CSE 304 Compiler Design Run-Time Environments

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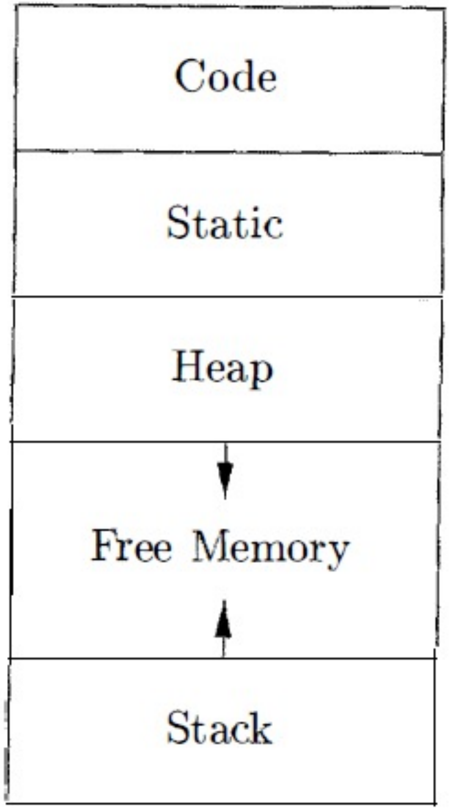
Overview

Learn the relationship between names and data objects

Storage Organization



Typical Run-time memory

Stack Storage

- Variables local to a procedure are usually allocated on a stack.

Heap Storage

- Data that may outlive a procedure are usually allocated on a heap.

Storage Allocation Strategies

Static allocation

- Names are bound to storage as the program is compiled.
  - E.g. Our simple compiler.
- Recursive procedures are restricted
- No dynamic data structure

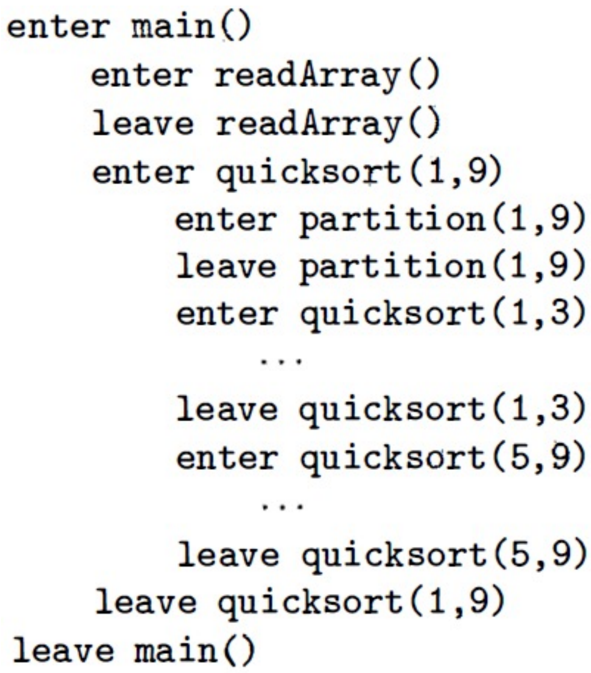
Heap allocation

- When the values of local variables must be retained.

```
main()
{
    int *p;
    p = dangle();
}
```

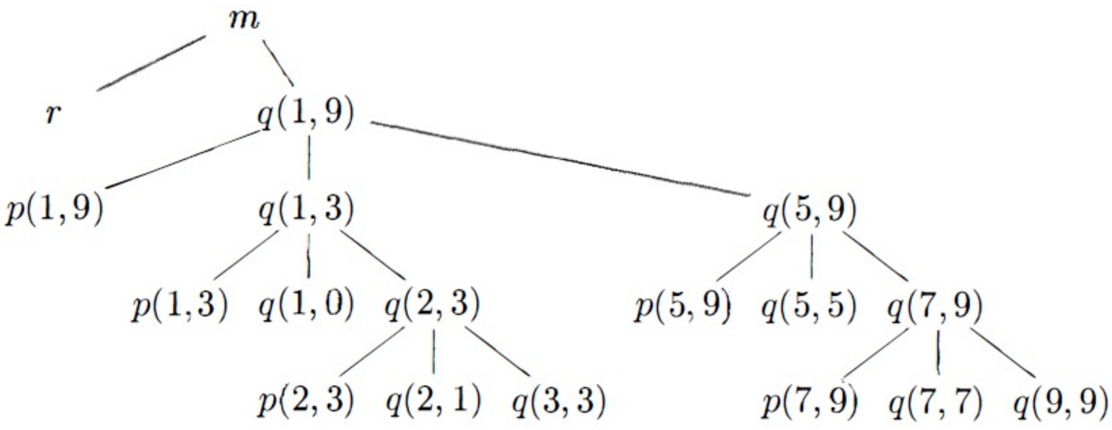
```
int *dangle ()
{
    int i = 23;
    return &i;
}
```

