CS 314 Principles of Programming Languages

Lecture 12: Names, Scopes and Bindings

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Review: Names, Scopes and Binding

What's in a name? — Each name "means" something!

- Denotes a programming language construct
- Has associated "attributes"
  Examples: type, memory location, read/write permission, storage class, access restrictions.
- Has a meaning
  Examples: represents a semantic object, a type description, an integer value, a function value, a memory address.

Review: Names, Bindings and Memory

Bindings – Association of a name with the thing it "names" (e.g., a name and a memory location, a function name and its "meaning", a name and a value)

- **Compile time**: during compilation process - static (e.g.: macro expansion, type definition)
- **Link time**: separately compiled modules/files are joined together by the linker (e.g: adding the standard library routines for I/O (stdio.h), external variables)
- **Run time**: when program executes - dynamic

Compiler needs bindings to know meaning of names during translation (and execution).

Review: How to Maintain Bindings

- Symbol table: maintained by compiler during compilation
- Referencing Environment: maintained by compiler-generated-code during program execution

Question:

- How long do bindings last for a name hold in a program?
- What initiates a binding?
- What ends a binding?

Scope of a binding:
The part of program the in which the binding is active.

Review: Lexical Scope v.s. Dynamic Scope

Lexical Scope

- Non-local variables are associated with declarations at *compile* time
- Find the smallest block ***syntactically*** enclosing the reference and containing a declaration of the variable

Dynamic Scope

- Non-local variables are associated with declarations at *run* time
- Find the ***most recent, currently*** active run-time stack frame containing a declaration of the variable

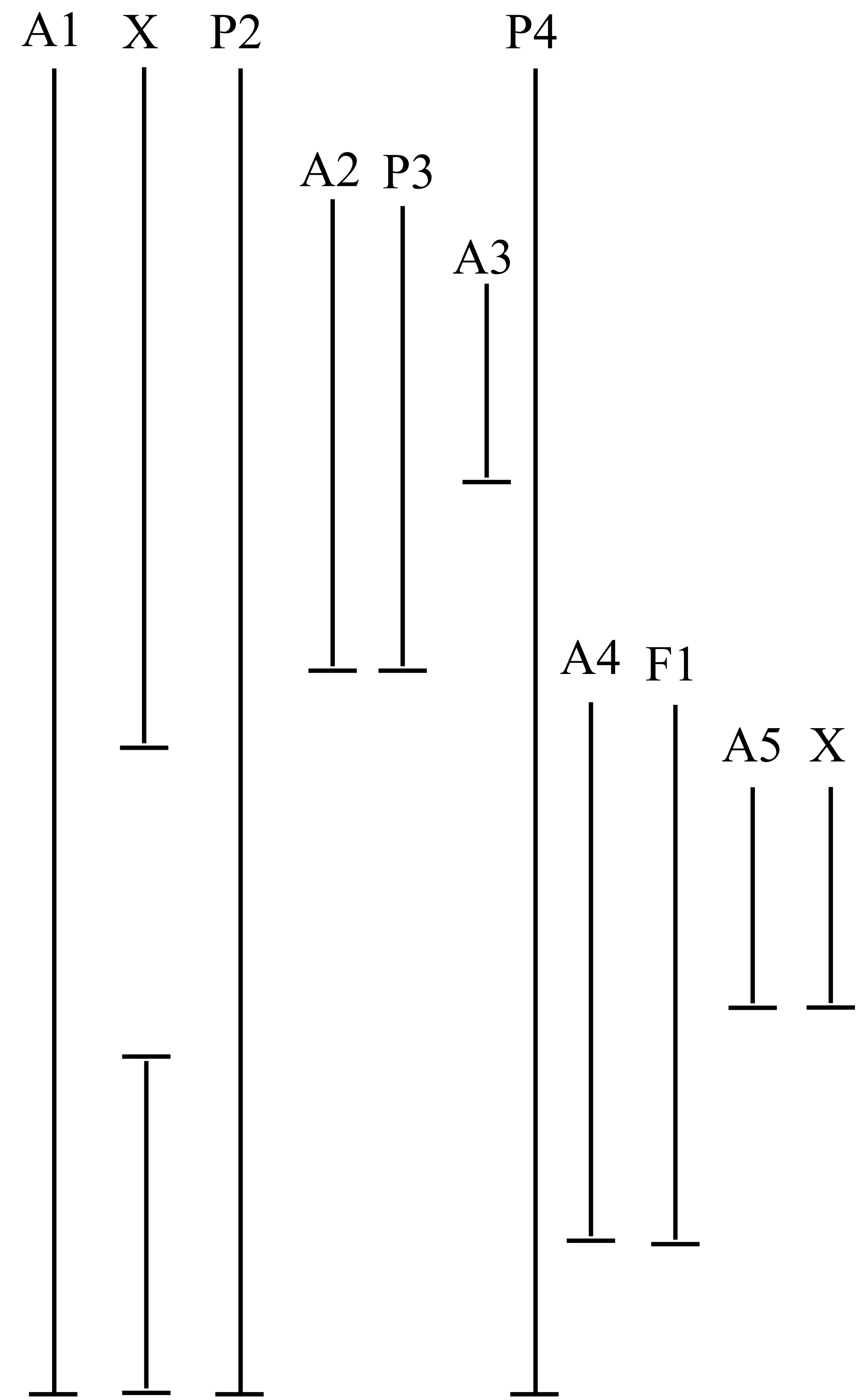
Lexical Scope

Closest scope rule

A name that is introduced in a declaration is known in the scope in which it is declared, and in each internally nested scope, unless it is hidden by another declaration of the same name in one or more nested scopes.

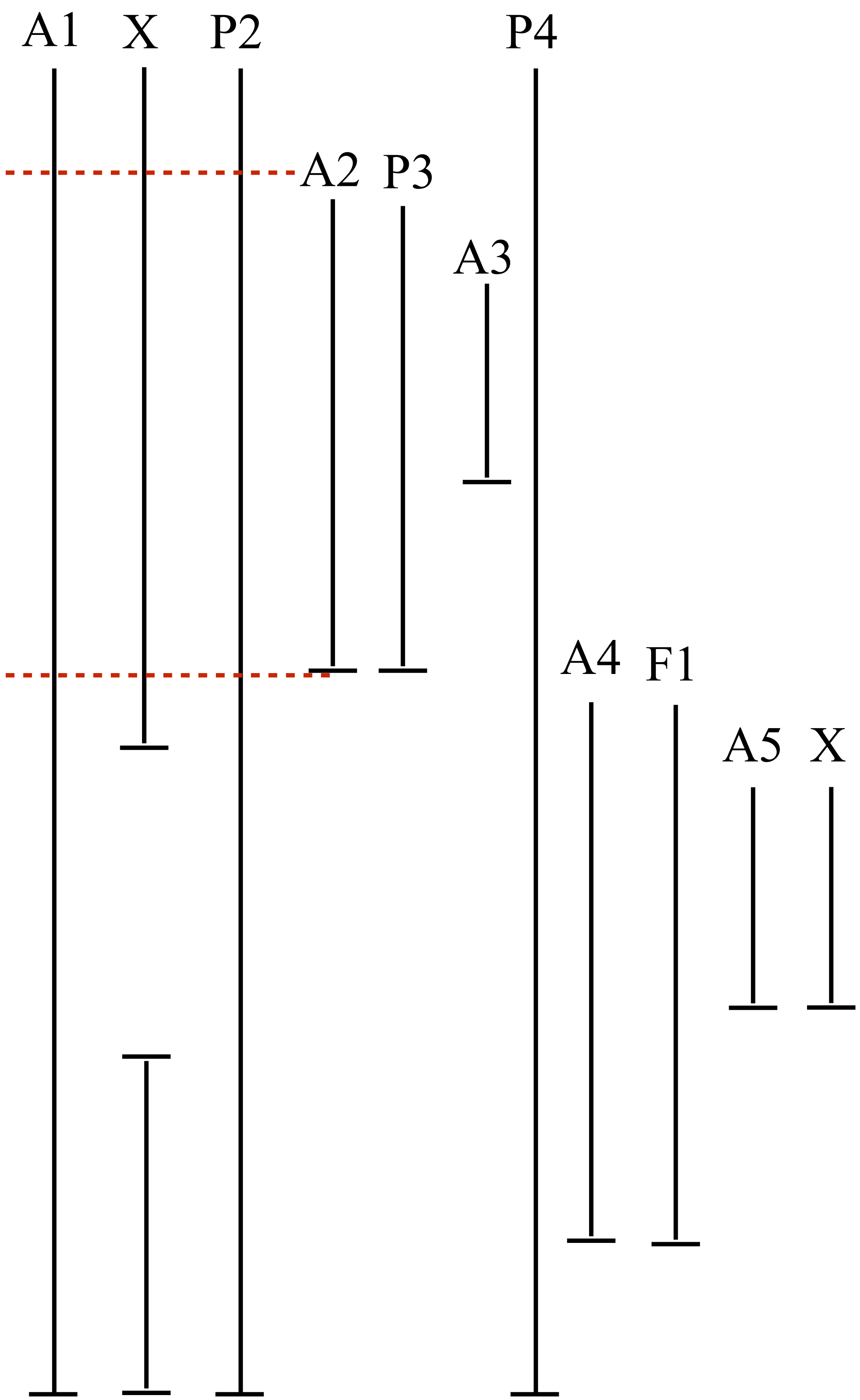
Scope Example

```
procedure P1(A1)
        var X                       — local to P1
        ...
        procedure P2(A2)
            ...
            procedure P3(A3)
                ...
            begin
                ...                 — body of P3
            end
            ...
        begin
            ...                     — body of P2
        end
        procedure P4(A4)
            ...
            function F1(A5)
                var X               — local to F1
                ...
            begin
                ...                 — body of F1
            end
            ...
        begin
            ...                     — body of P4
        end
        ...
begin
    ...                             — body of P1
end
```



