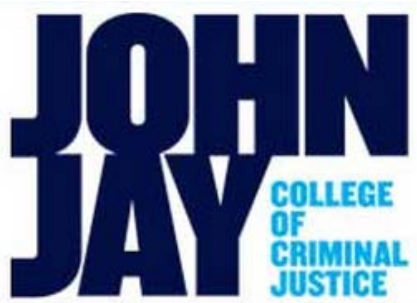

Programming Languages:

Lecture 12

Chapter 10: Implementing Subprograms

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Chapter 10 Topics

- The General Semantics of Calls and Returns
- Implementing “Simple” Subprograms
- Implementing Subprograms with Stack-Dynamic Local Variables
- Nested Subprograms
- Blocks
- Implementing Dynamic Scoping

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The General Semantics of Calls and Returns

- The subprogram call and return operations of a language are together called its *subprogram linkage*

- A subprogram call has numerous actions associated with it
  - Implement parameter passing
  - Storage arrangement for local variables
  - Save execution status of calling program
  - Transfer of control
  - Necessary action if nested subprograms supported

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Implementing "Simple" Subprograms: Call Semantics

- Basic assumption of "Simple" subprogram
  - No nested subprograms
  - All local variables are static
- Save the execution status of the caller
- Carry out the parameter-passing process
- Pass the return address to the callee
- Transfer control to the callee

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Implementing "Simple" Subprograms: Return Semantics

- If pass-by-value-result parameters are used, move the current values of those parameters to their corresponding actual parameters
- If it is a function, move the functional value to a place the caller can get it
- Restore the execution status of the caller
- Transfer control back to the caller

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Implementing "Simple" Subprograms: Storage required for Call & Return

- Status information about the caller
- Parameters
- Return address
- Return value for functions

Implementing "Simple" Subprograms: Parts

- Two separate parts of the simple subprogram
  - Actual code part
    - **Constant**
  - Noncode part
    - **local variables and data that can change**
  - They are fixed in size

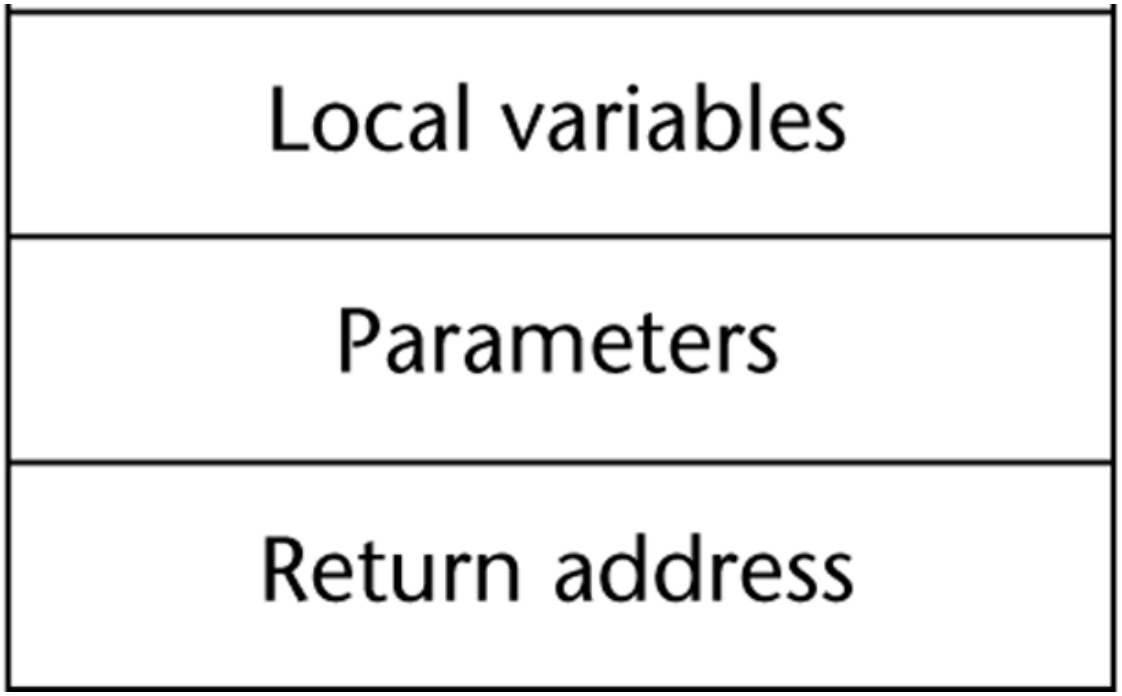
- The format, or layout, of the noncode part of an executing subprogram is called an *activation record*
  - The data it describes are relevant only during activation

