The Procedure Abstraction Part II: Symbol Tables and Activation Records

The Procedure as a Name Space

Why introduce lexical scoping?

- Provides a compile-time mechanism for binding variables
- Lets the programmer introduce "local" names

How can the compiler keep track of all those names?

```
procedure p {
    int a, b, c
            ....
    {
        int v, b, x, w
            ....
    }
}
```

The Procedure as a Name Space

The Problem

- At point *X* in the execution of the program, which declaration of "*b*" is current?
- At run-time, where is "*b*" found?
- How does compiler delete "b" going in & out of scopes?

The Answer

- The compiler must model the name space
- Lexically scoped symbol tables

```
procedure p {
    int a, b, c
            ....
    {
        int v, b, x, w
            ....
    }
}
```

§ 5.7 in EaC

Lexically-scoped Symbol Tables

The problem

- The compiler needs a distinct record for each declaration
- Nested lexical scopes allow duplicate declarations

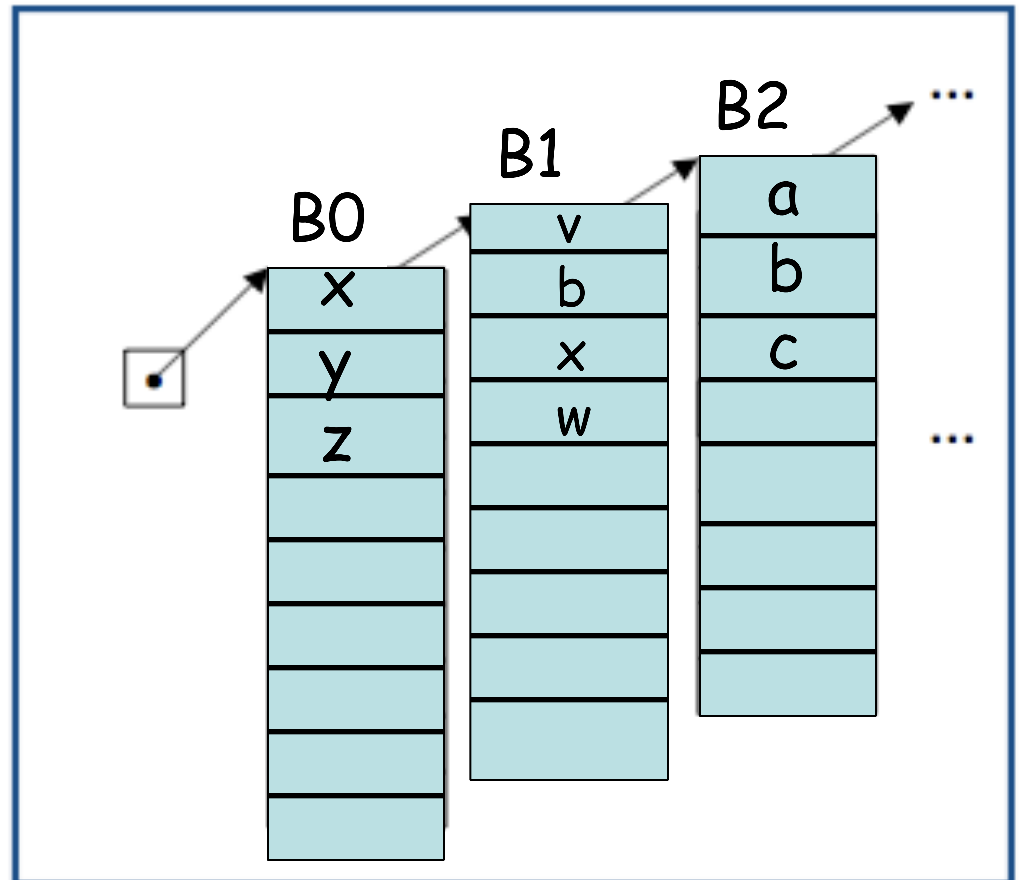
The interface

- insert(*name*, *level*) – creates record for *name* at *level*
- lookup(*name*, *level*) – returns pointer or index
- delete(*level*) – removes all names declared at *level*

High-level idea

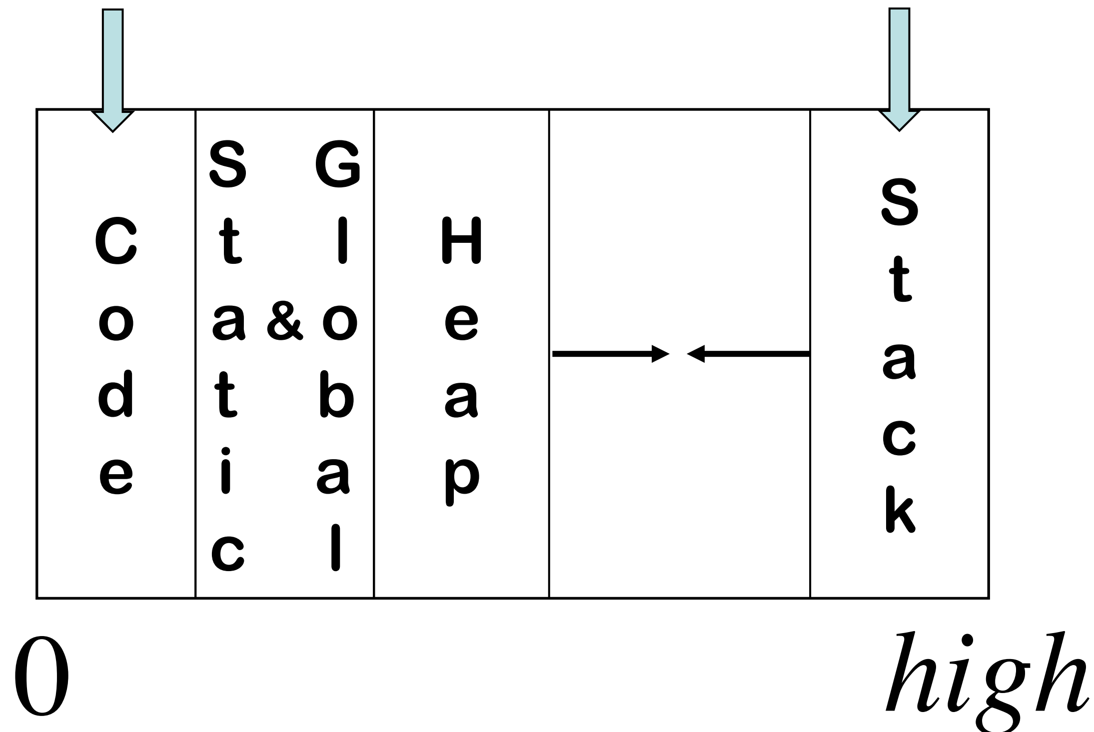
- Create a new table for each scope
- Chain them together for lookup

```
B0: procedure b {
      int x, y, z
B1:  {
            int v, b, x, w

B2:        {
                int a, b, c
                ....
              }

B3:        {
                int x, a, v
                ...
              }
              ...
      }
    ...
}
```



