Week 7

Subprograms

Chapter 9 Topics

- Introduction
- Fundamentals of Subprograms
- Design Issues for Subprograms
- Local Referencing Environments
- Parameter-Passing Methods
- 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
- 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
- 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

Examples

return type

subprogram header

signature / parameter profile

subprogram definition

subprogram call

```
float divider(int x, int y)
{
     return (float)x/y;
}
void main( )
{
   float result;
   int a=5, b=2;
   result = divider(a/b);
   printf("%.2f", result);
}
```

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

Examples

```
float divider(int, int);
int main( )
{
    float result;
    int a=5, b=2;
    result = divider(a/b);
    printf("%.2f", result);
}
float divider(int x, int y)
{
     return (float)x/y;
}
```

subprogram declaration

formal parameter

formal parameter

Formal Parameter Default Values

- In certain languages (e.g., C++, Ada), formal parameters can have default values (if not actual parameter is passed)
  - In C++, default parameters must appear last because parameters are positionally associated
- C# methods can accept a variable number of parameters as long as they are of the same type

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

Examples

```
float divider(int x, int y)
{
    return (float)x/y;
}
void main( )
{
 int a=5, b=2;
 printf("%f", divider(a/b));
}
```

```
void divider(int x, int y)
{
   printf("%f", (float)x/y);
}
void main( )
{
   int a=5, b=2;
   divider(a/b);
}
```

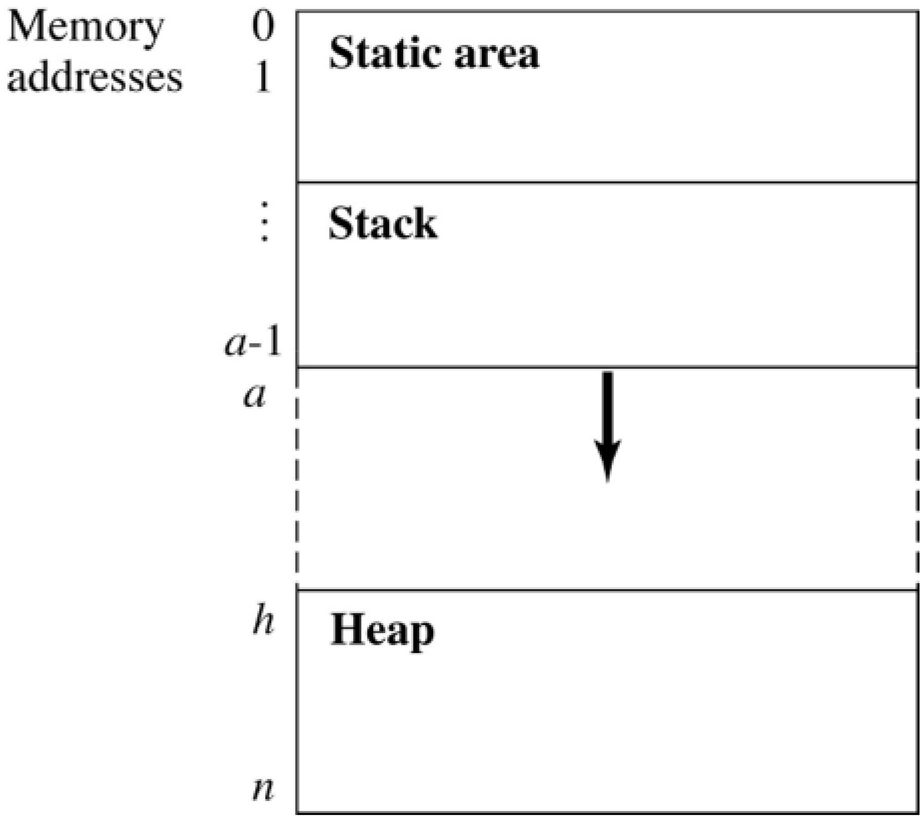
Design Issues for Subprograms

- What parameter passing methods are provided?
- Are parameter types checked?
- Are local variables static or dynamic?
- Can subprogram definitions appear in other subprogram definitions?
- Can subprograms be overloaded?
- Can subprogram be generic?

