Run-Time Environments

Chapter 7

Procedure Activation and Lifetime

- A procedure is *activated* when called
- The *lifetime* of an activation of a procedure is the sequence of steps between the first and last steps in the execution of the procedure body
- A procedure is *recursive* if a new activation can begin before an earlier activation of the same procedure has ended

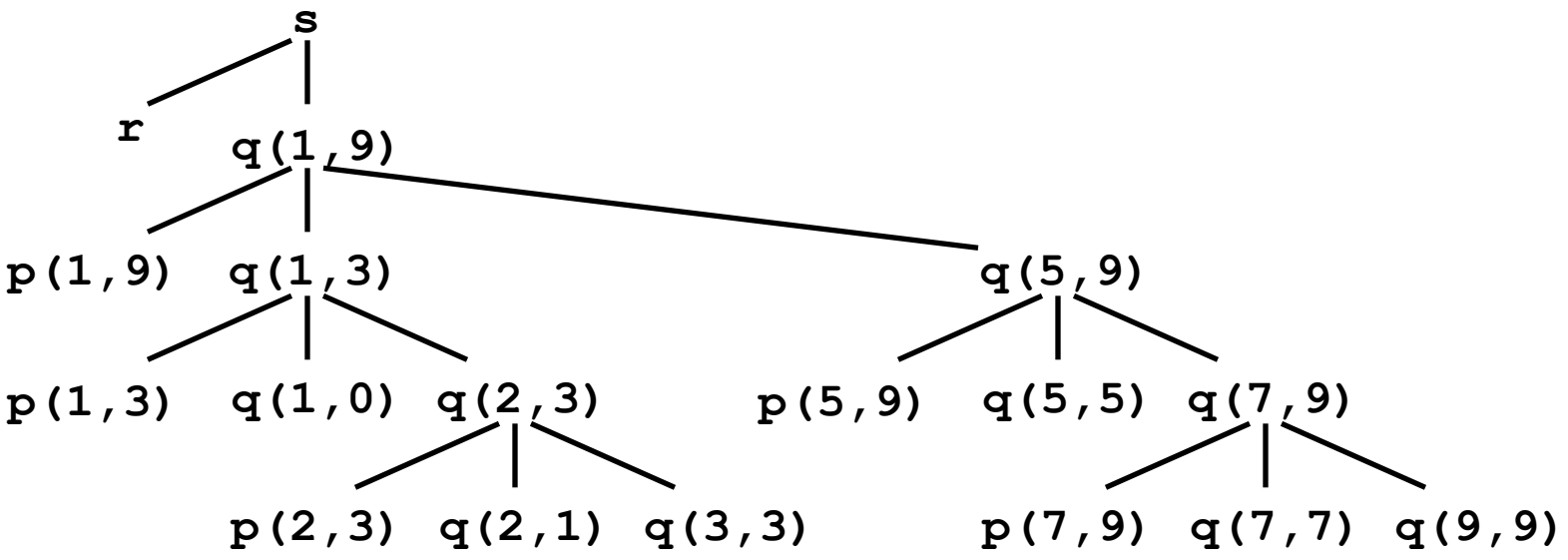
Procedure Activations: Example

```
program sort(input, output)
   var a : array [0..10] of integer;
   procedure readarray;
      var i : integer;
      begin
         for i := 1 to 9 do read(a[i])
      end;
   function partition(y, z : integer) : integer
      var i, j, x, v : integer;
      begin …
      end
   procedure quicksort(m, n : integer);
      var i : integer;
      begin
         if (n > m) then begin
            i := partition(m, n);
            quicksort(m, i - 1);
            quicksort(i + 1, n)
         end
      end;
   begin
      a[0] := -9999; a[10] := 9999;
      readarray;
      quicksort(1, 9)
   end.
```

Activations:

```
begin sort
 enter readarray
 leave readarray
 enter quicksort(1,9)
  enter partition(1,9)
  leave partition(1,9)
  enter quicksort(1,3)
   …
  leave quicksort(1,3)
  enter quicksort(5,9)
  …
  leave quicksort(5,9)
 leave quicksort(1,9)
end sort.
```