The Procedure as an External Interface

OS needs a way to start the program's execution



The Procedure as an External Interface

main function

Local variables go in function's activation record

Code	Static & Global	Heap	→ ←	Stack

0 *high*

on stack of ARs

fopen
main

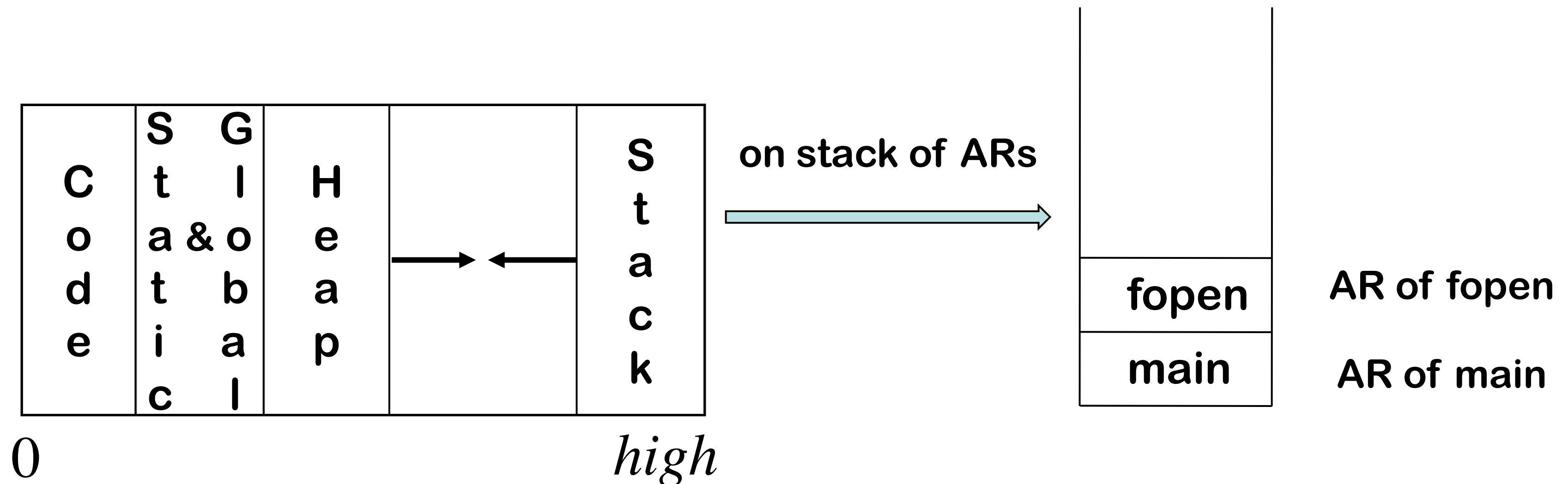
AR of fopen

AR of main

Where Do All These Variables Go?

Local

- Keep them in the procedure activation record or in a register
- Automatic ⇒ lifetime matches procedure's lifetime