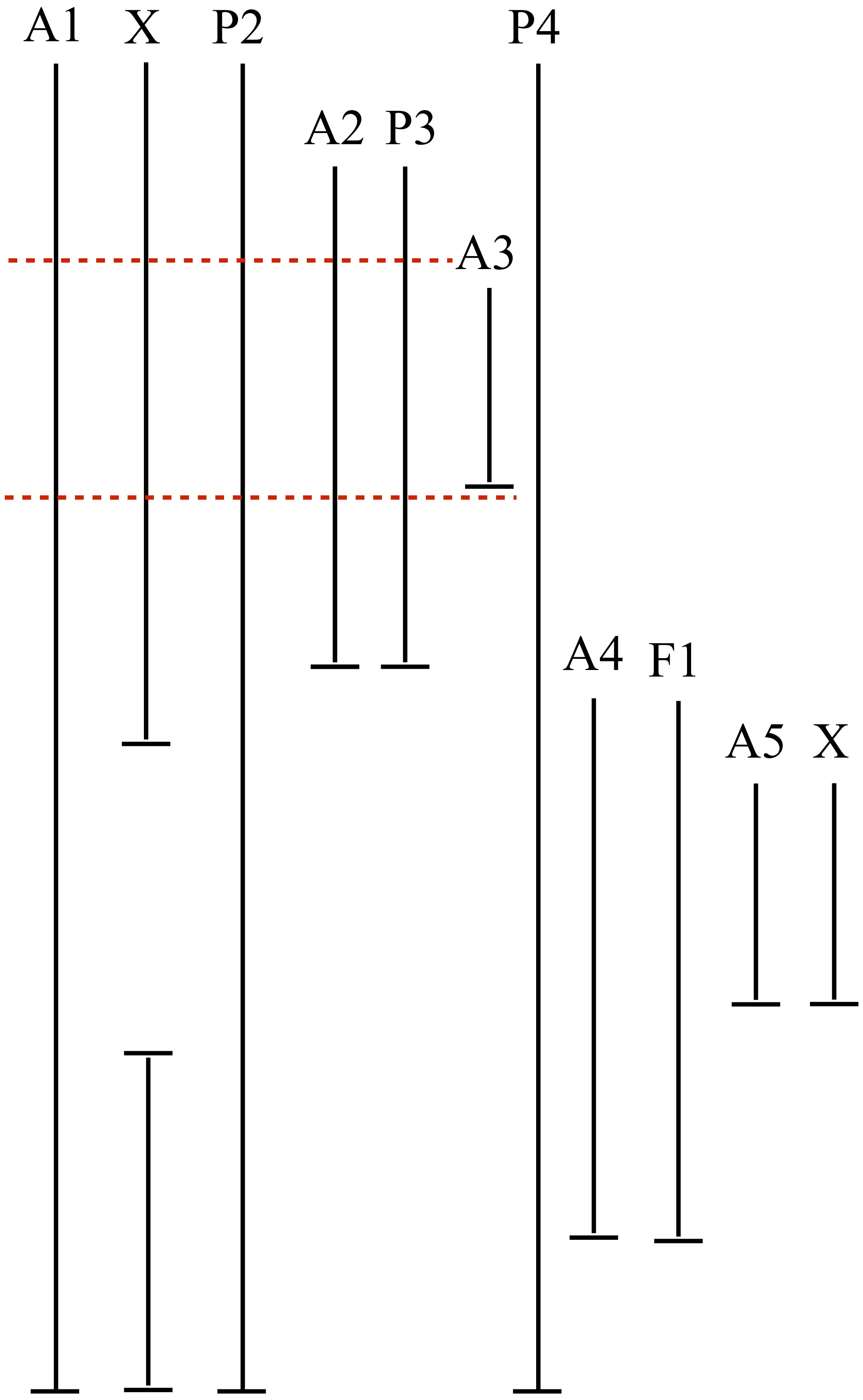
Scope Example

```
procedure P1(A1)
        var X                    — local to P1
        ...
        procedure P2(A2)
             ...
             procedure P3(A3)
                  ...
             begin
                  ...            — body of P3
             end
             ...
        begin
             ...                 — body of P2
        end
        procedure P4(A4)
             ...
             function F1(A5)
                  var X          — local to F1
                  ...
             begin
                  ...            — body of F1
             end
             ...
        begin
             ...                 — body of P4
        end
        ...
begin
   ...                           — body of P1
end
```



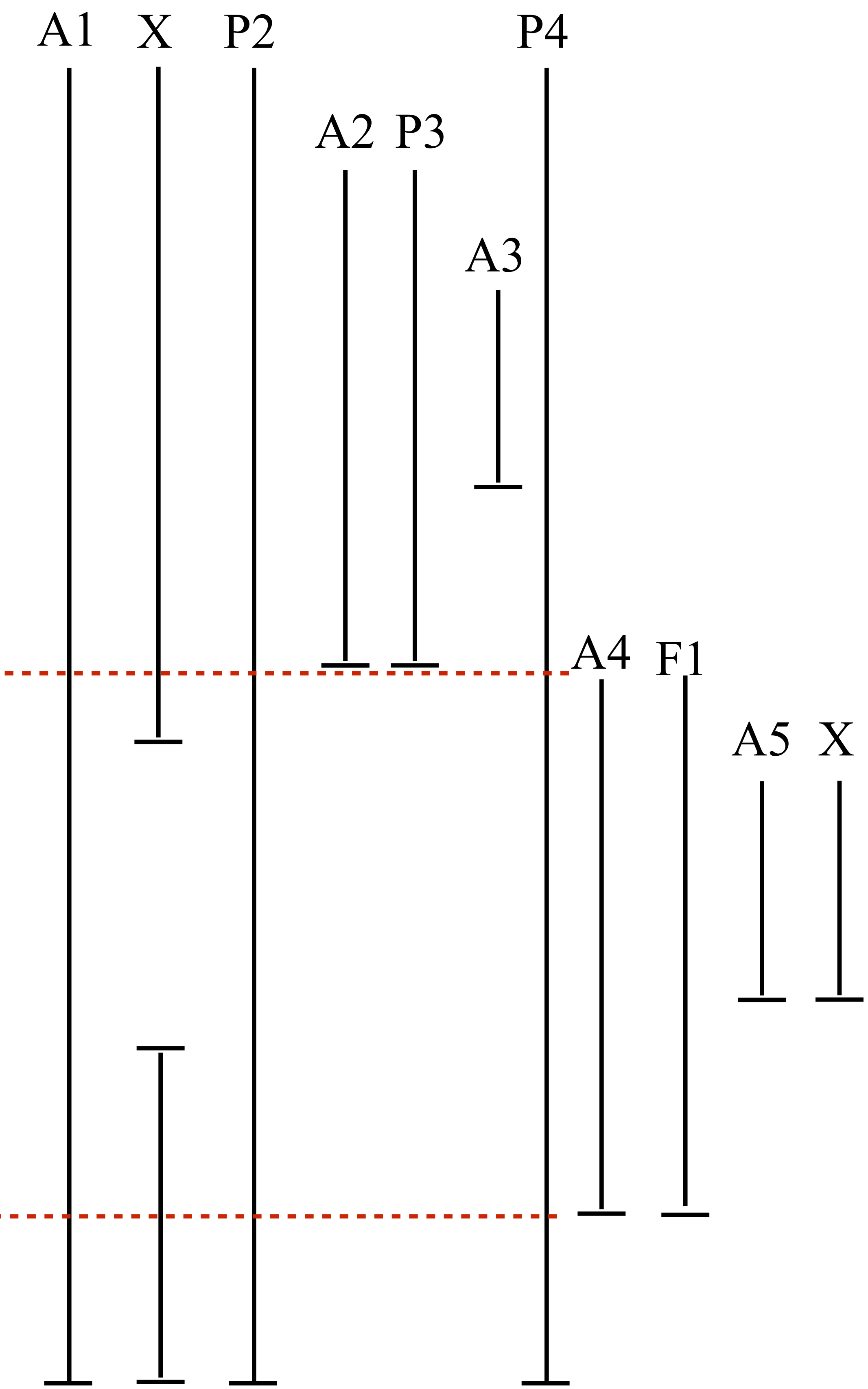
Scope Example

```
procedure P1(A1)
        var X                          — local to P1
        ...
        procedure P2(A2)
             ...
             procedure P3(A3)
                  ...
             begin
                  ...                  — body of P3
             end
             ...
        begin
             ...                       — body of P2
        end
        procedure P4(A4)
             ...
             function F1(A5)
                  var X                — local to F1
                  ...
             begin
                  ...                  — body of F1
             end
             ...
        begin
             ...                       — body of P4
        end
        ...
begin
   ...                                 — body of P1
end
```