Local Referencing Environments

- Local variables can be stack-dynamic (bound to storage)
  - Advantages
    - Support for recursion
    - Storage for locals is shared among some subprograms
  - Disadvantages
    - Allocation/de-allocation, initialization time
    - Indirect addressing
    - Subprograms cannot be history sensitive
- Local variables can be static
  - More efficient (no indirection)
  - No run-time overhead
  - Cannot support recursion

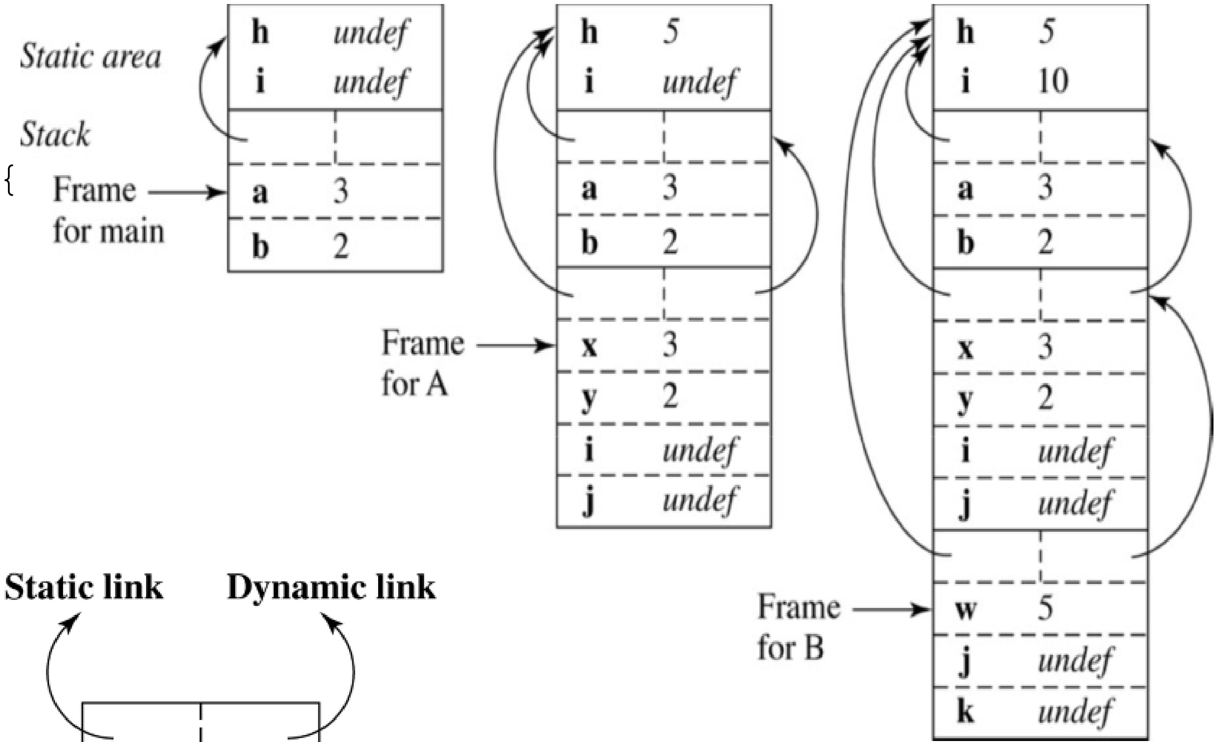
Run-time Memory Structure

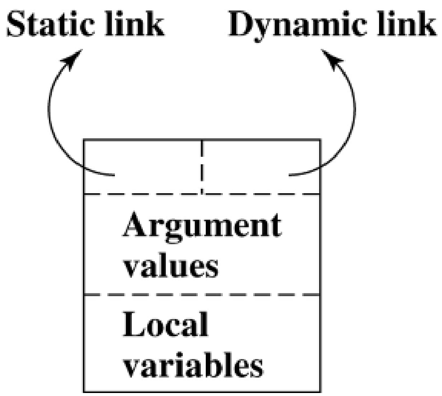



```
void DoSomeStuff (int data)
{
static int invocations = 0;
 int x, y, z;
 // do something
 invocations ++;
}
```