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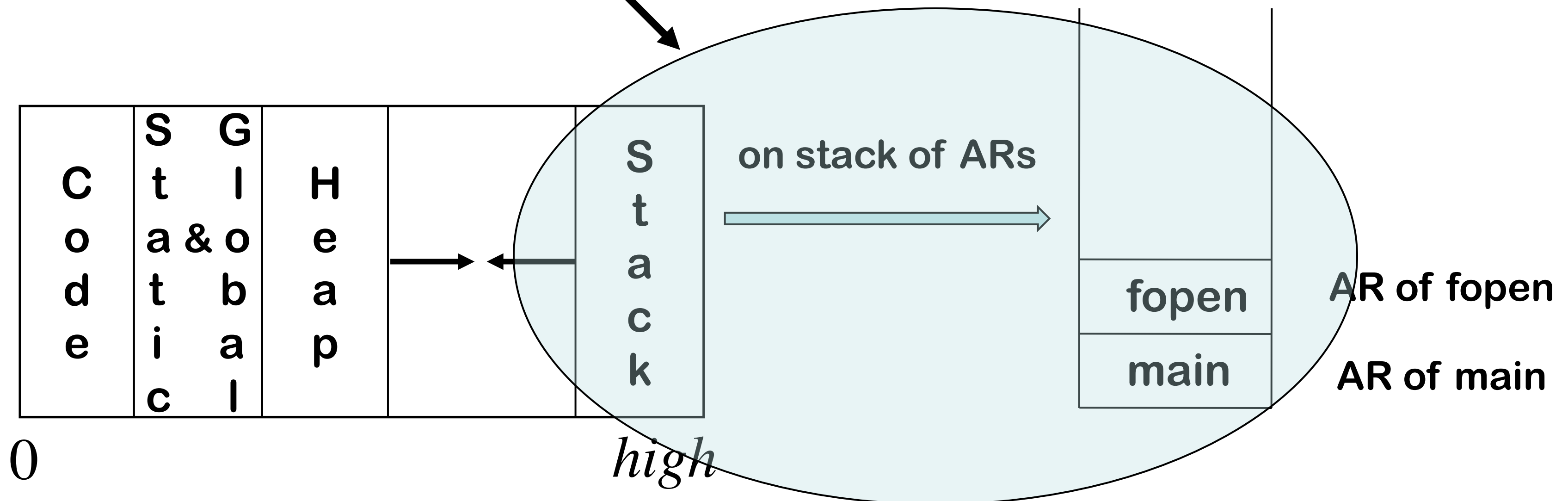
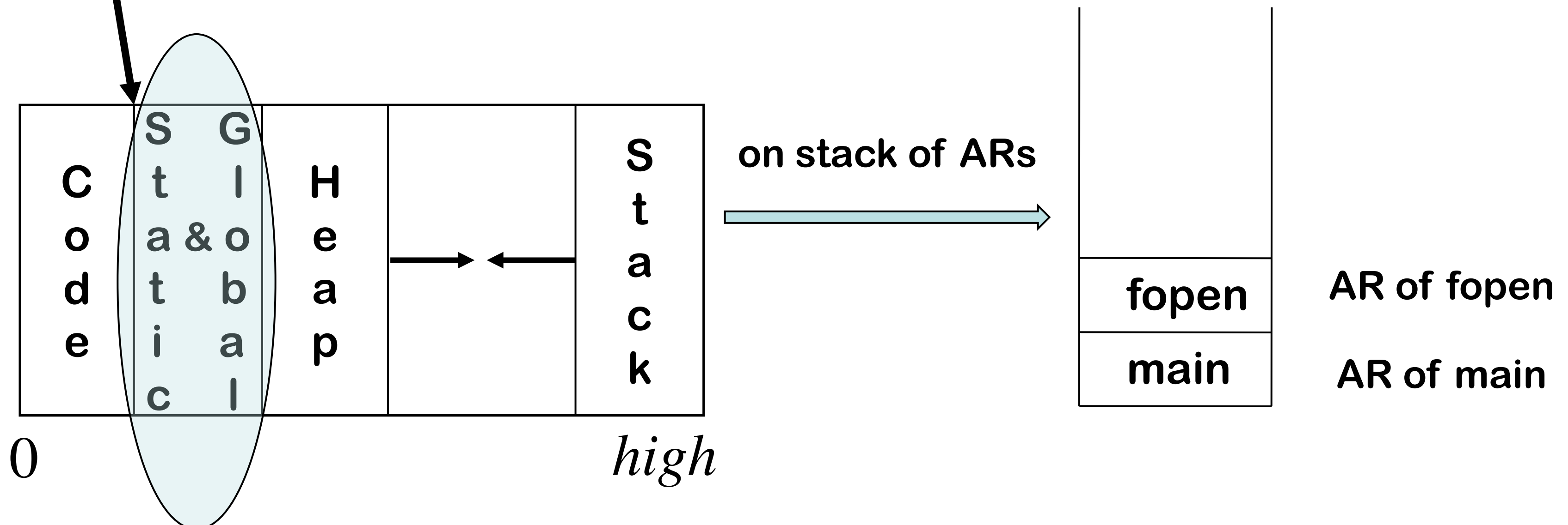


Where Do All These Variables Go?

Static (e.g., in C language)

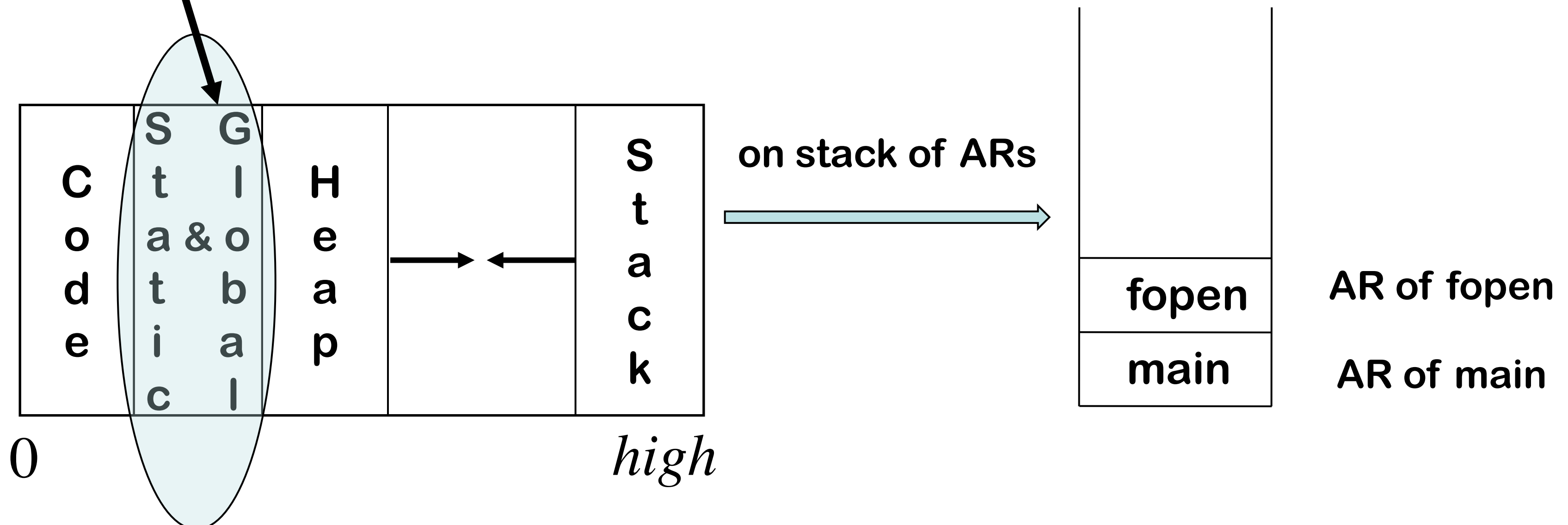
- File scope ⇒ storage area affixed with file name
- Lifetime is entire execution



Where Do All These Variables Go?