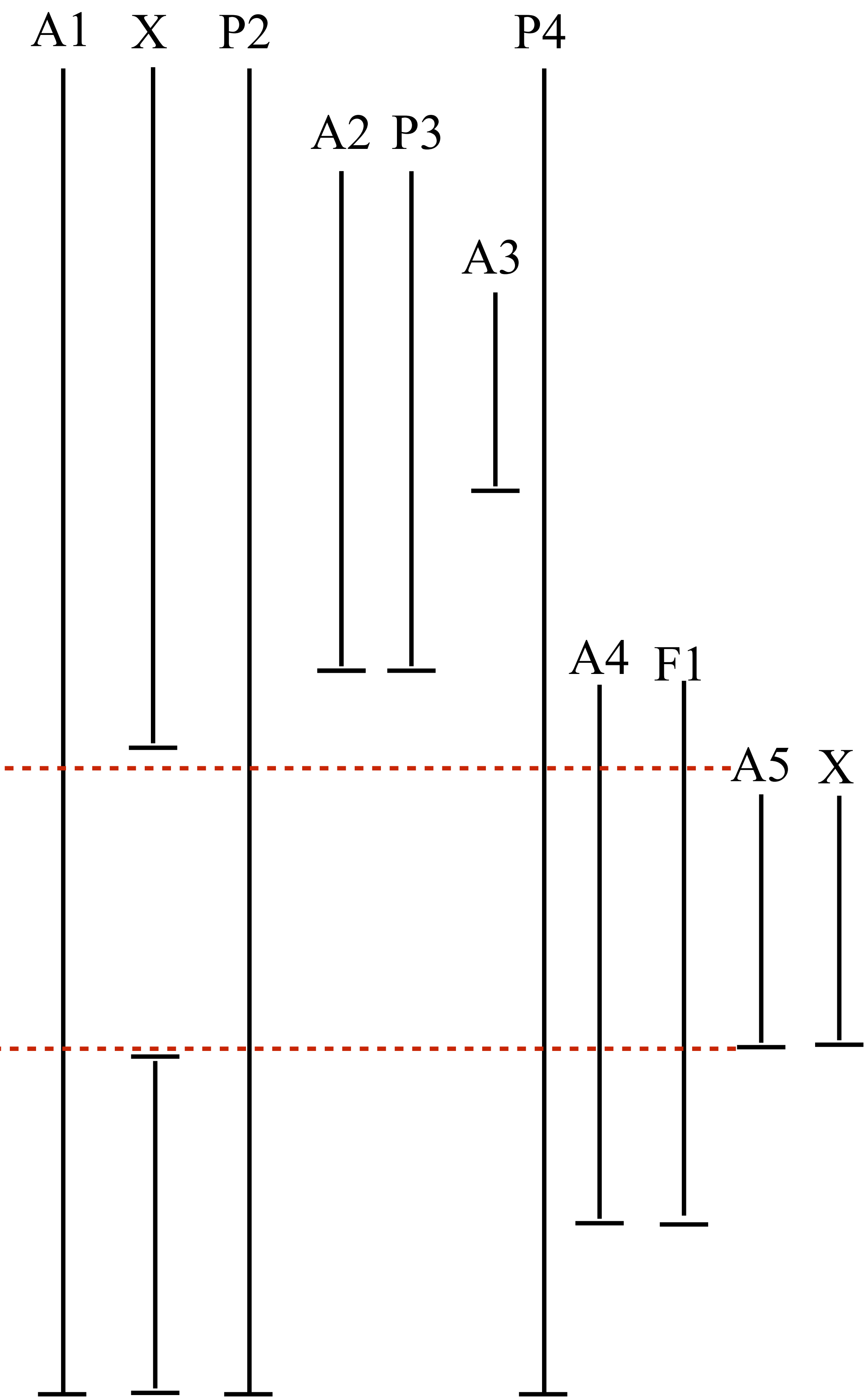
Scope Example

```
procedure P1(A1)
        var X                    — local to P1
        ...
        procedure P2(A2)
             ...
             procedure P3(A3)
                  ...
             begin
                  ...            — body of P3
             end
             ...
        begin
             ...                 — body of P2
        end
        procedure P4(A4)
             ...
             function F1(A5)
                  var X          — local to F1
                  ...
             begin
                  ...            — body of F1
             end
             ...
        begin
             ...                 — body of P4
        end
        ...
begin
   ...                           — body of P1
end
```



Scope Example

```
procedure P1(A1)
        var X                     — local to P1
        ...
        procedure P2(A2)
             ...
             procedure P3(A3)
                  ...
             begin
                  ...              — body of P3
             end
             ...
        begin
             ...                   — body of P2
        end
        procedure P4(A4)
             ...
             function F1(A5)
                  var X            — local to F1
                  ...
             begin
                  ...              — body of F1
             end
             ...
        begin
             ...                   — body of P4
        end
        ...
begin
   ...                             — body of P1
end
```



