pass-by-value
  - Pass-by-reference is specified by preceding both a formal parameter and its actual parameter with `ref`
- PHP: very similar to C#
- Perl: all actual parameters are implicitly placed in a predefined array named `@_`
- Python and Ruby use pass-by-assignment (all data values are objects)

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Type Checking Parameters

- Considered very important for reliability
- FORTRAN 77 and original C: none
- Pascal, FORTRAN 90, Java, and Ada: it is always required
- ANSI C and C++: choice is made by the user
  - Prototypes
- Relatively new languages Perl, JavaScript, and PHP do not require type checking
- In Python and Ruby, variables do not have types (objects do), so parameter type checking is not possible

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Multidimensional Arrays as Parameters

- 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

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Multidimensional Arrays as Parameters: C and C++

- Programmer is required to include the declared sizes of all but the first subscript in the actual parameter
- 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 in terms of the size parameters

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Multidimensional Arrays as Parameters: Ada

- Ada – not a problem
  - Constrained arrays – size is part of the array's type
  - Unconstrained arrays – declared size is part of the object declaration

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Multidimensional Arrays as Parameters: Fortran

- Formal parameter that are arrays have a declaration after the header
  - For single-dimension arrays, the subscript is irrelevant
  - For multidimensional arrays, the sizes are sent as parameters and used in the declaration of the formal parameter, so those variables are used in the storage mapping function

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Multidimensional Arrays as Parameters: Java and C#

- Similar to Ada
- Arrays are objects; they are all single-dimensioned, but the elements can be arrays
- Each array inherits a named constant (`length` in Java, `Length` in C#) that is set to the length of the array when the array object is created

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Design Considerations for Parameter Passing

- Two important considerations
  - Efficiency
  - One-way or two-way data transfer
- But the above considerations are in conflict
  - Good programming suggest limited access to variables, which means one-way whenever possible
  - But pass-by-reference is more efficient to pass structures of significant size

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Parameters that are Subprogram Names

- It is sometimes convenient to pass subprogram names as parameters
- Issues:
  1. Are parameter types checked?
  2. What is the correct referencing environment for a subprogram that was sent as a parameter?

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Parameters that are Subprogram Names: Parameter Type Checking

- C and C++: functions cannot be passed as parameters but pointers to functions can be passed and their types include the types of the parameters, so parameters can be type checked
- FORTRAN 95 type checks
- Ada does not allow subprogram parameters; an alternative is provided via Ada's generic facility
- Java does not allow method names to be passed as parameters

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Parameters that are Subprogram Names: Referencing Environment

- *Shallow binding*: The environment of the call statement that enacts the passed subprogram
  - Most natural for dynamic-scoped languages
- *Deep binding*: The environment of the definition of the passed subprogram
  - Most natural for static-scoped languages
- *Ad hoc binding*: The environment of the call statement that passed the subprogram

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Parameters that are Subprogram Names: JavaScript example

```
function sub1() {
  var x;
  function sub2() {alert(x); };
  function sub3() {var x = 3; sub4(sub2); };
  function sub4(subx) {var x=4; subx(); };
  x = 1;
  sub3();
}
```

Shallow binding: The output of the program is 4
Deep binding: The output of the program is 1
Ad hoc binding: The output of the program is 3

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Overloaded Subprograms

- An *overloaded subprogram* is one that has the same name as another subprogram in the same referencing environment
  - Every version of an overloaded subprogram has a unique protocol
- C++, Java, C#, and Ada include predefined overloaded subprograms
- In Ada, the return type of an overloaded function can be used to disambiguate calls (thus two overloaded functions can have the same parameters)
- Ada, Java, C++, and C# allow users to write multiple versions of subprograms with the same name

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Generic Subprograms

- A *generic* or *polymorphic subprogram* takes parameters of different types on different activations
- Overloaded subprograms is called *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*

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Generic Subprograms (continued)

- Ada
  - Versions of a generic subprogram are created by the compiler when explicitly instantiated by a declaration statement
  - Generic subprograms are preceded by a `generic` clause that lists the generic variables, which can be types or other subprograms

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Generic Subprograms (continued)

- C++
  - Versions of a generic subprogram are created implicitly when the subprogram is named in a call or when its address is taken with the & operator
  - Generic subprograms are preceded by a `template` clause that lists the generic variables, which can be type names or class names

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Examples of parametric polymorphism: C++

```
template <class Type>
Type max(Type first, Type second) {
    return first > second ? first : second;
}
```

- The above template can be instantiated for any type for which operator > is defined

```
int max (int first, int second) {
  return first > second? first : second;
}
```

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Design Issues for Functions

- Are side effects allowed?
  - Parameters should always be in-mode to reduce side effect (like Ada)
- What types of return values are allowed?
  - Most imperative languages restrict the return types
  - C allows any type except arrays and functions
  - C++ is like C but also allows user-defined types
  - Ada subprograms can return any type (but Ada subprograms are not types, so they cannot be returned)
  - Java and C# methods can return any type (but because methods are not types, they cannot be returned)
  - Python and Ruby treat methods as first-class objects, so they can be returned, as well as any other class
  - Lua allows functions to return multiple values

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User-Defined Overloaded Operators

- Operators can be overloaded in Ada, C++, Python, and Ruby
- An Ada example

```
function "*" (A,B: in Vec_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 "*";
…
c = a * b; -- a, b, and c are of type Vec_Type
```

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Coroutines

- A *coroutine* is a subprogram that has multiple entries and controls them itself – supported directly in Lua
- Also called *symmetric control:* caller and called coroutines are on a more equal basis
- 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
- Coroutines repeatedly resume each other, possibly forever
- Coroutines provide *quasi-concurrent execution* of program units (the coroutines); their execution is interleaved, but not overlapped

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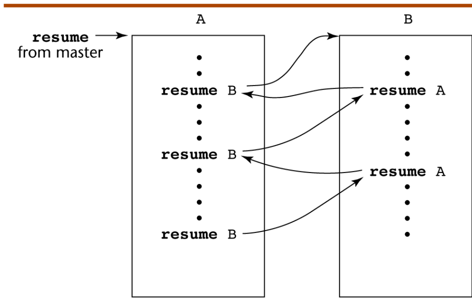
Coroutines Illustrated: Possible Execution Controls



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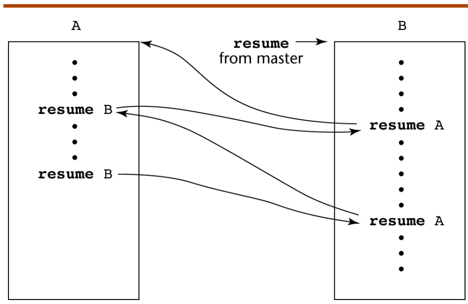
Coroutines Illustrated: Possible Execution Controls



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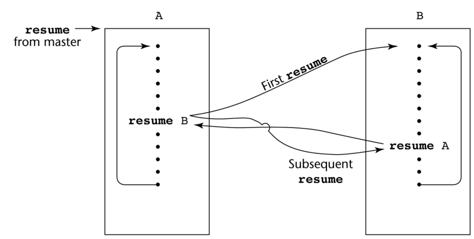
Coroutines Illustrated: Possible Execution Controls with Loops



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Summary

- A subprogram definition describes the actions represented by the subprogram
- Subprograms can be either functions or procedures
- Local variables in subprograms can be stack-dynamic or static
- Three models of parameter passing: in mode, out mode, and inout mode
- Some languages allow operator overloading
- Subprograms can be generic
- A coroutine is a special subprogram with multiple entries

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