- An *activation record instance* is a concrete example of an activation record
  - The collection of data for a particular subprogram activation

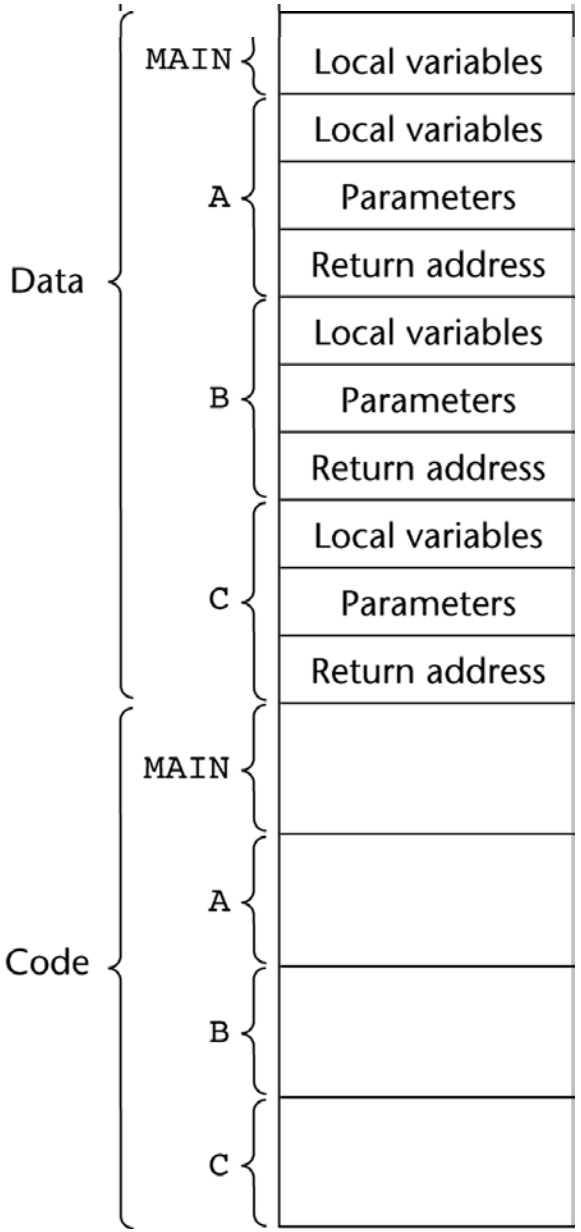
An Activation Record for "Simple" Subprograms

Since simple subprograms do not supports recursion, there can be only one active version of a given subprogram at a time