Activation Trees: Example

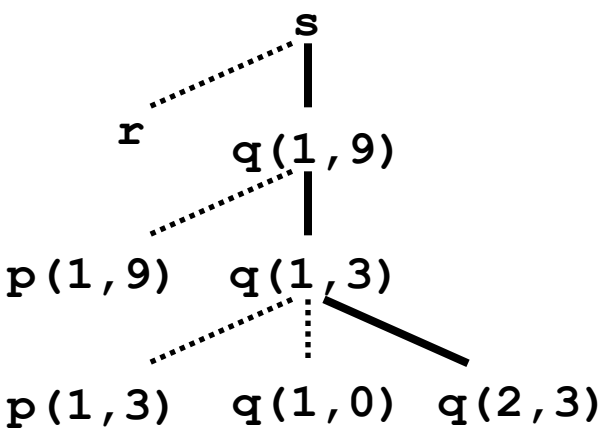


Activation tree for the sort program

Note: also referred to as the dynamic call graph

Control Stack

Activation tree:



Control stack:

s
q(1,9)
q(1,3)
q(2,3)

Activations:

```
begin sort
 enter readarray
 leave readarray
 enter quicksort(1,9)
  enter partition(1,9)
  leave partition(1,9)
  enter quicksort(1,3)
   enter partition(1,3)
   leave partition(1,3)
   enter quicksort(1,0)
   leave quicksort(1,0)
   enter quicksort(2,3)
   …
```

Scope Rules

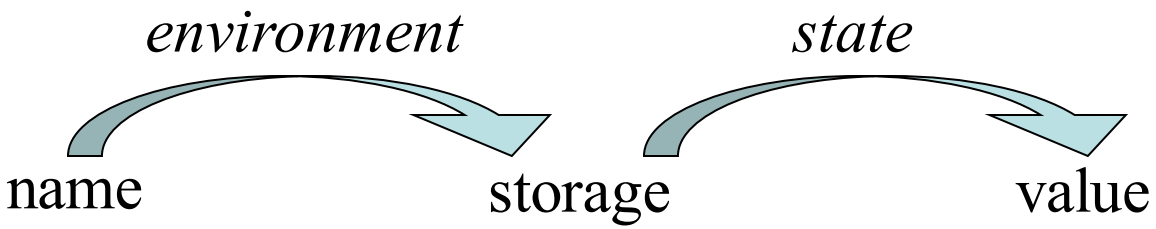
- *Environment* determines name-to-object bindings: which objects are in *scope*?