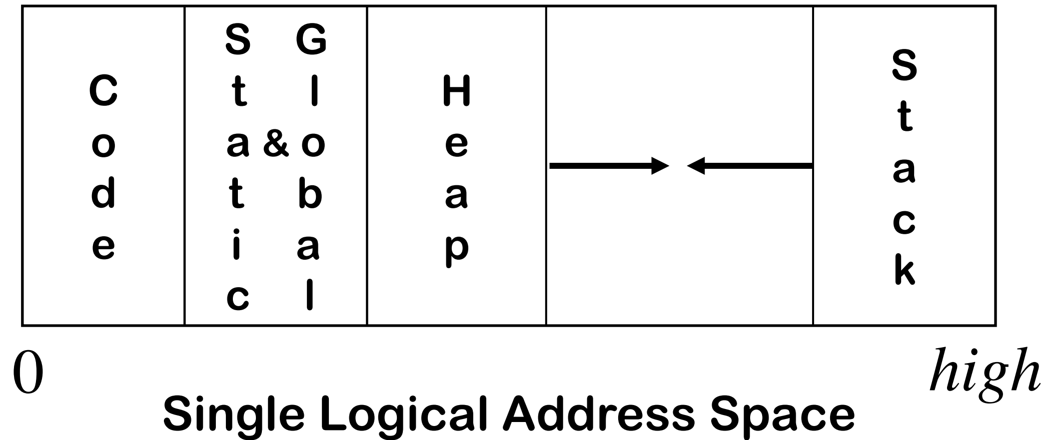
Global

- One or more named global data areas
- One per variable, or per file, or per program, …
- Lifetime is entire execution



Placing Run-time Data Structures

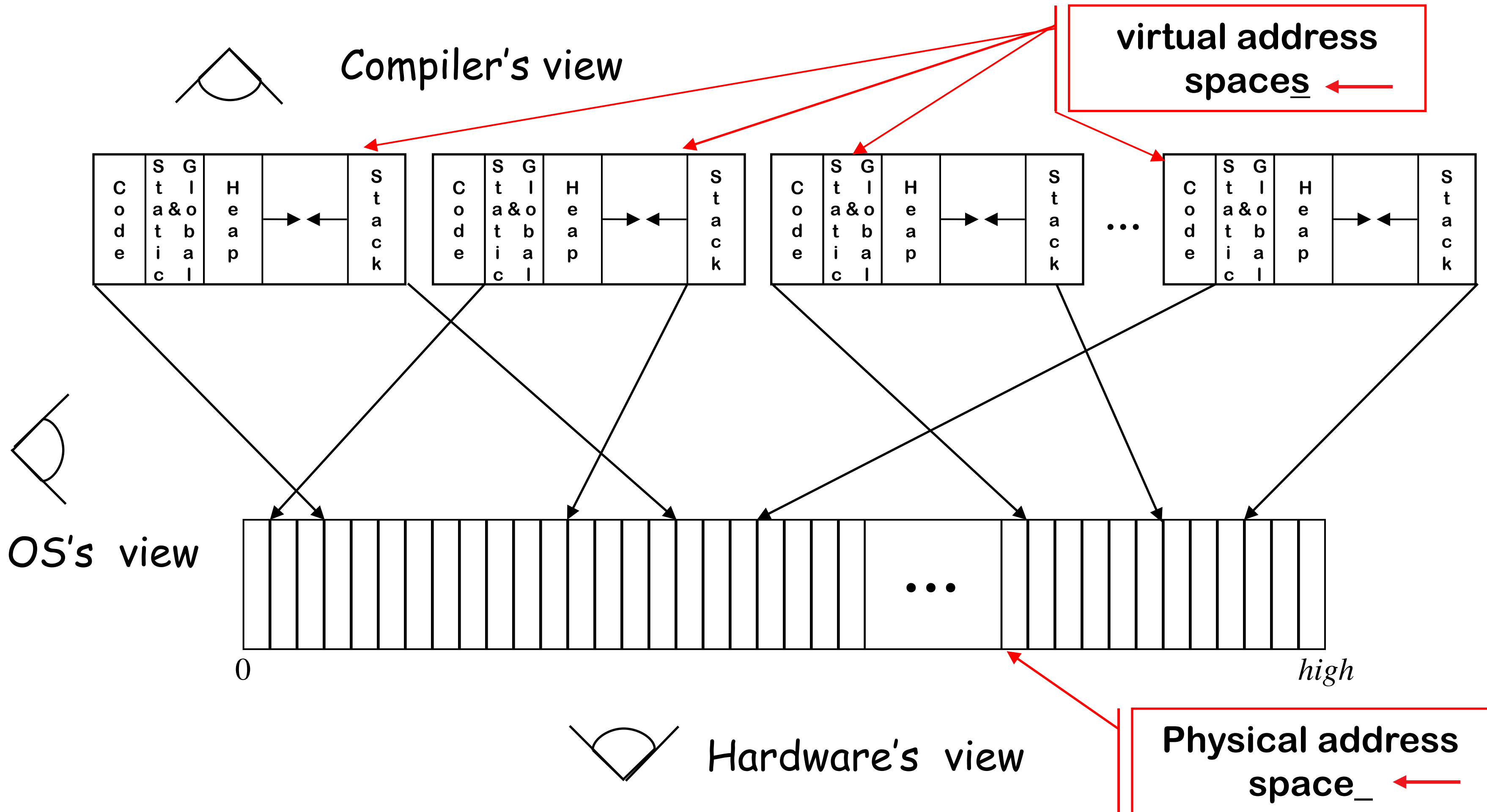
Classic Organization



- Code, static, & global data have known size
- Heap & stack both grow & shrink over time
- This is a virtual address space

How Does This Really Work?