Single instance of activation record for a subprogram exists



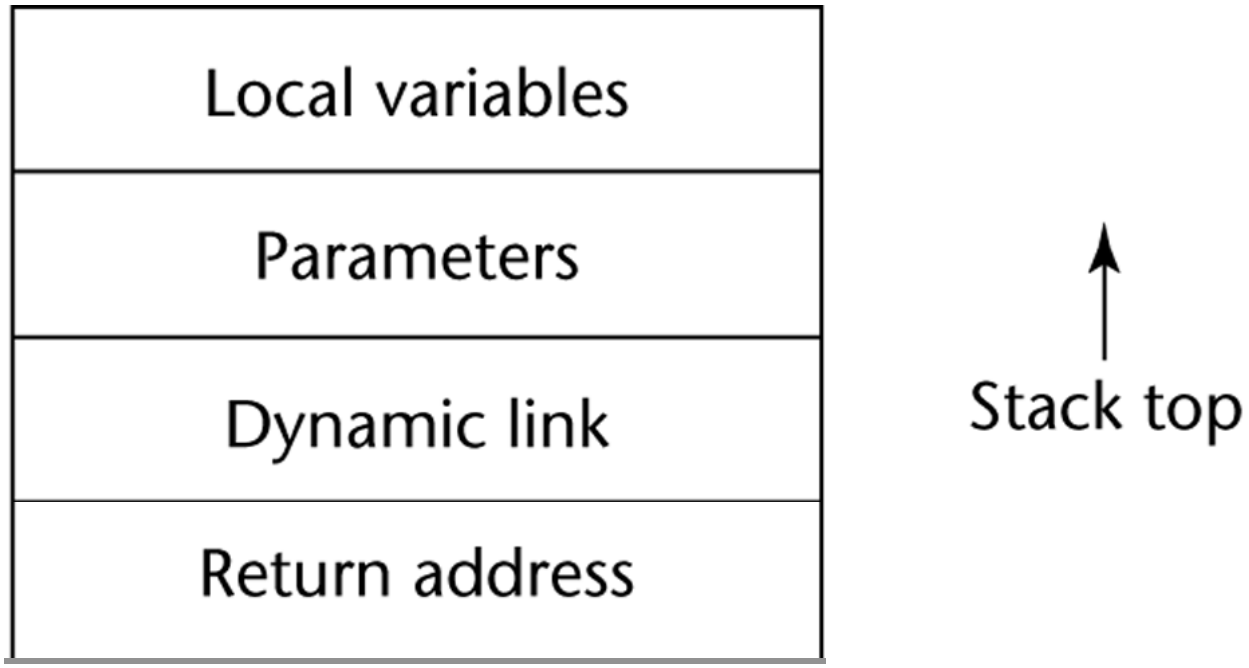
Code and Activation Records of a Program with "Simple" Subprograms



Implementing Subprograms with Stack-Dynamic Local Variables

- More complex activation record
  - The compiler must generate code to cause implicit allocation and de-allocation of local variables
  - Recursion must be supported (adds the possibility of multiple simultaneous activations of a subprogram)

Typical Activation Record for a Language with Stack-Dynamic Local Variables

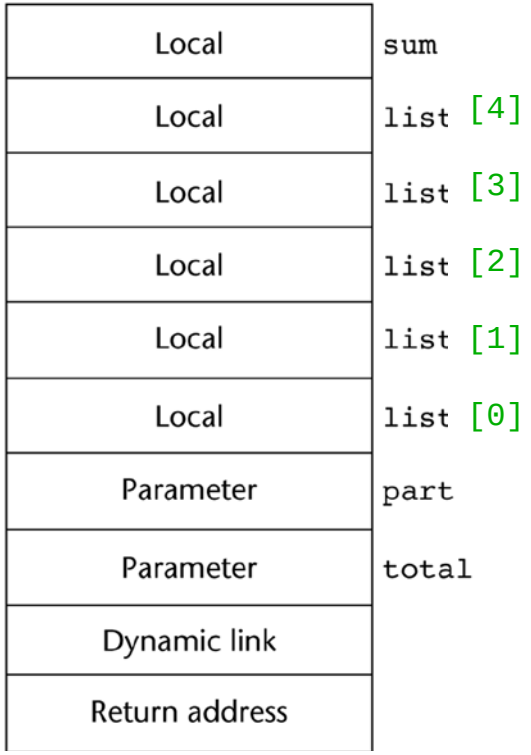


Implementing Subprograms with Stack-Dynamic Local Variables: Activation Record

- The activation record format is static, but its size may be dynamic
- The *dynamic link* points to the top of an instance of the activation record of the caller
- An activation record instance is dynamically created when a subprogram is called
- Run-time stack

An Example: C Function

```
void sub(float total, int part)
{
   int list[4];
   float sum;
   …
}
```