Variable **x** locally declared in **p**

A function **x**

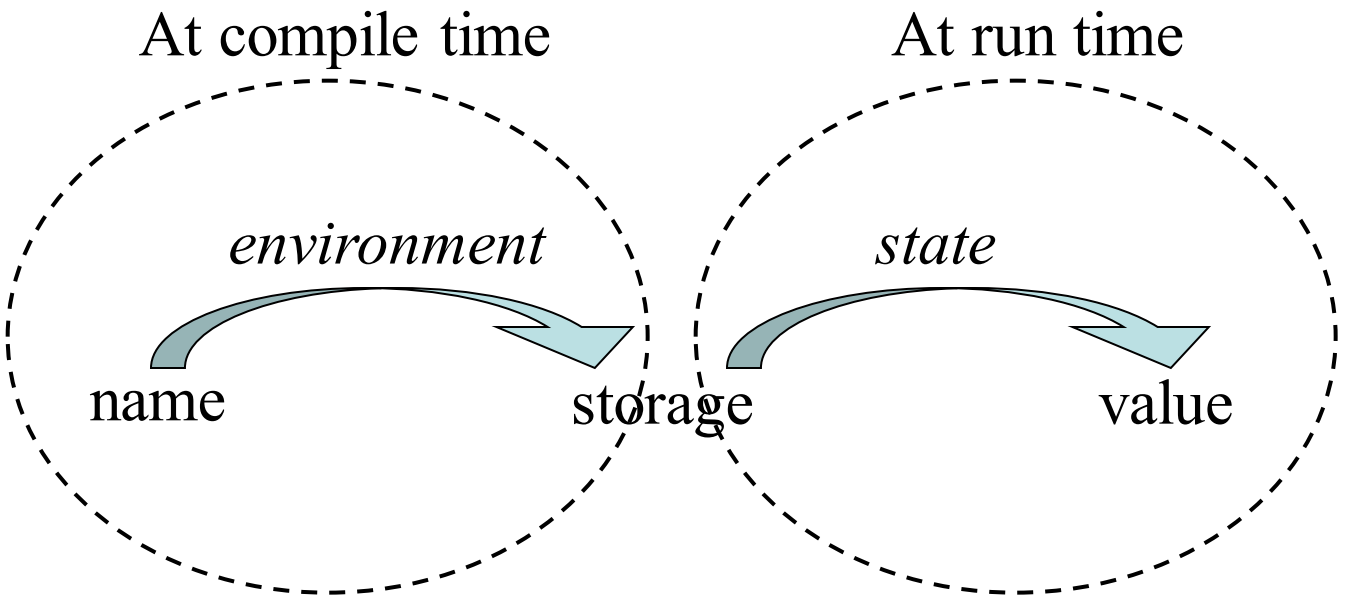
```
program prg;
  var y : real;
function x(a : real) : real;
  begin … end;
procedure p;
  var x : integer;
  begin
    x := 1;
    …
  end;
begin
  y := x(0.0);
  …
end.
```