Scope Example

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procedure P1(A1)
        var X                     — local to P1
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        procedure P2(A2)
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                  …
             begin
                  …                — body of P3
             end
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             …
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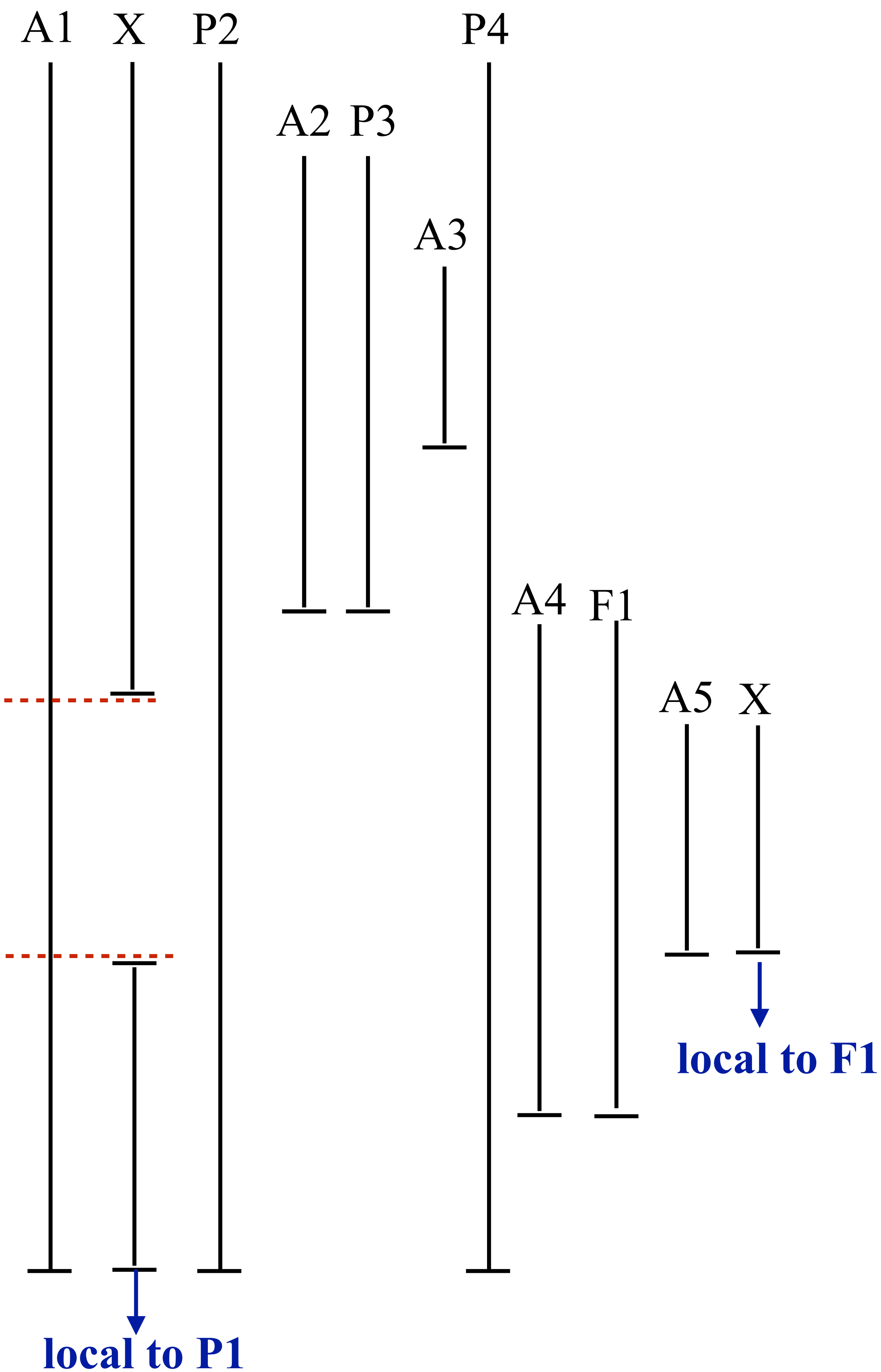
                  var X            — local to F1
                  …
             begin
                  …                — body of F1
             end
             …
        begin
             …                     — body of P4
        end
        …
begin
   …                               — body of P1
end
```

X local to F1 is hidden by X local to F1

also called a “hole”



Dynamic Scope

Depending on the Flow of Execution at Run Time

The “current” binding for a given name is the one encountered most recently during execution, and not yet destroyed by returning from its scope.

Dynamic Scope

The output is ?

D

Which "n"?

Caller

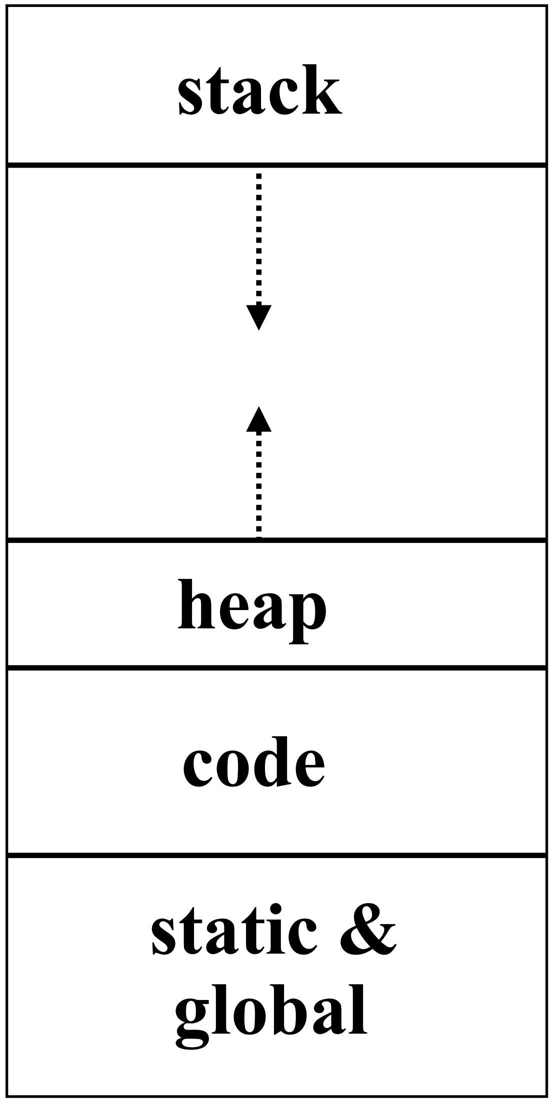
Calling Chain:

$L \Rightarrow D \Rightarrow W$