The Big Picture

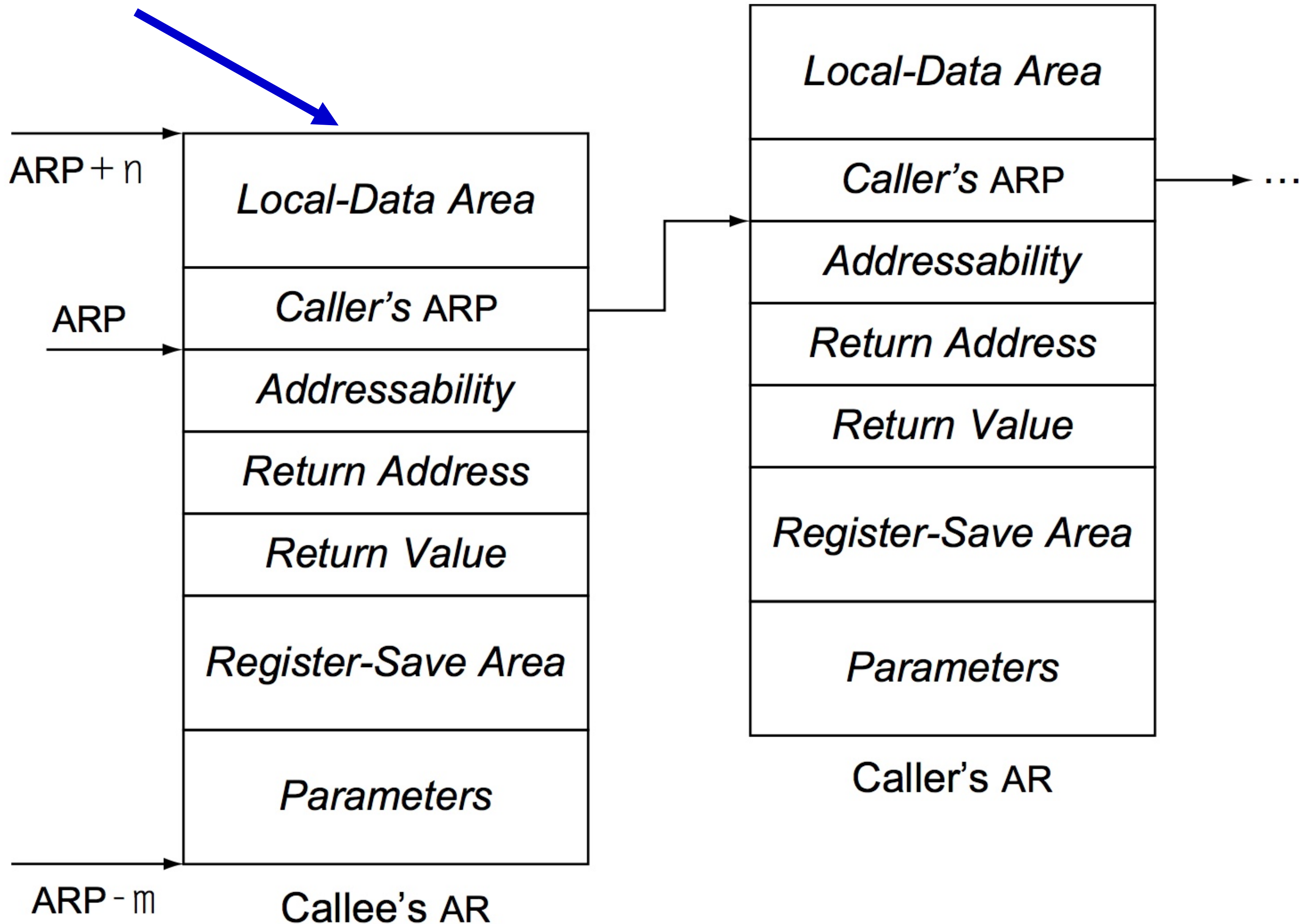


Where Do Local Variables Live?

A Simplistic model

- Allocate a data area for each distinct scope
- Need a data area per invocation (or activation) of a scope
- We call this the scope's activation record
- The compiler can store control info there!