Mapping Names to Values




```
var i;
…
i := 0;
…
i := i + 1;
```

Mapping Names to Values




```
var i;
…
i := 0;
…
i := i + 1;
```

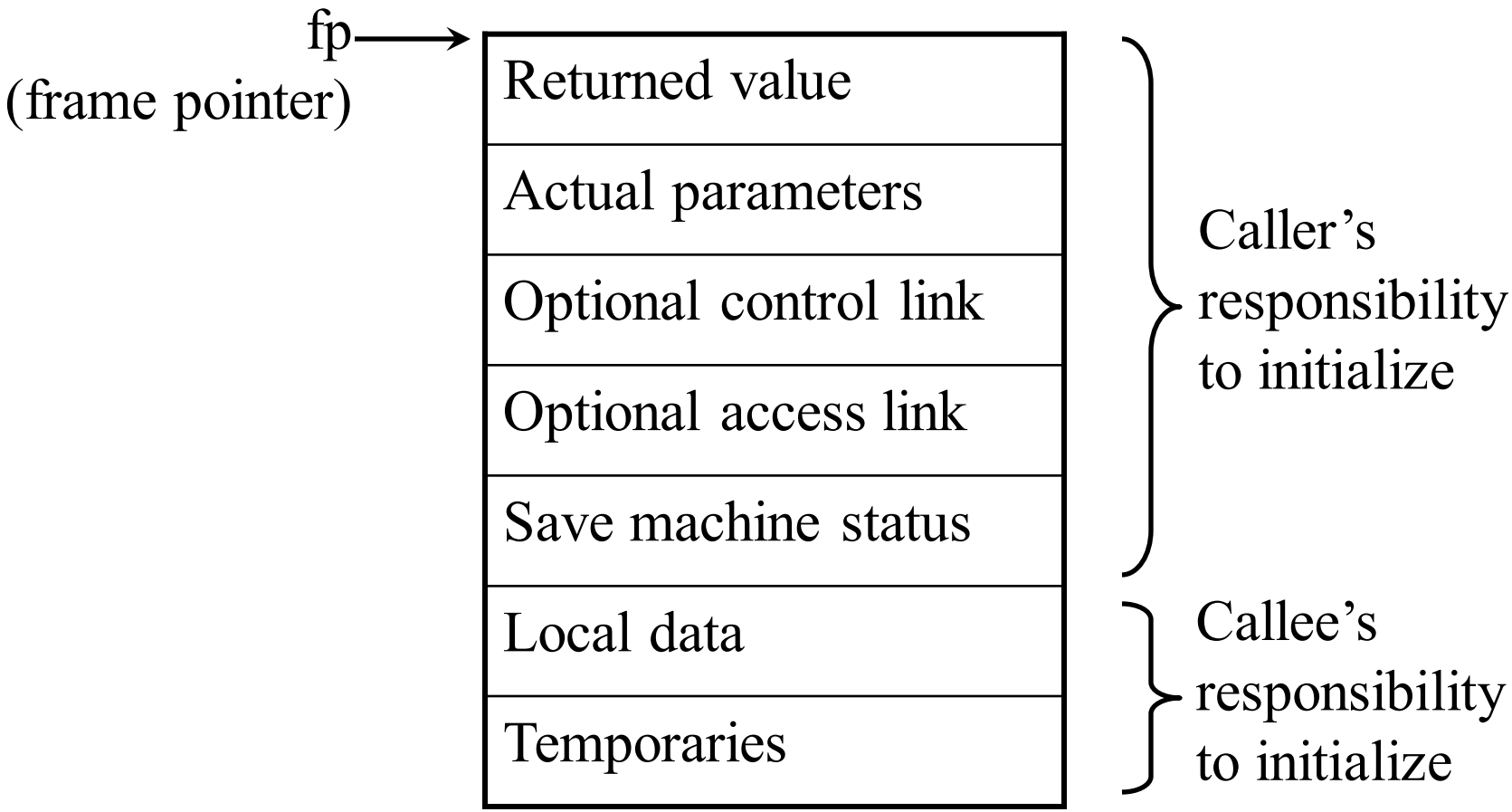
Static and Dynamic Notions of Bindings

Static Notion	*Dynamic Notion*
Definition of a procedure	Activations of the procedure
Declaration of a name	Bindings of the name
Scope of a declaration	Lifetime of a binding