```
program L;
        var n: char; {n declared in L}
        procedure W;
        begin
                write (n); {n referenced in W}
        end;
        procedure D;
                var n: char; {n declared in D}
        begin
                n := 'D'; {n referenced in D}
                W
        end;
begin
        n := 'L';   {n referenced in L}
        ---
        D
end
```

Review: Program Memory Layout

- Static objects are given an absolute address that is retained throughout the execution of the program
- Stack objects are allocated and deallocated in last-in, first-out order, usually in conjunction with subroutine calls and returns
- Heap objects are allocated and deallocated at any arbitrary time



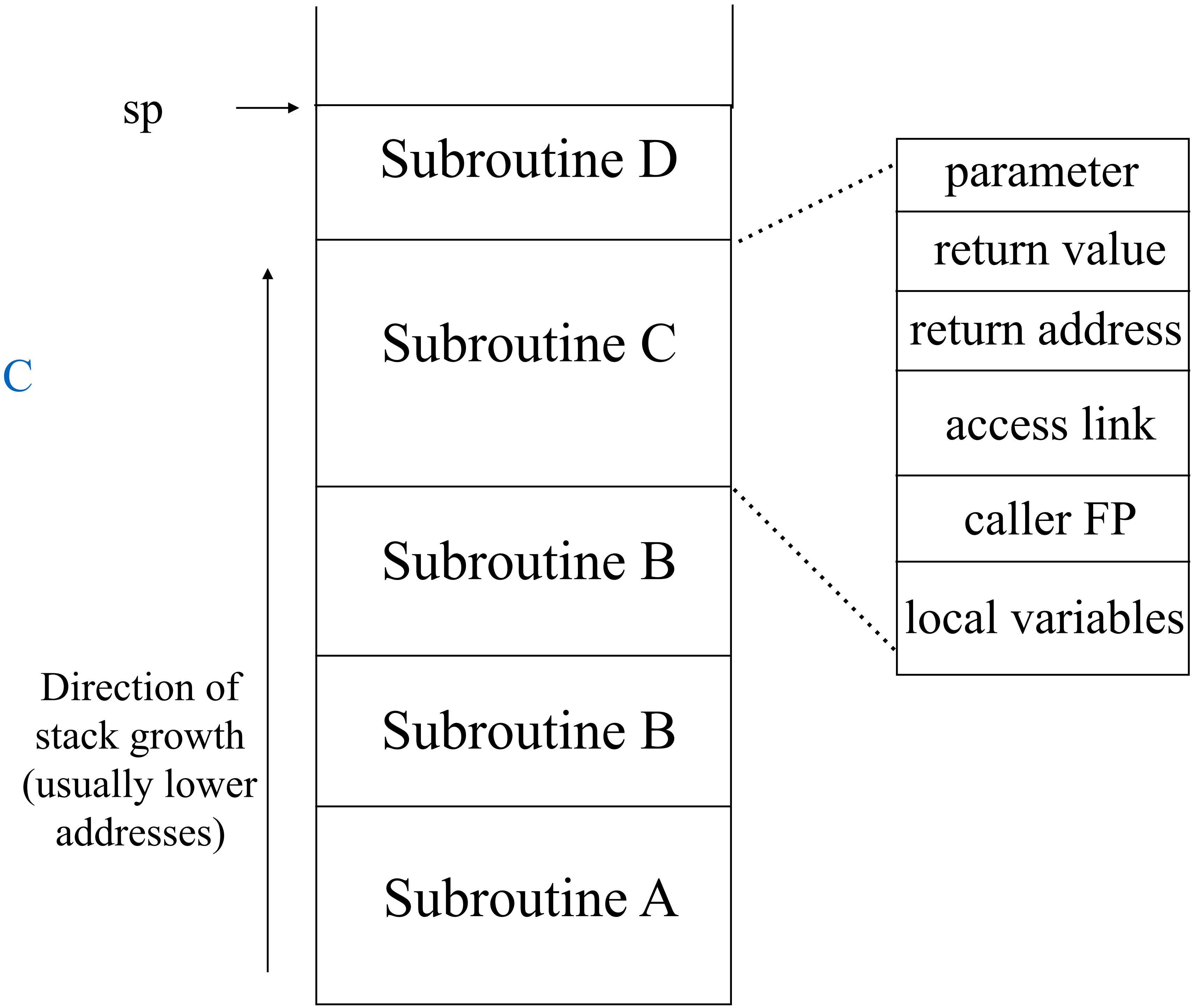
Procedure Activations

- Begins when control enters activation (call)
- Ends when control returns from call

Calling chain: $A \Rightarrow B \Rightarrow B \Rightarrow C \Rightarrow D$

Example:

procedure C:
  D
procedure B:
  if…then B else C
procedure A:
  B
main program:
  A



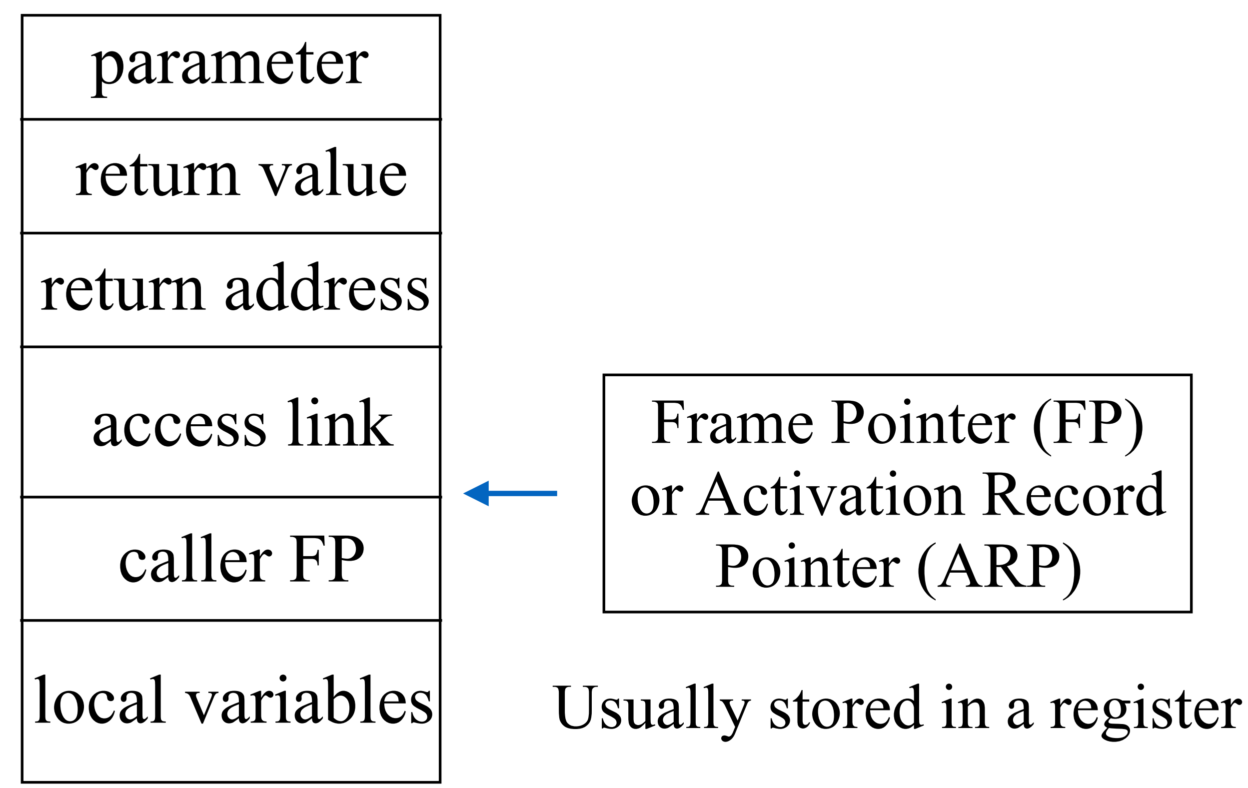
Procedure Activations

- Run-time stack contains frames from main program & active procedure
- Each **stack frame** includes:
  1. Pointer to stack frame of caller
     (**control link** for stack maintenance and dynamic scoping)
  2. Return address (within calling procedure)
  3. Mechanism to find non-local variables (**access link** for lexical scoping)
  4. Storage for parameters, local variables and final values
  5. Other temporaries including intermediate values & saved register

Stack Frame

or

Activation Record



Implementation of Lexical Scope and Dynamic Scope

Lexical Scope

- Non-local variables are associated with declarations at *compile* time
- Find the smallest block ***syntactically*** enclosing the reference and containing a declaration of the variable
- <u>Access link</u> points to the **most recently activated** immediate lexical ancestor

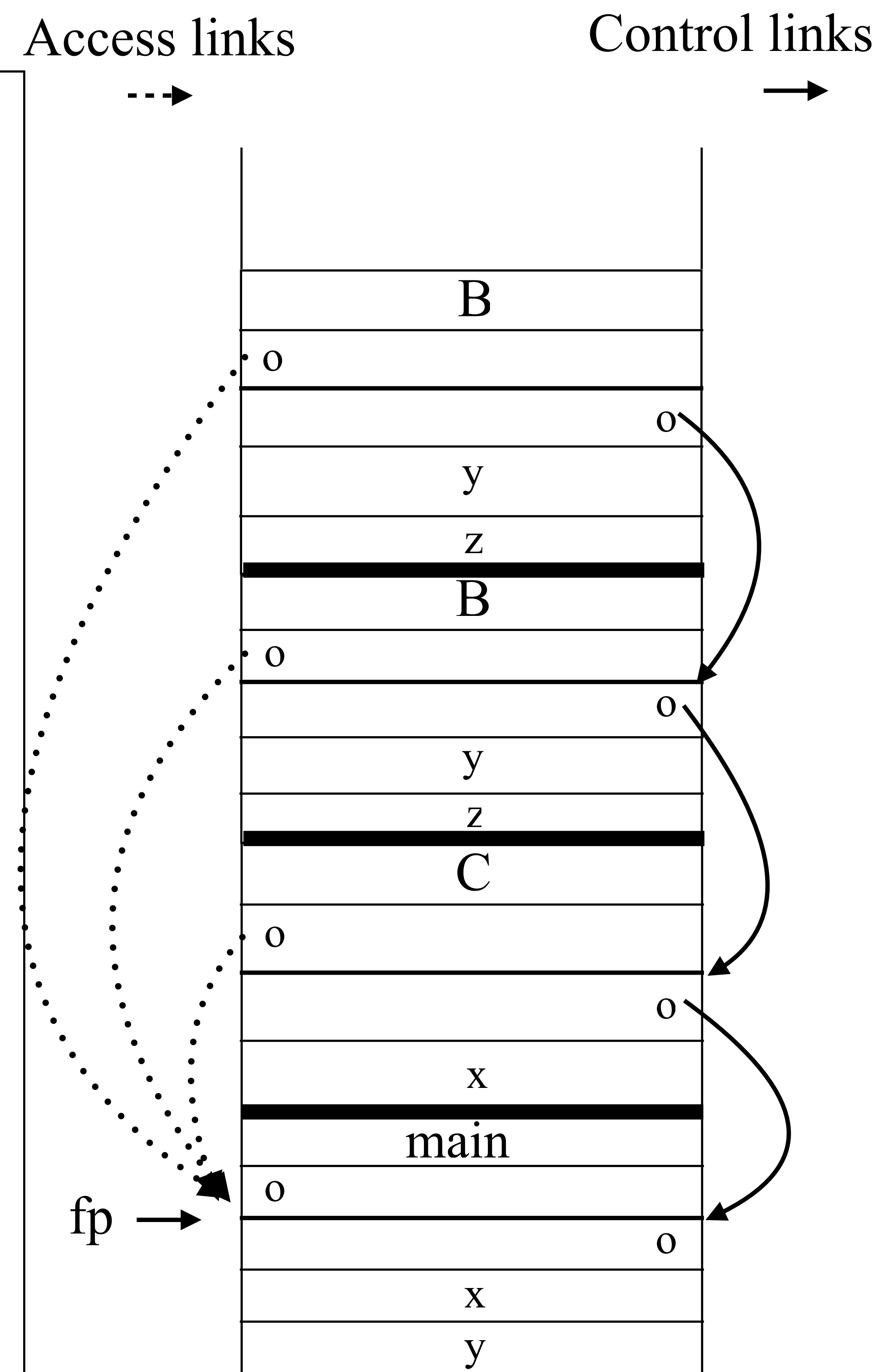
Dynamic Scope

- Non-local variables are associated with declarations at *run* time
- Find the ***most recent, currently*** active run-time stack frame containing a declaration of the variable
- <u>Control link</u> points to the caller

Implementation of Lexical Scope and Dynamic Scope

Calling chain: MAIN⇒ C ⇒ B ⇒ B