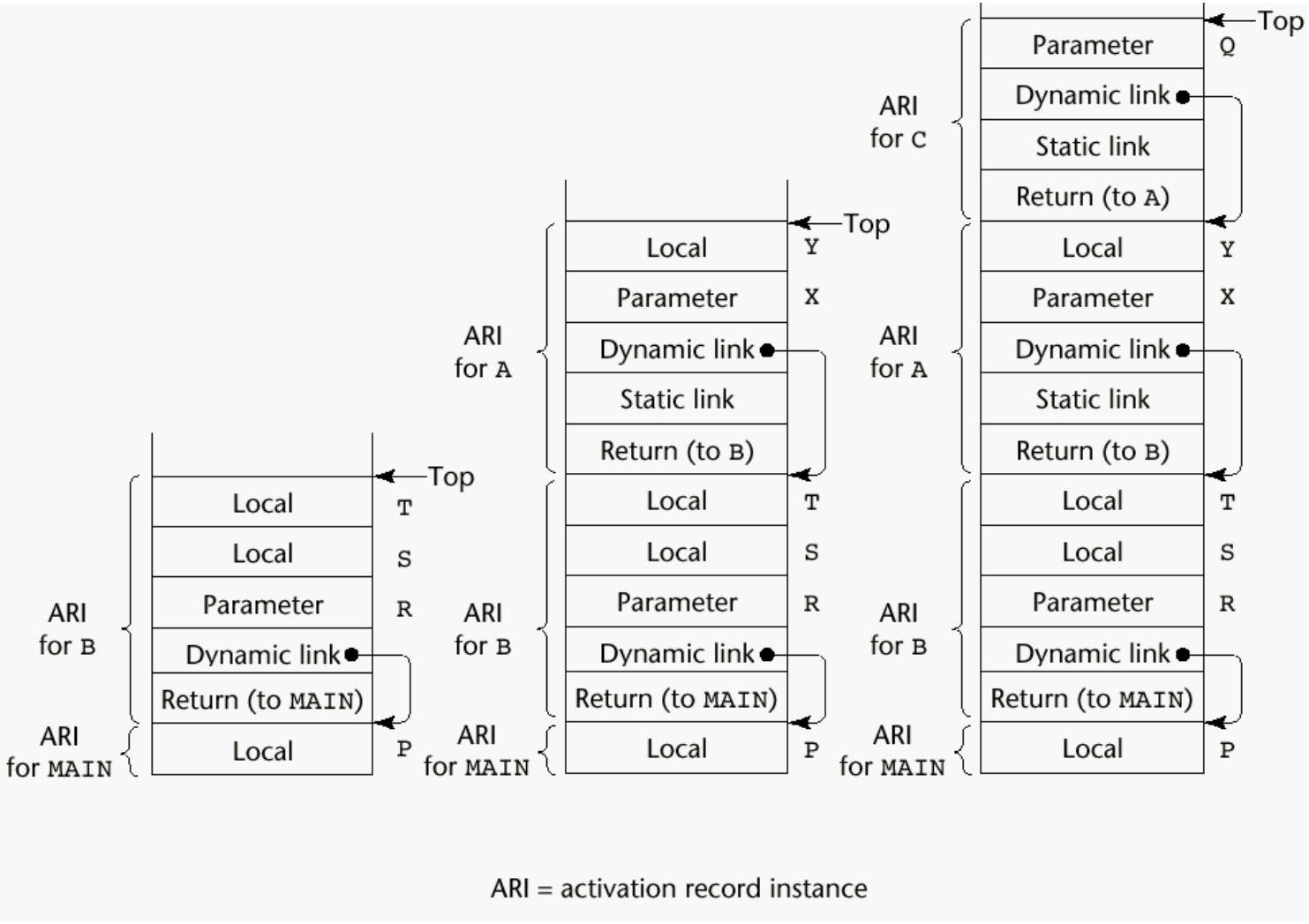


An Example Without Recursion

```
void A(int x) {
    int y;
    ...
    C(y);
    ...
}
void B(float r) {
    int s, t;
    ...
    A(s);
    ...
}
void C(int q) {
    ...
}
void main() {
    float p;
    ...
    B(p);
    ...
}
```

main calls B
B calls A
A calls C

An Example Without Recursion



Dynamic Chain and Local Offset

- The collection of dynamic links in the stack at a given time is called the *dynamic chain*, or *call chain*
- Local variables can be accessed by their offset from the beginning of the activation record
  - This offset is called the *local_offset*
- The local_offset of a local variable can be determined by the compiler at compile time