Stack Allocation (Activation Trees)



```
enter main()
    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)
leave main()
```

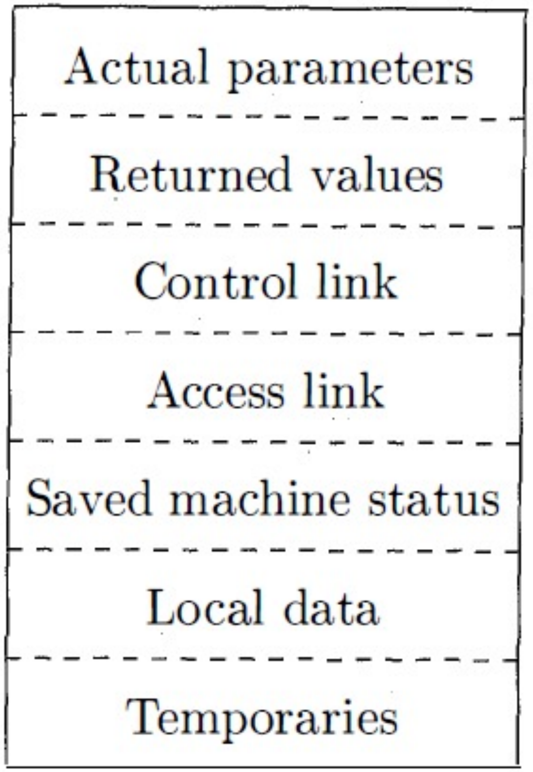
A possible execution of a quicksort



An activation tree for the execution

- Activation: execution of a procedure

Stack Allocation (Activation Records)


Actual parameters

Returned values

Control link

Access link

Saved machine status

Local data

Temporaries

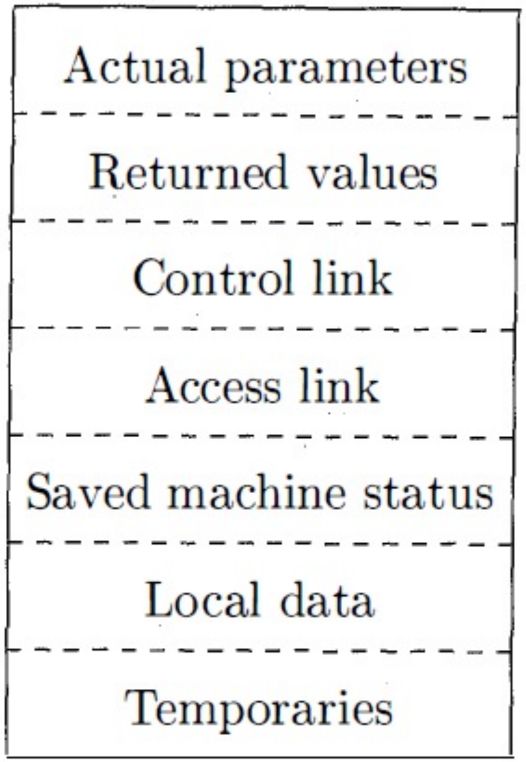
Control stack keeps track of live procedure activations.

Temporaries: temporary results of expressions

Local data: local data belonging to the procedure

Saved machine status: return address, registers used in the procedure

Stack Allocation (Activation Records)



Actual parameters

Returned values

Control link

Access link

Saved machine status

Local data

Temporaries

Access link: nonlocal data held in other activation records (nested procedure)