```
Program
        x, y: integer   // declarations of x and y
        Procedure B     // declaration of B
                y, z: real  // declaration of y and z
                begin
                ...
                y = x + z // occurrences of y, x, and z
                if (...) call B // occurrence of B
                end
         Procedure C    // declaration of C
                x: real
                begin
                ...
                call B // occurrence of B
                end
         begin
           ...
         call C     // occurrence of C
         call B     // occurrence of B
end
```



Context of Procedures

Two contexts

- *static* placement in source code (same for each invocation)
- *dynamic* run-time stack context (different for each invocation)

Scope Rules:

Each variable reference must be associated with a single declaration.

Context of Procedures

Two choices:

1. Use static and dynamic context: *lexical scope*
2. Use dynamic context: *dynamic scope*
   - Easier for variables declared locally: same for *lexical* and *dynamic* scoping
   - Harder for variables not declared locally: not same for *lexical* and *dynamic* scoping

Access to Non-Local Data(Lexical Scoping)

Two important steps

1. ***Compile-time*:** How do we map a name into a (level, offset) pair?
   We use a block structured symbol table (**compile time**)
   - When we look up a name, we want to get the most recent declaration for the name
   - The declaration may be found in the current procedure or in any ancestor procedure
2. ***Run-time*:** Given a (level, offset) pair, what's the address?
   - Two classical approaches:
     - ⇒ access link (*static link*)
     - ⇒ display

Compile-Time

Symbol table generated at compile time matches declarations and occurrences.
⇒ Each name can be represented as a pair (nesting_level, local_index).

```
Program
  x, y: integer   // declarations of x and y
  Procedure B     // declaration of B
     y, z: real  // declaration of y and z
  begin
       ...
       y = x + z // occurrences of y, x, and z
       if (...) call B // occurrence of B
  end
  Procedure C     // declaration of C
     x: real
  begin
       ...
       call B // occurrence of B
  end
begin
  ...
  call C     // occurrence of C
  call B     // occurrence of B
end
```

```
Program
  (1,1), (1,2): integer   // declarations of x and y
  Procedure (1,3)    // declaration of B
     (2,1), (2,2): real  // declaration of y and z
  begin
       ...
       (2,1) = (1,1) + (2,2) // occurrences of y, x, and z
       if (...) call (1,3) // occurrence of B
  end
  Procedure (1,4)    // declaration of C
     (2,1): real
  begin
       ...
       call (1,3) // occurrence of B
  end
begin
  ...
  call (1,4)     // occurrence of C
  call (1,3)     // occurrence of B
end
```

Runtime Access to Non-Local Data (Lexical Scoping)

Using access link:

Runtime: To find the value specified by (l, o)

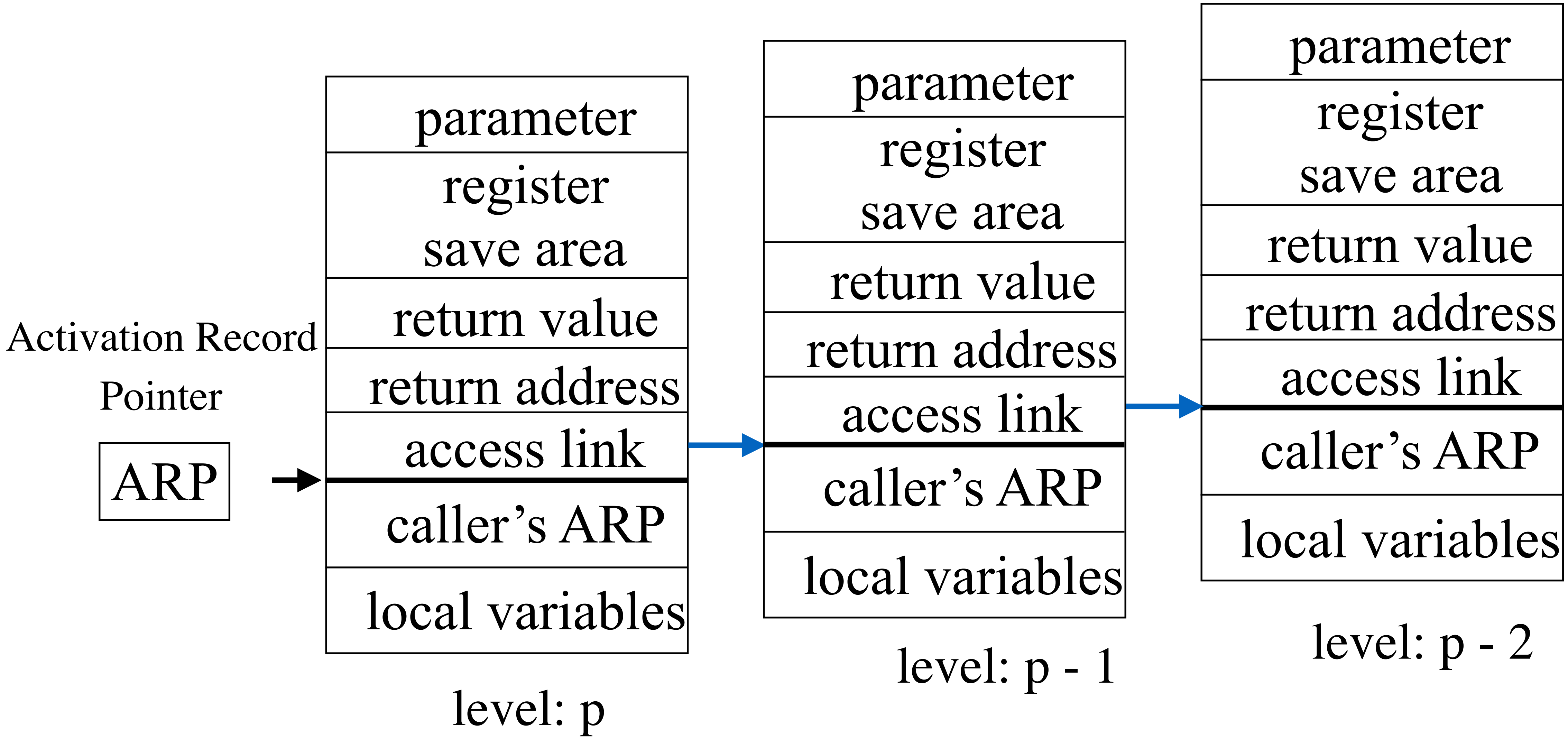
Assume nested procedure has higher index than its parent procedure.

- Assume current procedure level is **k**
- If $k = l$, it is a local variable
- If $k > l$, must find *l's* activation record (stack frame)
  $\Rightarrow$ follow $k - l$ access link
- $k < l$ cannot occur

Access to Non-Local Data(Lexical Scoping): Access Link

Using access links (static links)

- Each AR has a pointer to most recent AR of immediate lexical ancestor
- Lexical ancestor does not need to be the caller



Cost of access link is proportional to lexical distance

Maintaining Access Links

Setting up access link (the caller does the job):

If the callee procedure *p* is nested immediately within the caller procedure *q*, the access link for *p* points to the activation record of the *most recent* activation of *q*.

Assuming current level is k:

- Calling level k + 1 procedure
  1. Pass the caller's FP as access link
  2. The caller's backward chain will work for lower levels
- Calling procedure at level i ≤ k
  1. Find the caller's link to level i - 1 and pass it to callee
  2. Its access link will work for lower levels

An Improvement: The Display

To improve run-time access costs, use a *display*.

- table of access links for lower levels
- lookup is index from known offset
- takes slight amount of time at call
- a single display or one per frame

Access with the display

assume a value described by (l,o)

- find slot as DP[*l*] in display pointer array
- add offset to pointer from slot

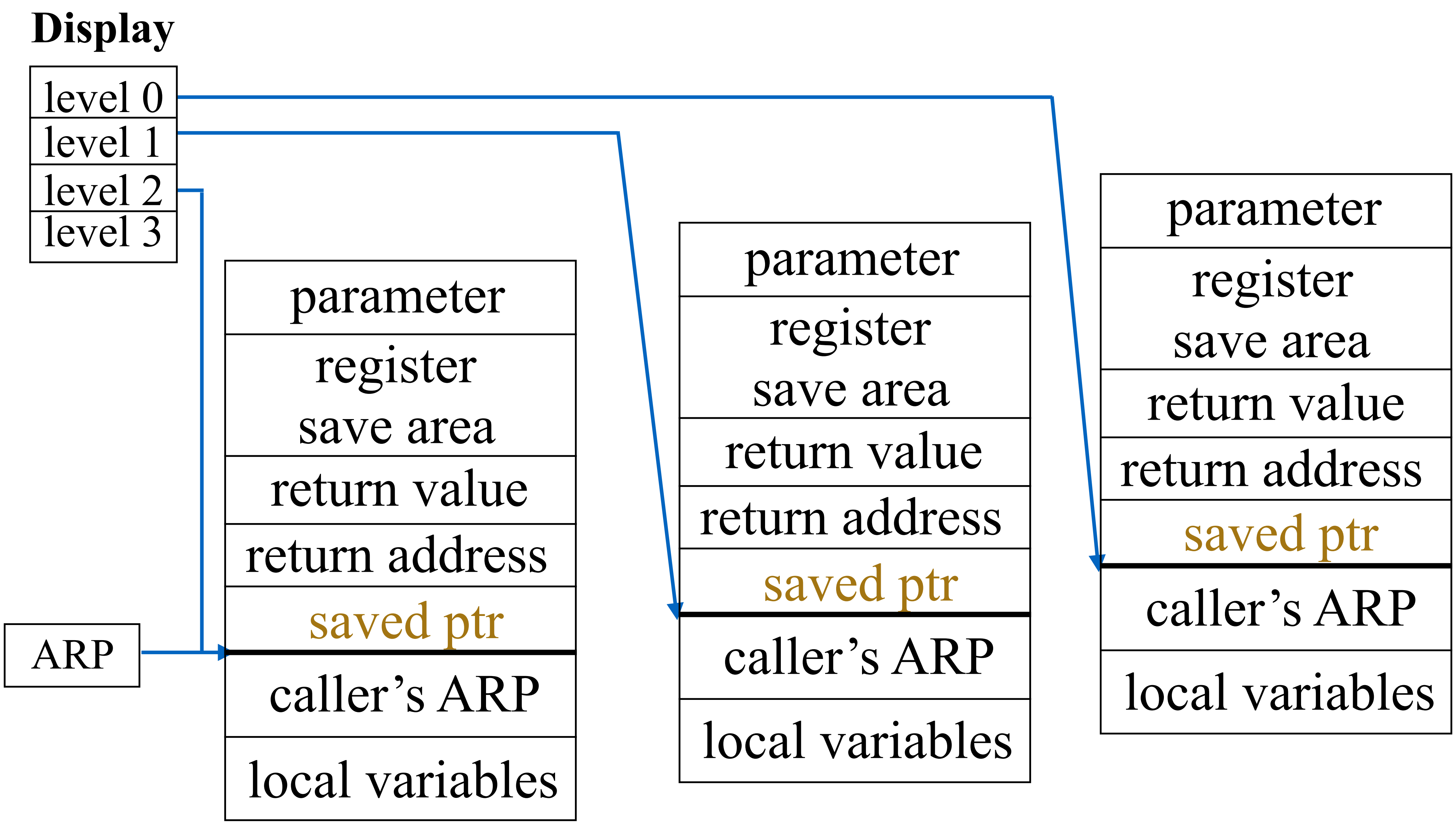
"Setting up the activation frame" now includes display manipulation.

Access to Non - Local Data(Lexical Scoping): Display

Using a display

Cost of access link is constant (APR + offset)

- Global arrays of pointers to nameable array
- Needed ARP is an array access away



Example: reference to <p, 16> looks up p's APR in display and add 16

Display Management

Single global display:

On entry to a procedure at level i:

Save the level i display value
push FP into level i display slot

On return:

Restore the level i display value

parameter
register save area
return value
return address
saved ptr
caller’s ARP
local variables

Procedures

- Modularize program structure
  - Actual parameter: information passed from caller to callee (*Argument*)
  - Formal parameter: local variable whose value (usually) is received from caller
- Procedure declaration
  - Procedure names, formal parameters, procedure body with formal local declarations and statement lists, optional result type

    Example: void translate(point *p, int dx)

Parameters

Parameter Association

- Positional association: Arguments associated with formals one-by-one; Example: C, Pascal, Java, Scheme
- Keyword association: formal/actual pairs; mix of positional and keyword possible;
  Example: Ada

  procedure plot(x, y: in real; z: in boolean)

  … plot (0.0, 0.0, z ⇒ true)

  … plot (z ⇒ true, x ⇒ 0.0, y ⇒ 0.0)

Parameter Passing Modes

- Pass-by-value: C/C++, Pascal, Java/C# (value types), Scheme
- Pass-by-result: Ada, Algol W
- Pass-by-value-result: Ada, Swift
- Pass-by-reference: Fortran, Pascal, C++, Ruby, ML

Pass-by-value