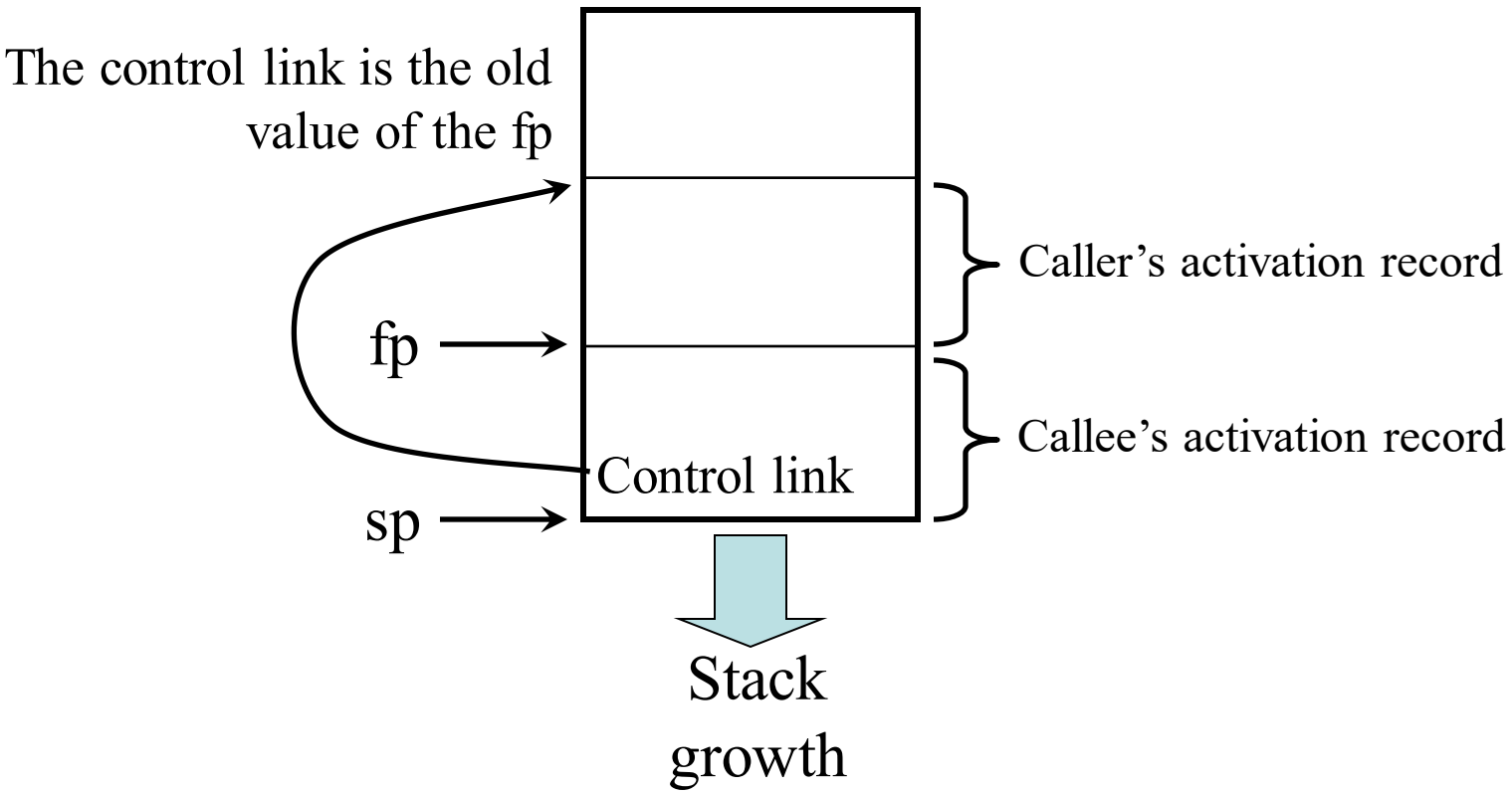
Stack Allocation

- *Activation records* (subroutine frames) on the run-time stack hold the state of a subroutine
- *Calling sequences* are code statements to create activations records on the stack and enter data in them
  - Caller's calling sequence enters actual arguments, control link, access link, and saved machine state
  - Callee's calling sequence initializes local data
  - Callee's return sequence enters return value
  - Caller's return sequence removes activation record

Activation Records (Subroutine Frames)