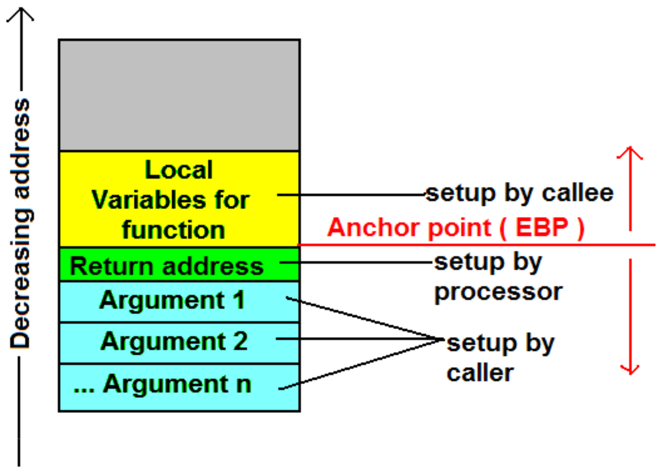
Stack Frame (activation record)

```
package K  {
 int   h, i;
 void A (int x, int y){
 boolean i, j;
 B (h);
}
void B(int w)  {
 int j, k;
 i = 2*w;
 w = w+1;
}
void main ( )  {
 int a, b;
 h=5; a=3; b=2;
 A=(a,b);
}
```