Activation Records

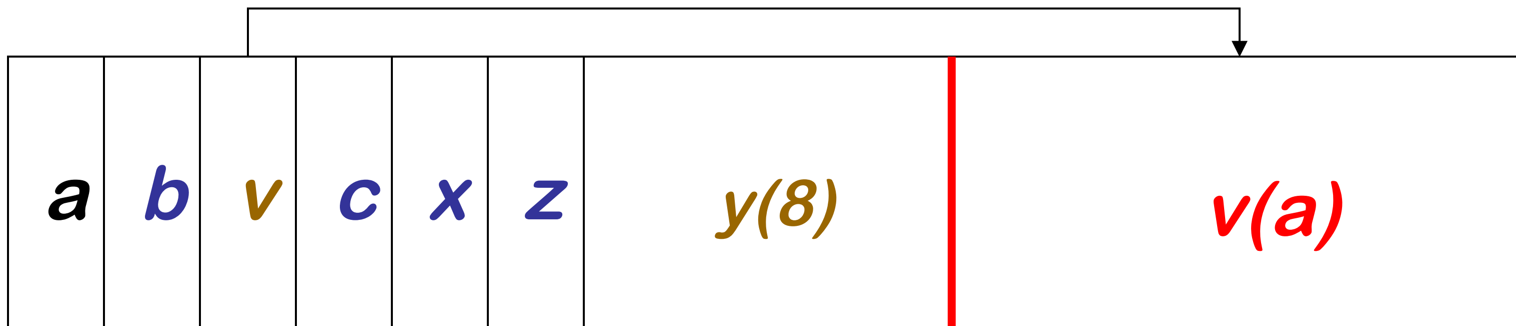


Local-Data Area

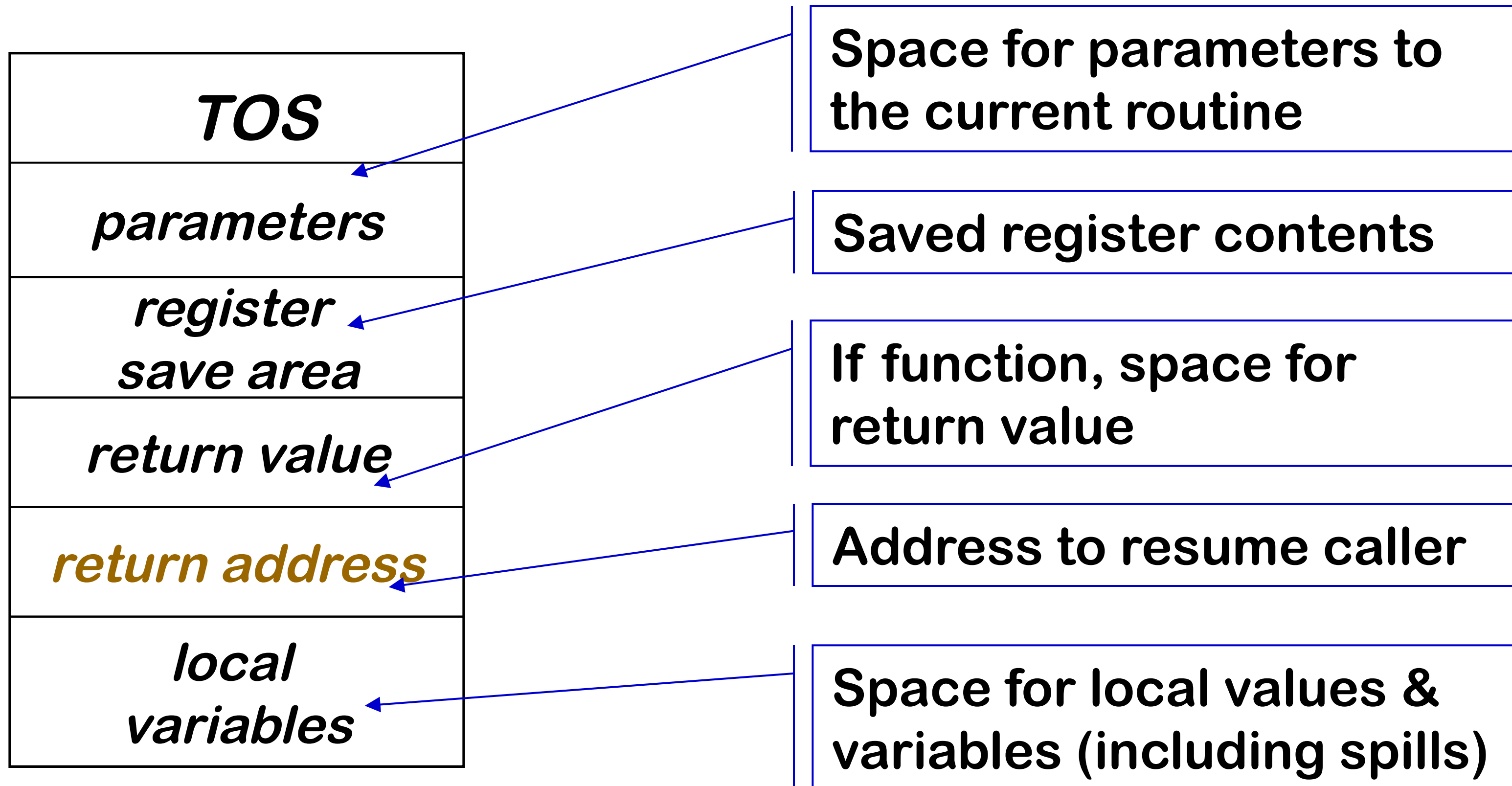
```
B0: {
      int a, b
      int v(a), c, x
      int z, y(8)
          ....

    }
```

Arrays

- If size is fixed at compile time, store in fixed-length data area
- If size is variable, store descriptor in fixed length area, with pointer to variable length area
- Variable-length data area is assigned at the end of the fixed length area for block in which it is allocated



Activation Record Basics



One AR for each invocation of a procedure

Communicating Between Procedures

Most languages provide a parameter passing mechanism

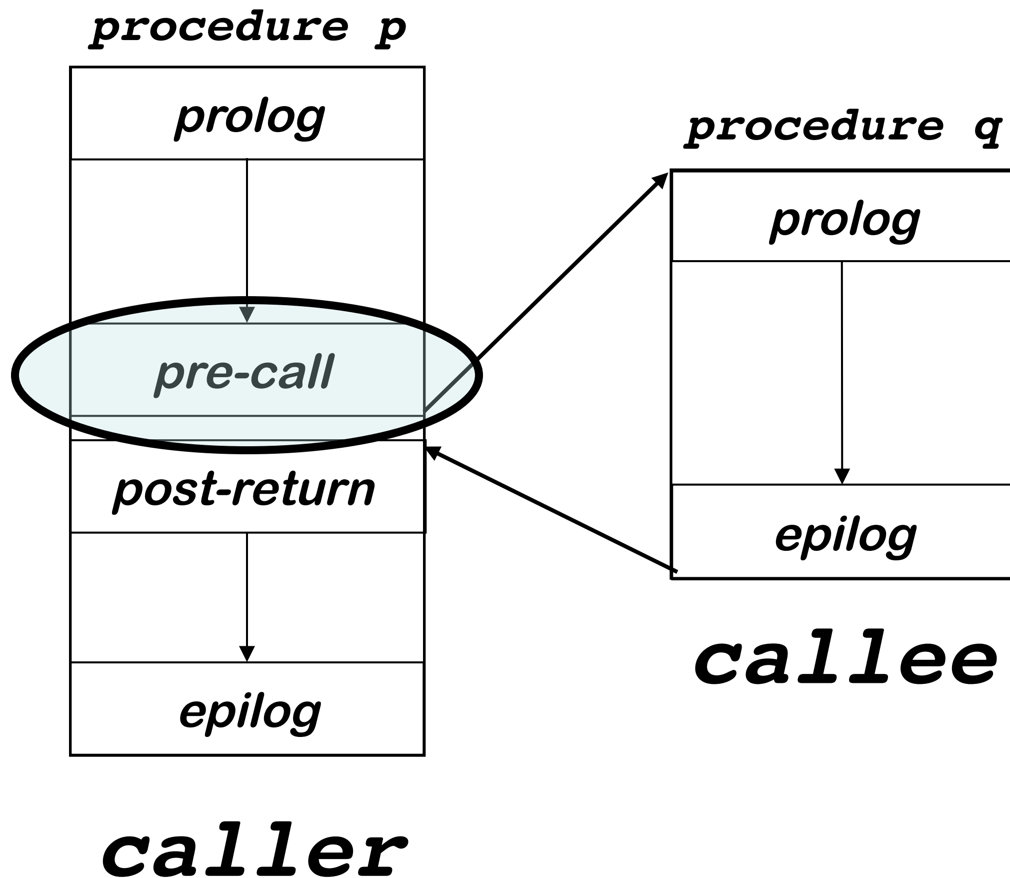
⇒ Expression used at "call site" becomes variable in callee