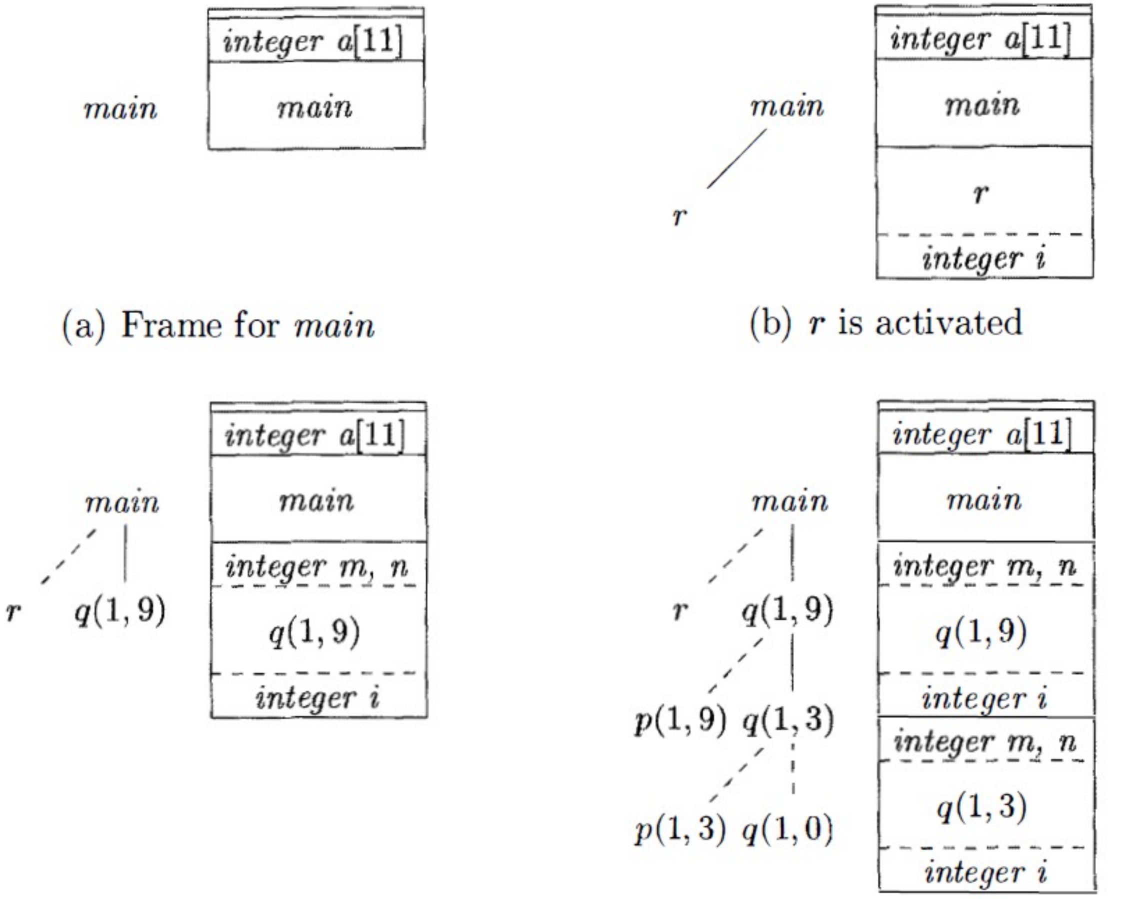
Control link: activation record of the caller

Return value: space for the return value (registers are often used instead for the efficiency).

Actual parameters: space for the actual parameters

Stack Allocation (Activation Records)

```
int a[11];
void readArray() {
    int i;
    ...
}
void quicksort(int m, int n) {
    int i;
    if (n > m) {
        i = partition(m, n);
        quicksort(m, i-1);
        quicksort(i+1, n);
    }
}
main() {
    readArray();
    a[0] = -9999;
    a[10] = 9999;
    quicksort(1,9);
}
```