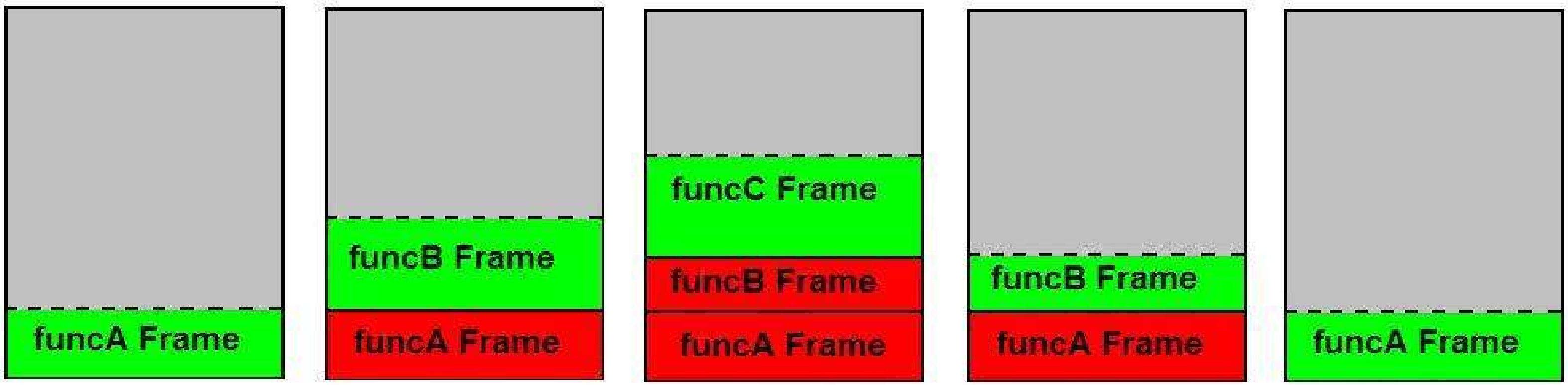




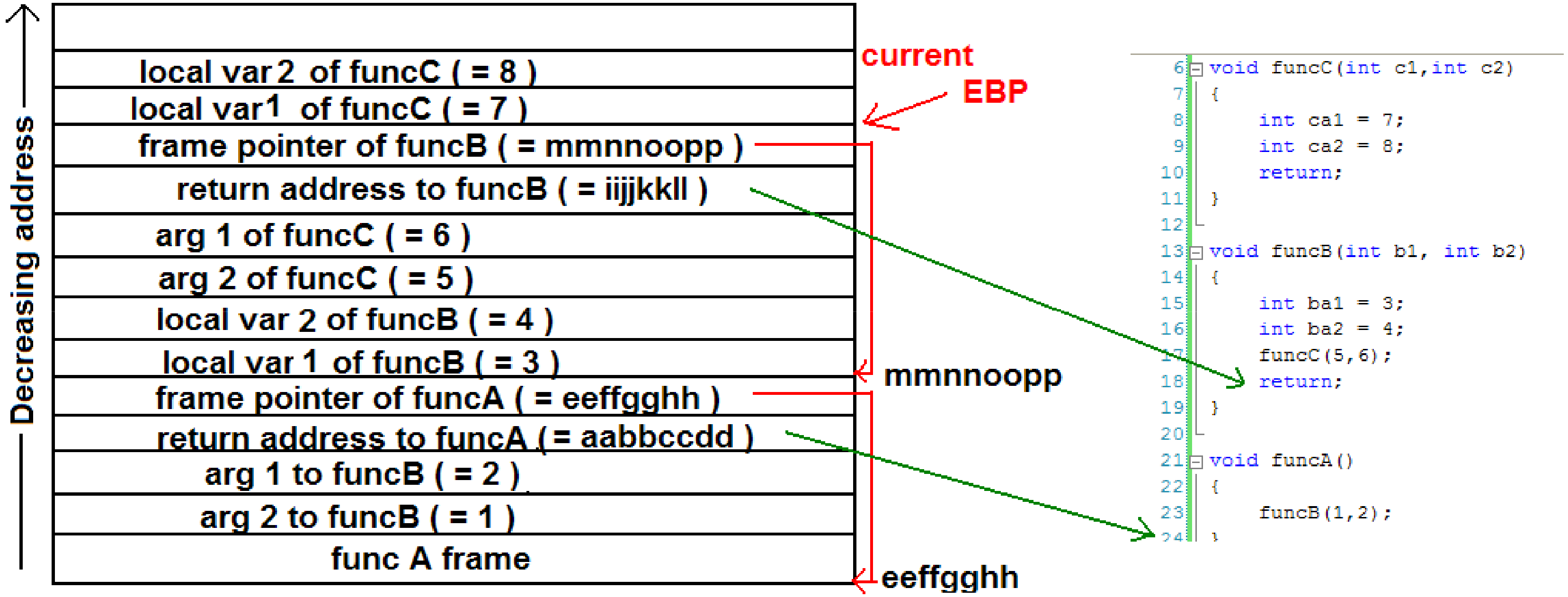
Stack Frame (activation record)