```
begin
    c: array[1...10] of integer;
    m, n: integer;
    procedure r(k, j: integer)
    begin
        k := k + 1;
        j := j + 2;
    end r;
  ...
  m := 5;
  n := 3;
  r(m, n);
  write m,n;
end
```

Output:

5 3

Advantage: Argument protected from changes in callee.
Disadvantage: Copying of values takes execution time and space, especially for aggregate values (e.g.: structs, arrays)

Pass-by-reference

```
begin
       c: array[1...10] of integer;
       m, n: integer;
       procedure r(k,j: integer)
       begin
              k := k + 1;
              j := j + 2;
       end r;
  ...
  m := 5;
  n := 3;
  r(m, n);
  write m, n;
end
```

Output:

6 5

Advantage: more efficient than copying
Disadvantage: leads to aliasing, there are two or more names for the storage location; hard to track side effects

Pass-by-result

```
begin
    c: array[1...10] of integer;
    m, n: integer;
    procedure r(k, j: integer)
    begin
        k := k + 1;  → ERROR:
        j := j + 2;      CANNOT USE PARAMETERS WHICH ARE UNINITIALIZED
    end r;
   ...
   m := 5;
   n := 3;
   r(m, n);
   write m, n;
end
```

Output:

Program doesn’t compile or has runtime error

Pass-by-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := 1;  → HERE IS A PROGRAM THAT WORKS
            j := 2;
      end r;
     ...
     m := 5;
     n := 3;
     r(m, n);
     write m, n;
end
```

Output: ?

Pass-by-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := 1;
            j := 2;
      end r;
    ...
    m := 5;
    n := 3;
    r(m, n);
    write m, n;
end
```

→ HERE IS A PROGRAM THAT WORKS

Output: 1 2

Pass-by-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := 1;
            j := 2;
      end r;
     ...
     m := 5;
     n := 3;
     r(m, m);→ NOTE: CHANGE THE CALL
     write m, n;
end
```

Output: 1 or 2 for m?

Problem: order of copy back makes a difference;
implementation dependent.