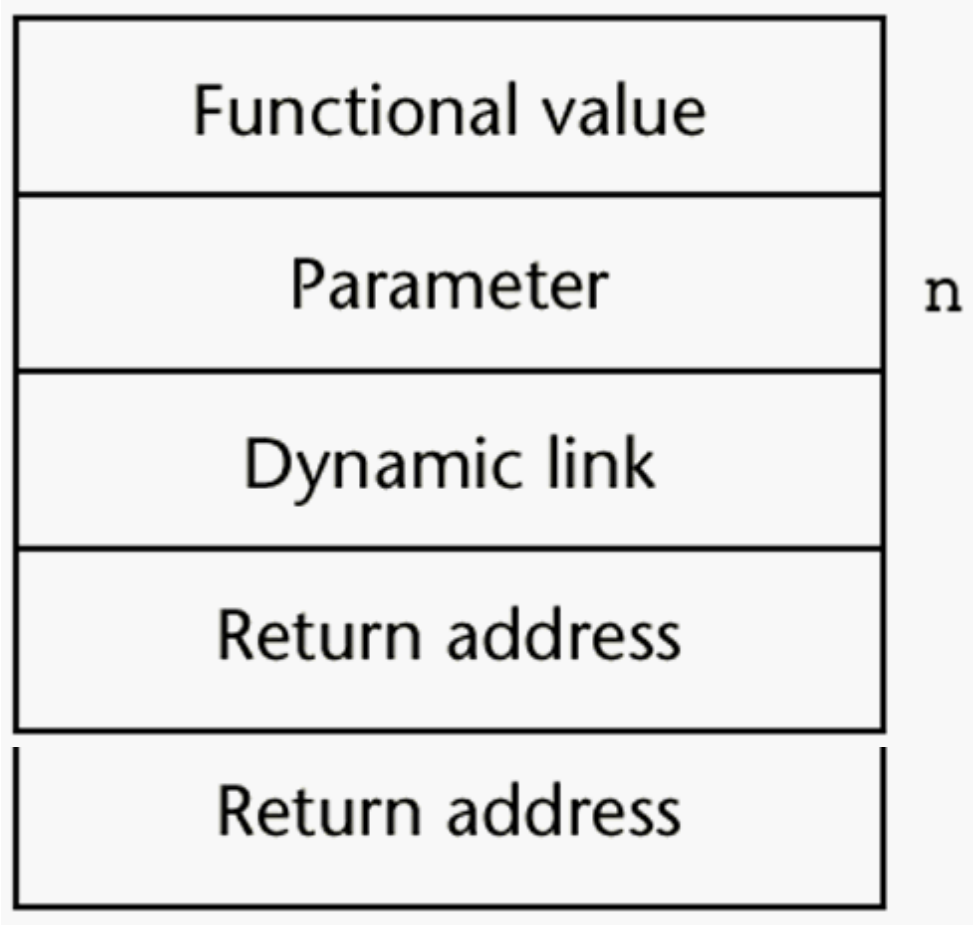
An Example With Recursion

- The activation record used in the previous example supports recursion, e.g.

```
int factorial (int n) {
    <------------------------------1
  if (n <= 1) return 1;
  else return (n * factorial(n - 1));
    <------------------------------2
}

void main() {
  int value;
  value = factorial(3);
    <------------------------------3
}
```

Activation Record for `factorial`



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Nested Subprograms

- Some non-C-based static-scoped languages (e.g., Fortran 95, Ada, JavaScript) use stack-dynamic local variables and allow subprograms to be nested

- All variables that can be non-locally accessed reside in some activation record instance in the stack

- The process of locating a non-local reference:
  1. Find the correct activation record instance
  2. Determine the correct offset within that activation record instance

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Locating a Non-local Reference

- Finding the offset is easy
- Finding the correct activation record instance
  - Static semantic rules guarantee that all non-local variables that can be referenced have been allocated in some activation record instance that is on the stack when the reference is made

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Static Scoping

- A *static chain* is a chain of static links that connects certain activation record instances
- The static link in an activation record instance for subprogram A points to one of the activation record instances of A's static parent
- The static chain from an activation record instance connects it to all of its static ancestors