The scenario is funcA calling into funcB which in turn calls into funcC.



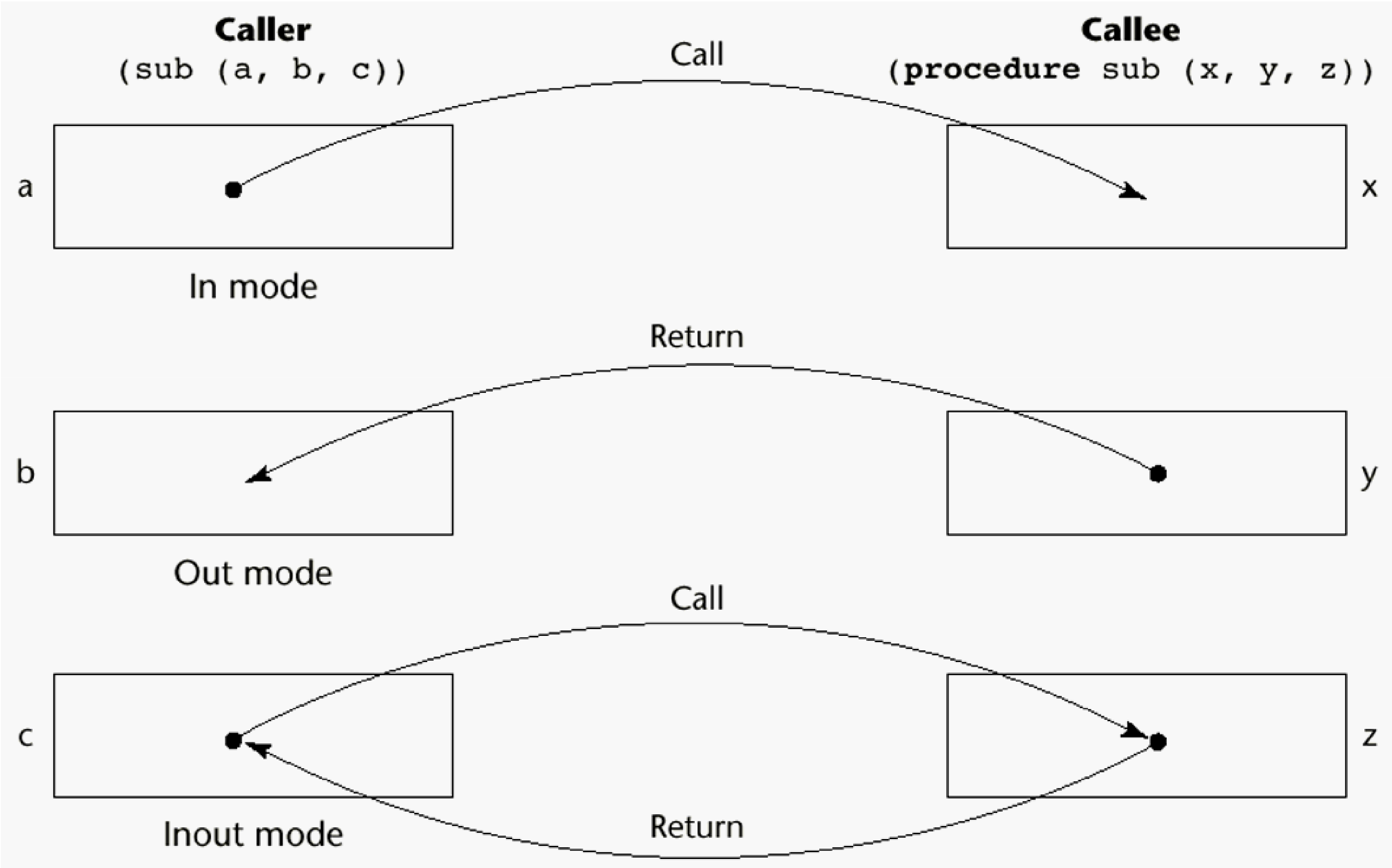
Stack Frame (activation record)