Two common binding mechanisms

- Call-by-reference passes a pointer to actual parameter
  - → Requires slot in the AR (for address of parameter)
- Call-by-value passes a copy of its value at time of call
  - → Requires slot in the AR (for value)
  - → Each name gets a unique location *(may have same value)*
  - → Arrays are mostly passed by reference, not value

Procedure Linkages

Standard procedure linkage



Procedure has

- standard prolog
- standard epilog

Each call involves a

- pre-call sequence
- post-return sequence

These are completely predictable from the call site ⇒ depend on the number & type of the actual parameters

Pre-call Sequence

- Sets up callee's basic AR
- Helps preserve its own environment

The Details

- Allocate space for the callee's AR
- Evaluates each parameter & stores value or address
- Saves return address, caller's ARP into callee's AR
- Save any caller-save registers
  - → Save into space in caller's AR
- Jump to address of callee's prolog code

Procedure Linkages

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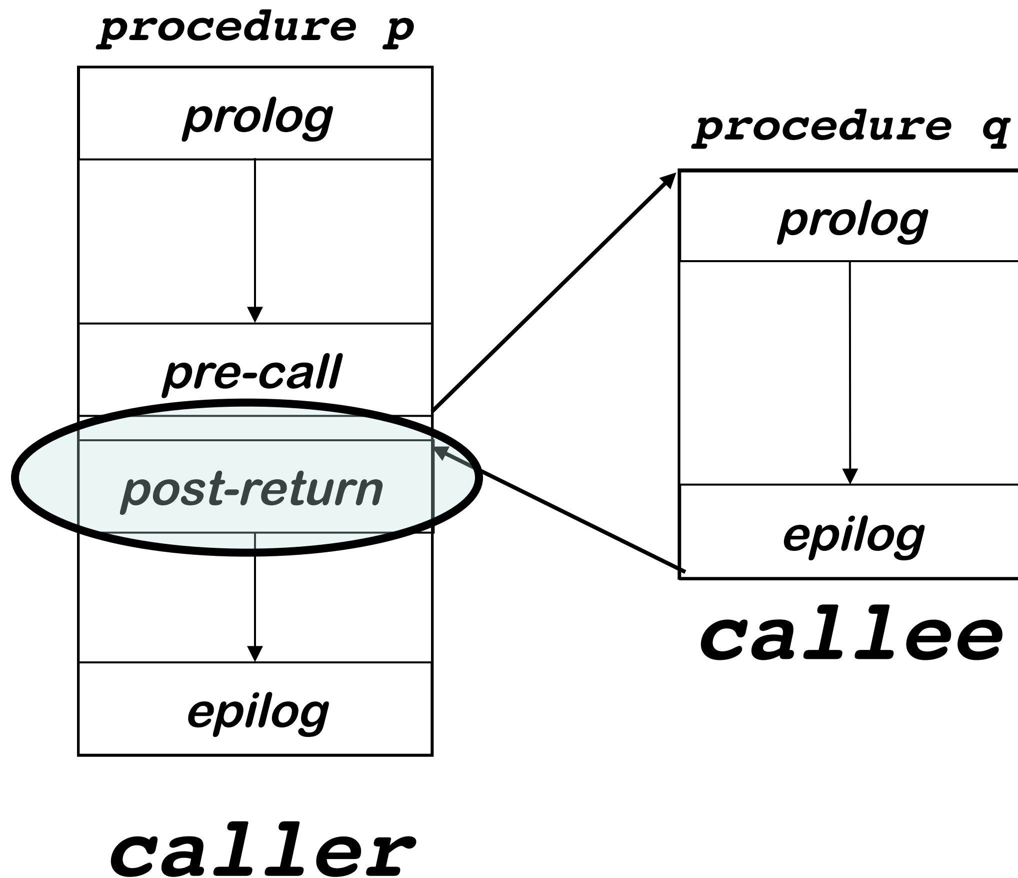