Pass-by-value-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := k + 1;
            j := j + 2;
      end r;
     ...
     m := 5;
     n := 3;
     r(m, n);
     write m, n;
end
```

Output: 6 5

Problem: order of copy back makes a difference;
implementation dependent.

Pass-by-value-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := k + 1;
            j := j + 2;
      end r;
     ...
     /* set c[m] = m */
     m := 2;
     r(m,c[m]);→ WHAT ELEMENT OF "c" IS ASSIGNED TO?
     write c[1], c[2], c[3], ... c[10];
end
```

Output:

Pass-by-value-result

```
begin
    c: array[1...10] of integer;
    m, n: integer;
    procedure r(k, j: integer)
    begin
        k := k + 1;
        j := j + 2;
    end r;
   ...
   /* set c[m] = m */
   m := 2;
   r(m,c[m]);→  WHAT ELEMENT OF "c" IS ASSIGNED TO?
   write c[1], c[2], c[3], ... c[10];
end
```

Output:

Problem: When is the address computed for the copy-back operation? At procedure call (procedure entry), just before procedure exit, or somewhere in between? (Example: ADA on entry)

Pass-by-value-result

```
begin
    c: array[1...10] of integer;
    m, n: integer;
    procedure r(k, j: integer)
    begin
        k := k + 1;
        j := j + 2;
    end r;
   ...
   /* set c[m] = m */
   m := 2;
   r(m,c[m]);→  WHAT ELEMENT OF "c" IS ASSIGNED TO?
   write c[1], c[2], c[3], ... c[10];
end
```

Output:

1 4 3 4 5 … 10 on entry

1 2 4 4 5 … 10 on exit

Problem: When is the address computed for the copy-back operation? At procedure call (procedure entry), just before procedure exit, or somewhere in between? (Example: ADA on entry)

Pass-by-value-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := k + 1;
            j := j + 2;
      end r;
     ...
     /* set c[m] = m */
     m := 2;
     r(m,c[m]);
     write c[1], c[2], c[3], ... c[10];
end
```

→ WHAT ELEMENT OF "c" IS ASSIGNED TO?

Output:

1 4 3 4 5 … 10 on entry

1 2 4 4 5 … 10 on exit

Problem: When is the address computed for the copy-back operation? At procedure call (procedure entry), just before procedure exit, or somewhere in between? (Example: ADA on entry)

Aliasing

Aliasing:

More than two ways to name the same object within a scope

Even without pointers, you can have aliasing through (global⟷formal) and (formal⟷formal) parameter passing.

```
begin
        j, k, m: integer;
        procedure r(a, b: integer)
        begin
                b := 3;
                m := m * a;
        end
        ...
        q(m, k);  → global/formal <m,a> ALIAS PAIR
        q(j, j);  → formal/formal <a,b> ALIAS PAIR
        write y;
end
```

Comparison: by-value-result vs. by-reference

Actual parameters need to evaluate to L-values (addresses).

```
begin
        y: integer;
        procedure p(x: integer)
        begin
                x := x + 1      → ref: x and y are ALIASED
                x := x + y      → val-res: x and y are NOT ALIASED
        end
        ...
        y := 2;
        p(y);
        write y;
end
```

Output:

- pass-by-reference: 6
- pass-by-value-result: 5

Note: *by-value-result*: Requires copying of parameter values (expansive for aggregate values); does not have aliasing, but copy-back order dependence.

Next Lecture

Things to do:

- Read Scott, Chapter 9.1 - 9.3 (4th Edition) or Chapter 8.1 - 8.3 (3rd Edition), Chapter 11.1 - 11.3 (4th Edition)

Procedures

- Modularize program structure
  - Actual parameter: information passed from caller to callee (*Argument*)
  - Formal parameter: <u>local</u> variable whose <u>value</u> is received from caller
- Procedure declaration
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  write m,n;
end
```

Output:

5 3

Advantage: Argument protected from changes in callee.
Disadvantage: Copying of values takes execution time and space, especially for aggregate values (e.g.: structs, arrays)

Pass-by-reference

```
begin
        c: array[1...10] of integer;
        m, n: integer;
        procedure r(k,j: integer)
        begin
                k := k + 1;
                j := j + 2;
        end r;
   ...
   m := 5;
   n := 3;
   r(m, n);
   write m, n;
end
```

Output:

6 5

Advantage: more efficient than copying
Disadvantage: leads to aliasing, there are two or more names for the storage location; hard to track side effects

Pass-by-result

```
begin
        c: array[1...10] of integer;
        m, n: integer;
        procedure r(k, j: integer)
        begin
                k := k + 1;  → ERROR:
                j := j + 2;       CANNOT USE PARAMETERS WHICH ARE UNINITIALIZED
        end r;
       ...
       m := 5;
       n := 3;
       r(m, n);
       write m, n;
end
```

Output:

Program doesn't compile or has runtime error

Pass-by-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := 1;   → HERE IS A PROGRAM THAT WORKS
            j := 2;
      end r;
     ...
     m := 5;
     n := 3;
     r(m, n);
     write m, n;
end
```

Output: ?

Pass-by-result

```
begin
        c: array[1...10] of integer;
        m, n: integer;
        procedure r(k, j: integer)
        begin
                k := 1;  → HERE IS ANOTHER PROGRAM THAT WORKS
                j := 2;
        end r;
       ...
       m := 5;
       n := 3;
       r(m, m);→ NOTE: CHANGE THE CALL
       write m, n;
end
```

Output: 1 or 2 for m?

Problem: order of copy back makes a difference;
implementation dependent.

Pass-by-value-result

```
begin
    c: array[1...10] of integer;
    m, n: integer;
    procedure r(k, j: integer)
    begin
        k := k + 1;
        j := j + 2;
    end r;
   ...
   m := 5;
   n := 3;
   r(m, n);
   write m, n;
end
```

Output: 6 5

Problem: order of copy back makes a difference;
implementation dependent.

Pass-by-value-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := k + 1;
            j := j + 2;
      end r;
     ...
     /* set c[m] = m */
     m := 2;
     r(m,c[m]);→  WHAT ELEMENT OF "c" IS ASSIGNED TO?
     write c[1], c[2], c[3], ... c[10];
end
```

Output:

Pass-by-value-result

```
begin
     c: array[1...10] of integer;
     m, n: integer;
     procedure r(k, j: integer)
     begin
          k := k + 1;
          j := j + 2;
     end r;
    ...
    /* set c[m] = m */
    m := 2;
    r(m,c[m]);
    write c[1], c[2], c[3], ... c[10];
end
```

WHAT ELEMENT OF "c" IS ASSIGNED TO?

Output:

Problem: When is the address computed for the copy-back operation? At procedure call (procedure entry), just before procedure exit, or somewhere in between? (Example: ADA on entry)

Pass-by-value-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := k + 1;
            j := j + 2;
      end r;
     ...
     /* set c[m] = m */
     m := 2;
     r(m,c[m]);→ WHAT ELEMENT OF "c" IS ASSIGNED TO?
     write c[1], c[2], c[3], ... c[10];
end
```

Output:
1 4 3 4 5 … 10 on entry
1 2 4 4 5 … 10 on exit

Problem: When is the address computed for the copy-back operation? At procedure call (procedure entry), just before procedure exit, or somewhere in between? (Example: ADA on entry)

Pass-by-value-result

```
begin
      c: array[1...10] of integer;
      m, n: integer;
      procedure r(k, j: integer)
      begin
            k := k + 1;
            j := j + 2;
      end r;
     ...
     /* set c[m] = m */
     m := 2;
     r(m,c[m]);→  WHAT ELEMENT OF "c" IS ASSIGNED TO?
     write c[1], c[2], c[3], ... c[10];
end
```

Output:

1 4 3 4 5 … 10 on entry

1 2 4 4 5 … 10 on exit

Problem: When is the address computed for the copy-back operation? At procedure call (procedure entry), just before procedure exit, or somewhere in between? (Example: ADA on entry)

Aliasing

Aliasing:

More than two ways to name the same object within a scope

Even without pointers, you can have aliasing through (global⟷formal) and (formal⟷formal) parameter passing.

```
begin
    j, k, m: integer;
    procedure r(a, b: integer)
    begin
        b := 3;
        m := m * a;
    end
    ...
    q(m, k);  → global/formal <m,a> ALIAS PAIR
    q(j, j);  → formal/formal <a,b> ALIAS PAIR
    write y;
end
```

Comparison: by-value-result vs. by-reference

Actual parameters need to evaluate to L-values (addresses).

```
begin
        y: integer;
        procedure p(x: integer)
        begin
                x := x + 1      → ref: x and y are ALIASED
                x := x + y      → val-res: x and y are NOT ALIASED
        end
        ...
        y := 2;
        p(y);
        write y;
end
```

Output:

- pass-by-reference: 6
- pass-by-value-result: 5

Note: *by-value-result*: Requires copying of parameter values (expansive for aggregate values); does not have aliasing, but copy-back order dependence.

Next Lecture

Things to do:

- Read Scott, Chapter 9.1 - 9.3 (4th Edition) or Chapter 8.1 - 8.3 (3rd Edition), Chapter 11.1 - 11.3 (4th Edition)

Look up Non-local Variable Reference

Access links and **control links** are used to look for non-local variable references.

Static Scope:

*Access link points to the stack frame of the **most recently** activated lexically enclosing procedure*

⇒ Non-local name binding is *determined* at *compile time*, and *implemented* at *run-time*

Dynamic Scope:

*Control link points to the stack frame of **caller***

⇒ Non-local name binding is *determined* and *implemented* at *run-time*