Example Pascal Program

```
program MAIN_2;
  var X : integer;
  procedure BIGSUB;
    var A, B, C : integer;
    procedure SUB1;
      var A, D : integer;
      begin { SUB1 }
      A := B + C;  <------------------------1
      end;  { SUB1 }
    procedure SUB2(X : integer);
      var B, E : integer;
      procedure SUB3;
        var C, E : integer;
        begin { SUB3 }
        SUB1;
        E := B + A:   <--------------------2
        end; { SUB3 }
      begin { SUB2 }
      SUB3;
      A := D + E;  <------------------------3
      end; { SUB2 }
    begin { BIGSUB }
    SUB2(7);
    end; { BIGSUB }
  begin
  BIGSUB;
  end; { MAIN_2 }
```

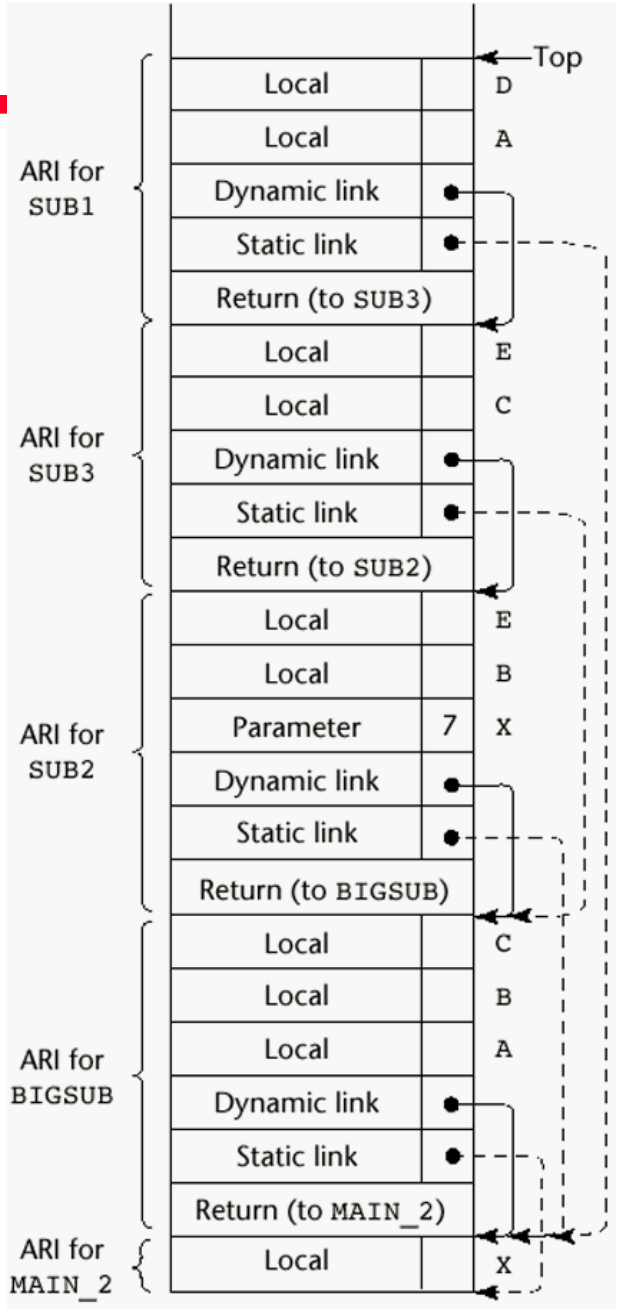
Example Pascal Program (continued)

- Call sequence for `MAIN_2`

  `MAIN_2` calls `BIGSUB`
  `BIGSUB` calls `SUB2`
  `SUB2` calls `SUB3`
  `SUB3` calls `SUB1`

Stack Contents at Position 1

```
program MAIN_2;
  var X : integer;
  procedure BIGSUB;
    var A, B, C : integer;
    procedure SUB1;
      var A, D : integer;
      begin { SUB1 }
      A := B + C;  <-----------------------1
      end;  { SUB1 }
    procedure SUB2(X : integer);
      var B, E : integer;
      procedure SUB3;
        var C, E : integer;
        begin { SUB3 }
        SUB1;
        E := B + A:   <--------------------2
        end; { SUB3 }
      begin { SUB2 }
      SUB3;
      A := D + E;  <-----------------------3
      end; { SUB2 }
    begin { BIGSUB }
    SUB2(7);
    end; { BIGSUB }
  begin
  BIGSUB;
  end; { MAIN_2 }
```



Displays

- An alternative to static chains
- Static links are stored in a single array called a display
- The contents of the display at any given time is a list of addresses of the accessible activation record instances