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Post-return Sequence

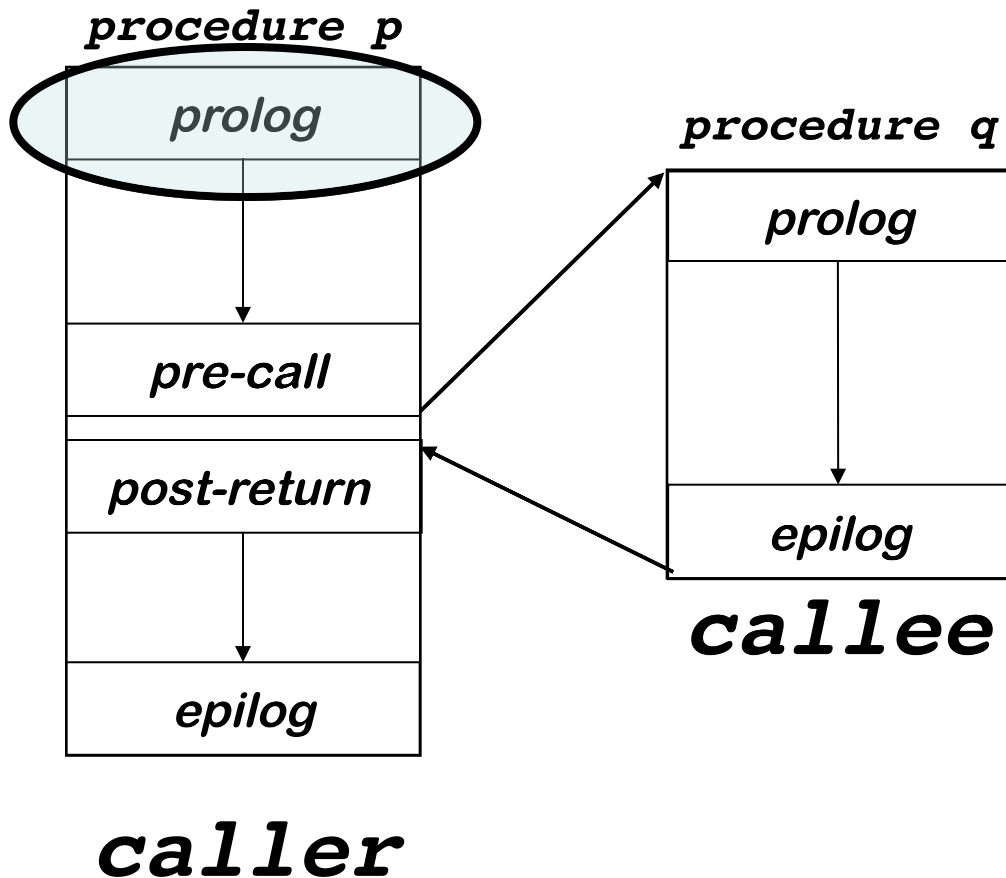
- Restores caller's environment

The Details

- Copy return value from callee's AR, if necessary
- Free the callee's AR
- Restore any caller-save registers
- Restore any call-by-reference parameters to registers, if needed
  - → Also copy back call-by-value/result parameters
- Continue execution after the call

Procedure Linkages

Standard procedure linkage



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Prolog Code

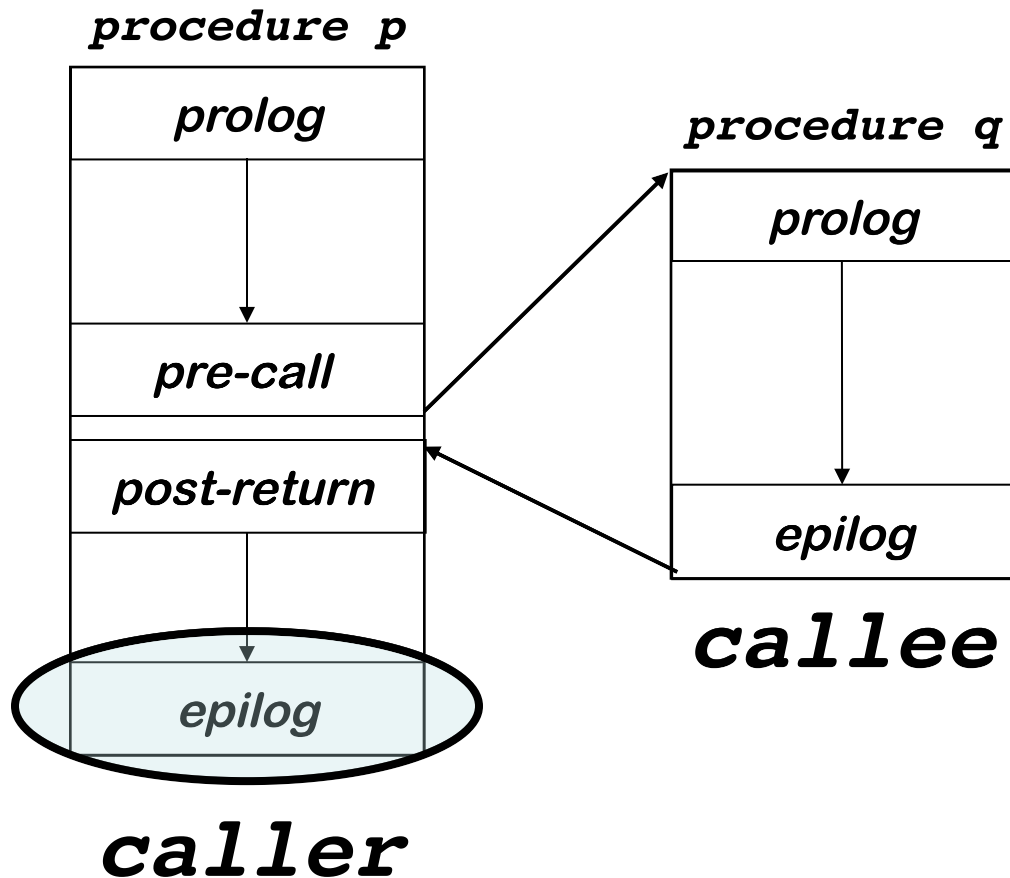
- Finish setting up the callee's environment
- Preserve parts of the caller's environment that will be disturbed

The Details

- Preserve any callee-save registers
- Allocate space for local data
  - → Easiest scenario is to extend the AR
- Find any static data areas referenced in the callee
- Handle any local variable initializations

Procedure Linkages

Standard procedure linkage



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Epilog Code

- Wind up the business of the callee
- Start restoring the caller's environment

The Details

- Store return value? No, this happens on the return statement
- Restore callee-save registers
- Free space for local data, if necessary
- Load return address from AR
- Restore caller's ARP
- Jump to the return address