Parameter Passing Methods

- Ways in which parameters are transmitted to and/or from called subprograms
  - Pass-by-value
  - Pass-by-result
  - Pass-by-value-result
  - Pass-by-reference
  - Pass-by-name

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
  - Can be implemented by transmitting an access path but not recommended (enforcing write protection is not easy)
  - When copies are used, additional storage is required
  - Storage and copy operations can be costly

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
- Potential problem: `sub(p1, p1);` whichever formal parameter is copied back will represent the current value of p1

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

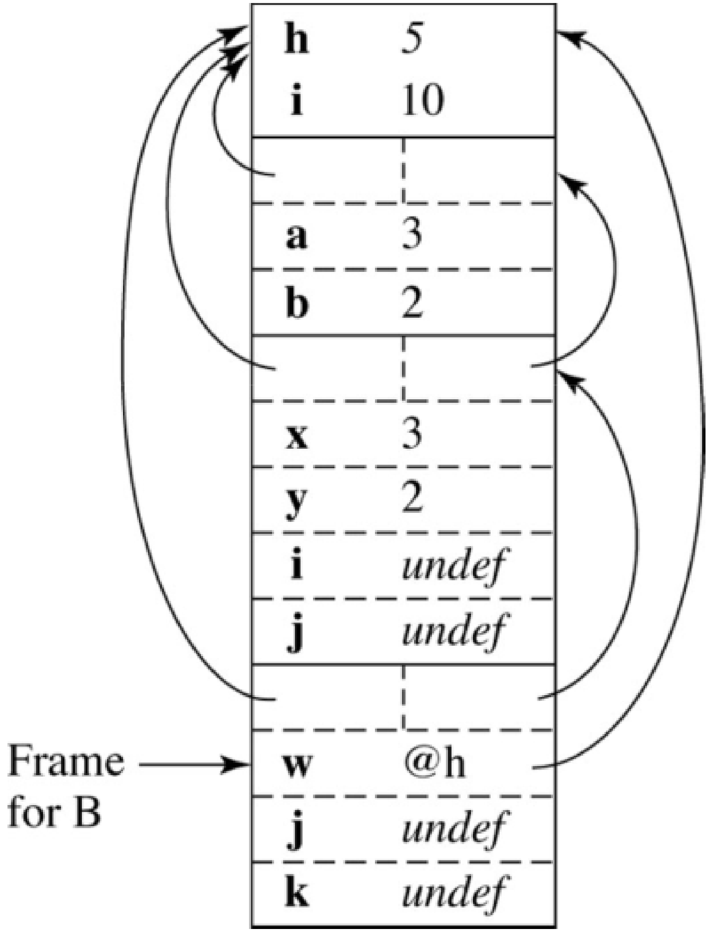
Pass-by-Reference (Inout Mode)

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

Pass-by-Reference

```
void  B (int& w)
{
 int j, k;
 i = 2*w;
 w = w+1;
 …
}

B(h);
```



Pass-by-Name (Inout Mode)

- 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
- Allows flexibility in late binding