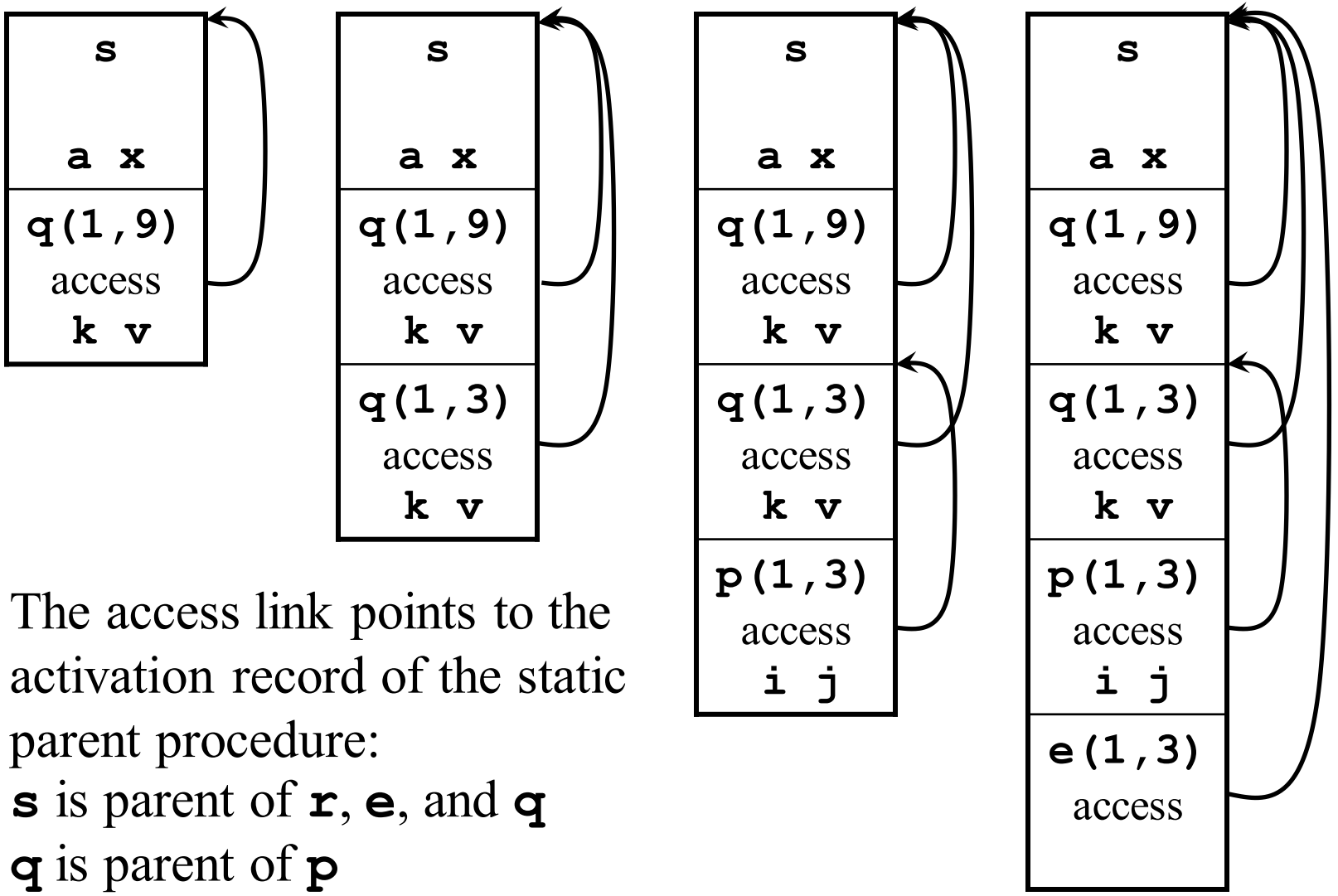
Control Links



Scope with Nested Procedures

```
program sort(input, output)
   var a : array [0..10] of integer;
       x : integer;
   procedure readarray;
      var i : integer;
      begin … end;
   procedure exchange(i, j : integer);
      begin x := a[i]; a[i] := a[j]; a[j] := x end;
   procedure quicksort(m, n : integer);
      var k, v : integer;
      function partition(y, z : integer) : integer
         var i, j : integer;
         begin … exchange(i, j) … end
      begin
         if (n > m) then begin
            i := partition(m, n);
            quicksort(m, i - 1);
            quicksort(i + 1, n)
         end
      end;
   begin
      …
      quicksort(1, 9)
   end.
```

Access Links (Static Links)



The access link points to the activation record of the static parent procedure:

s is parent of **r**, **e**, and **q**

q is parent of **p**

Accessing Nonlocal Data

- To implement access to nonlocal data *a* in procedure *p*, the compiler generates code to traverse n_p - n_a access links to reach the activation record where *a* resides
  - n_p is the nesting depth of procedure p
  - n_a is the nesting depth of the procedure containing *a*

Parameter Passing Modes

- *Call-by-value*: evaluate actual parameters and enter r-values in activation record
- *Call-by-reference*: enter pointer to the storage of the actual parameter
- *Copy-restore* (aka *value-result*): evaluate actual parameters and enter r-values, after the call copy r-values of formal parameters into actuals
- *Call-by-name*: use a form of in-line code expansion (*thunk*) to evaluate parameters