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Blocks

- Blocks are user-specified local scopes for variables
- An example in C

```
{int temp;
 temp = list [upper];
 list [upper] = list [lower];
 list [lower] = temp
}
```

- The lifetime of `temp` in the above example begins when control enters the block
- An advantage of using a local variable like `temp` is that it cannot interfere with any other variable with the same name

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Implementing Blocks

- Two Methods:
  1. Treat blocks as parameter-less subprograms that are always called from the same location
     - **Every block has an activation record; an instance is created every time the block is executed**
  2. Since the maximum storage required for a block can be statically determined, this amount of space can be allocated after the local variables in the activation record

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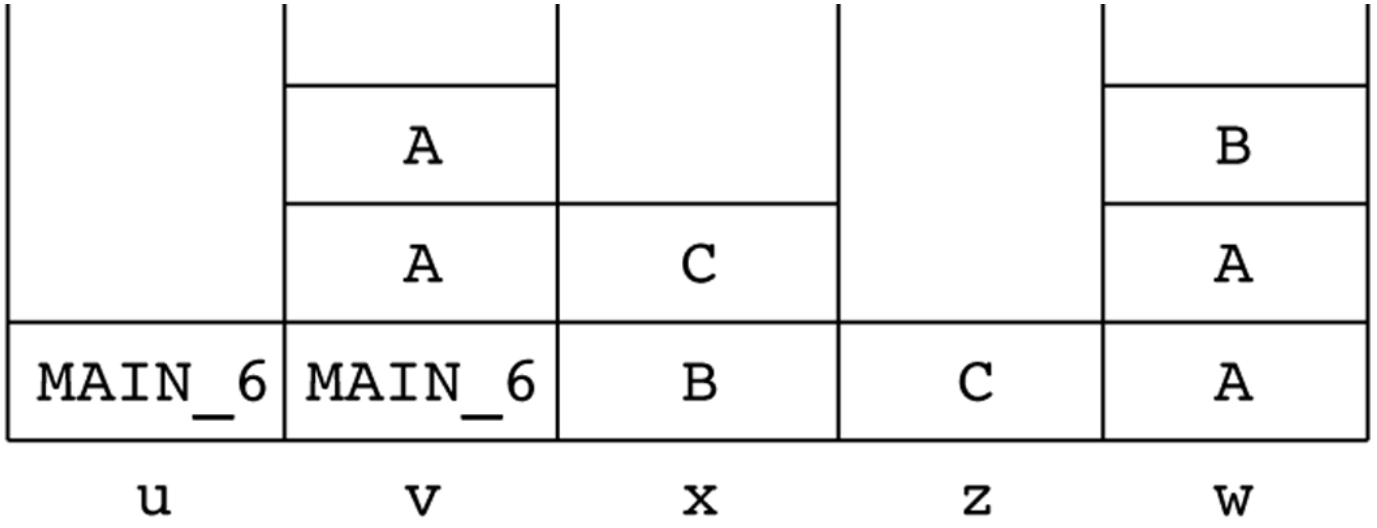
Implementing Dynamic Scoping

- *Deep Access*: non-local references are found by searching the activation record instances on the dynamic chain

- *Shallow Access*: put locals in a central place
  - One stack for each variable name
  - Central table with an entry for each variable name

Using Shallow Access to Implement Dynamic Scoping



(The names in the stack cells indicate the program units of the variable declaration.)

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Summary

- Subprogram linkage semantics requires many action by the implementation
- Simple subprograms have relatively basic actions
- Stack-dynamic languages are more complex
- Subprograms with stack-dynamic local variables and nested subprograms have two components
  - actual code
  - activation record

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Summary (continued)

- Activation record instances contain formal parameters and local variables among other things
- Static chains are the primary method of implementing accesses to non-local variables in static-scoped languages with nested subprograms
- Access to non-local variables in dynamic-scoped languages can be implemented by use of the dynamic chain or thru some central variable table method

Homework #7

- Problem Solving (P. 477 of class textbook)
  - 1, 3, 7, 8, 9

- Due date: One week from assigned date
  - Please hand in printed (typed) form
    - **I do not accept any handwritten assignment**
    - **Exception: pictures**