Pass-by-Name

```
int MyArray [10];
int foo (NamedVar)  {
 int x=3;
 NamedVar=7;
 return (NamedVar*17);
}
void main ( )  {
 int x=0;
 cout << foo (MyArray [x]);
 cout << foo (x);
}
```

```
foo(MyArray[x])

int foo (MyArray[x])  {
 int x=3;
 MyArray[x]=7;
 return (MyArray[x]*17);
}
```

```
foo(x)

int foo (x)  {
 int x=3;
 x=7;
 return (x*17);
}
```

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
- A subtle but fatal error can occur with pass-by-reference and pass-by-value-result: a formal parameter corresponding to a constant can mistakenly be changed

Parameter Passing Methods of Major Languages

- Fortran
  - Always used the inout semantics model
  - Before Fortran 77: pass-by-reference
  - Fortran 77 and later: scalar variables are often passed by value-result
- 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

Parameter Passing Methods of Major Languages (continued)

- 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
- 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 `@_`

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

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

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

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

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

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

Generic Subprograms

- A *generic* or *polymorphic subprogram* 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*

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;
}
```

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 allows any type
  - Java and C# do not have functions but methods can have any type

User-Defined Overloaded Operators

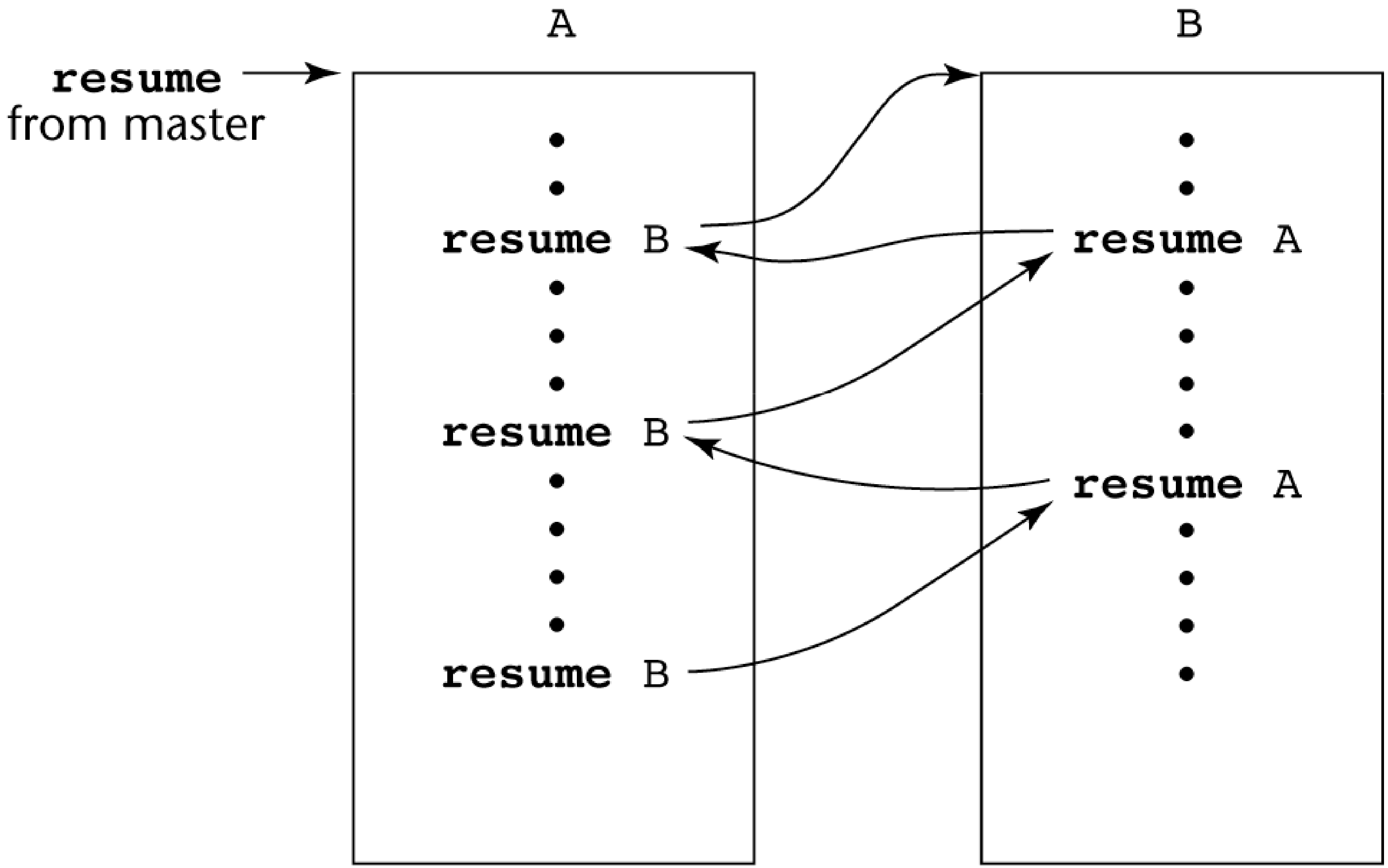
- Operators can be overloaded in Ada and C++
- An Ada example

```
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
```

Coroutines

- A *coroutine* is a subprogram that has multiple entries and controls them itself
- 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

Coroutines Illustrated: Possible Execution Controls



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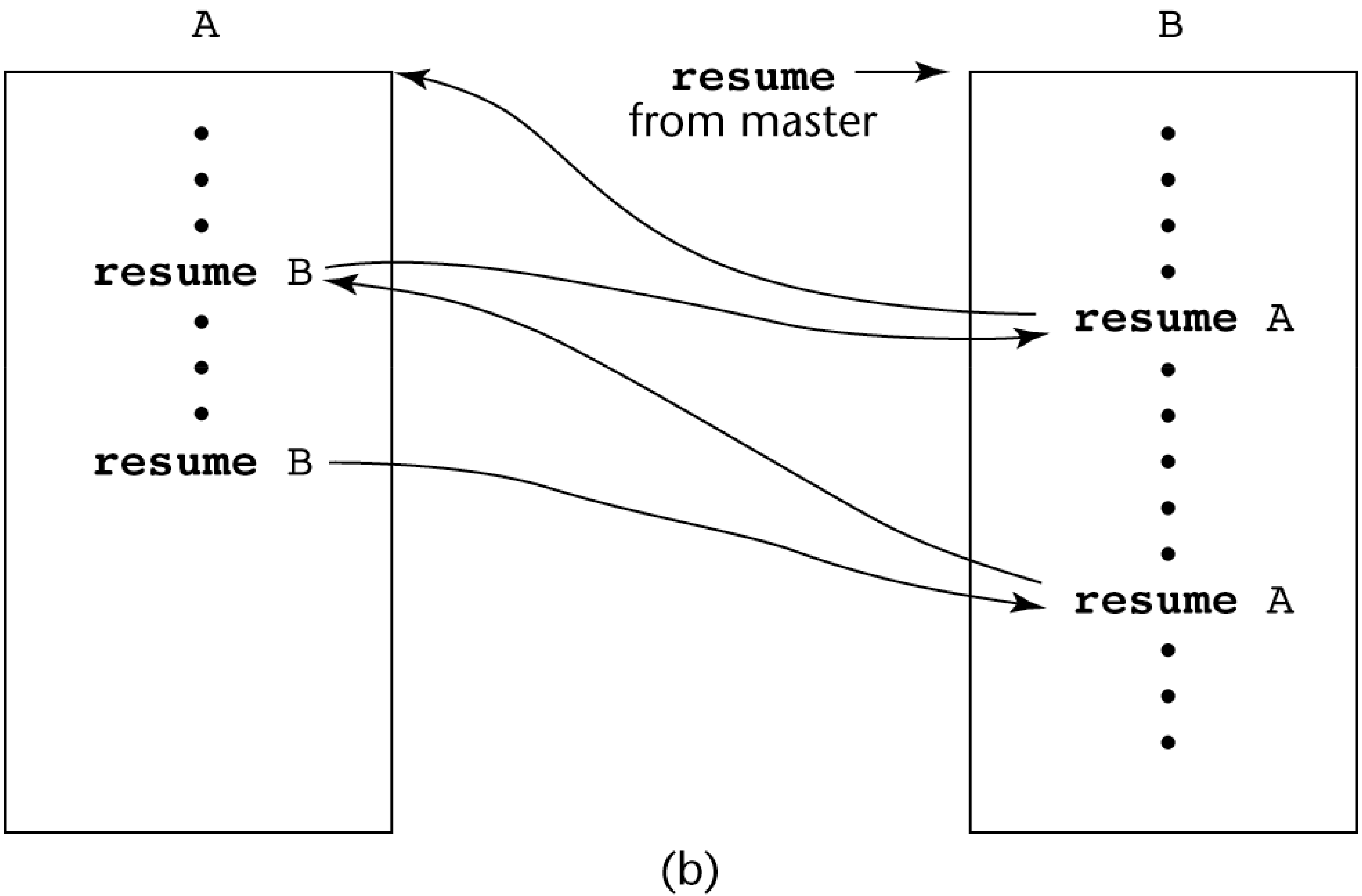
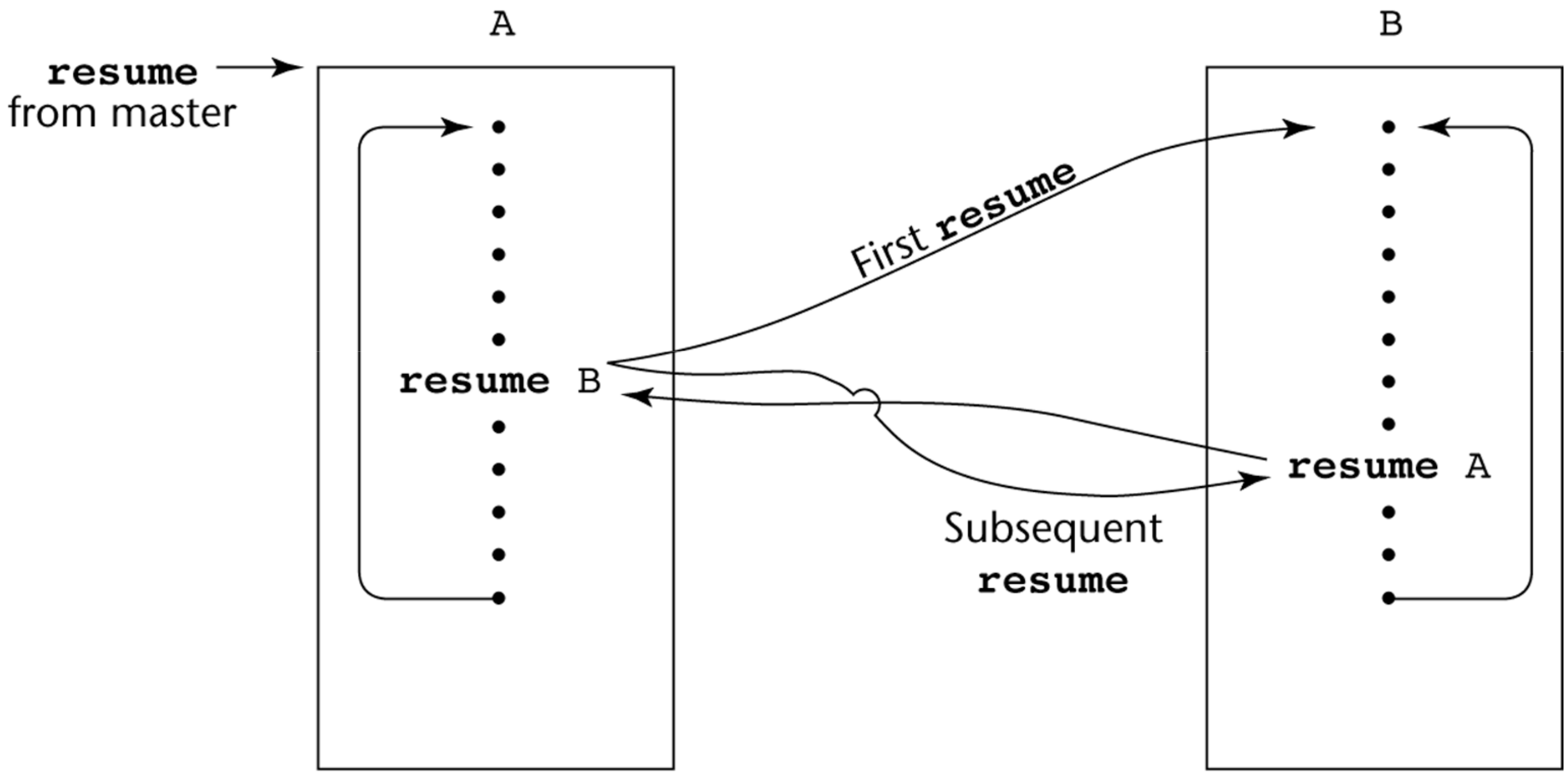
Coroutines Illustrated: Possible Execution Controls



Coroutines Illustrated: Possible Execution Controls with Loops



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