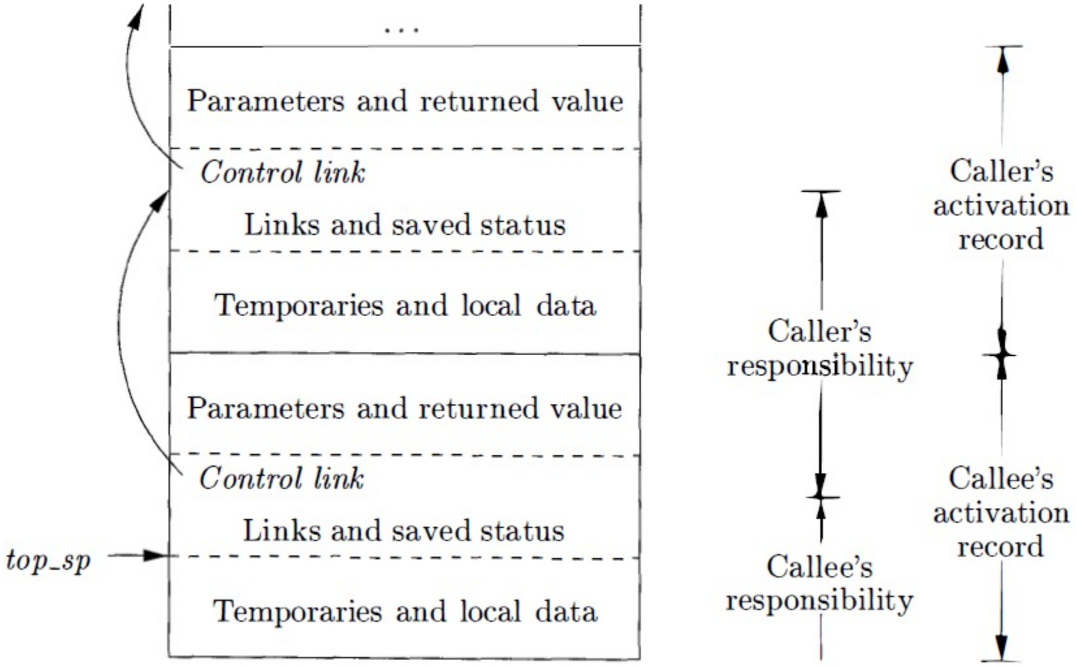
(a) Frame for *main*

(b) *r* is activated

(c) *r* has been popped and $q(1,9)$ pushed

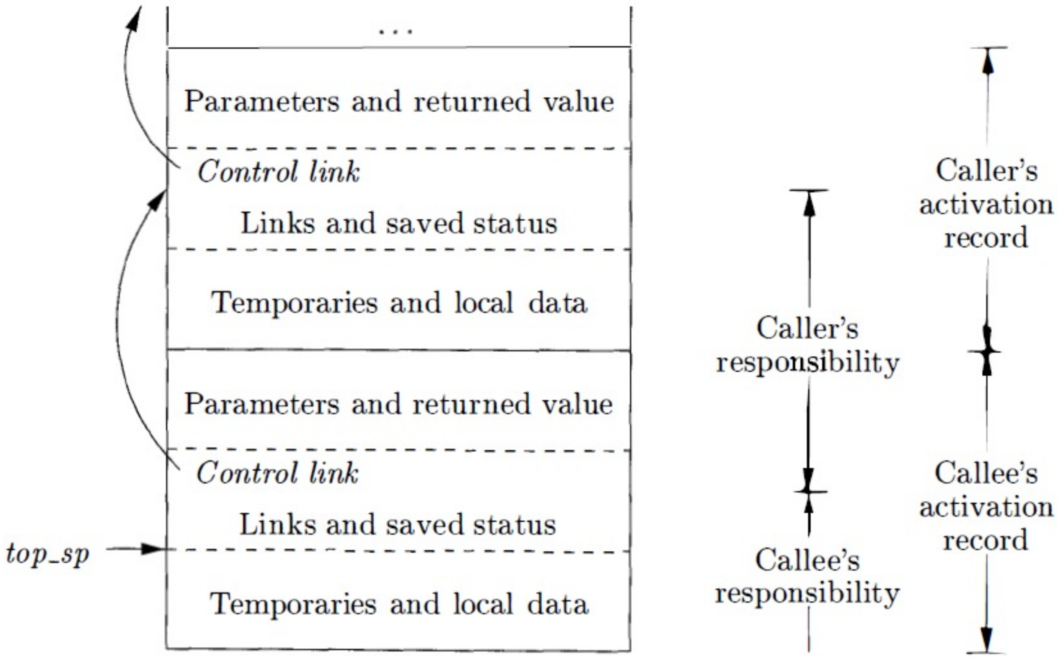
(d) Control returns to $q(1,3)$

Calling Sequence


. . .
Parameters and returned value
Control link
Links and saved status
Temporaries and local data
Parameters and returned value
Control link
Links and saved status
top_sp
Temporaries and local data
Caller's responsibility
Callee's responsibility
Caller's activation record
Callee's activation record

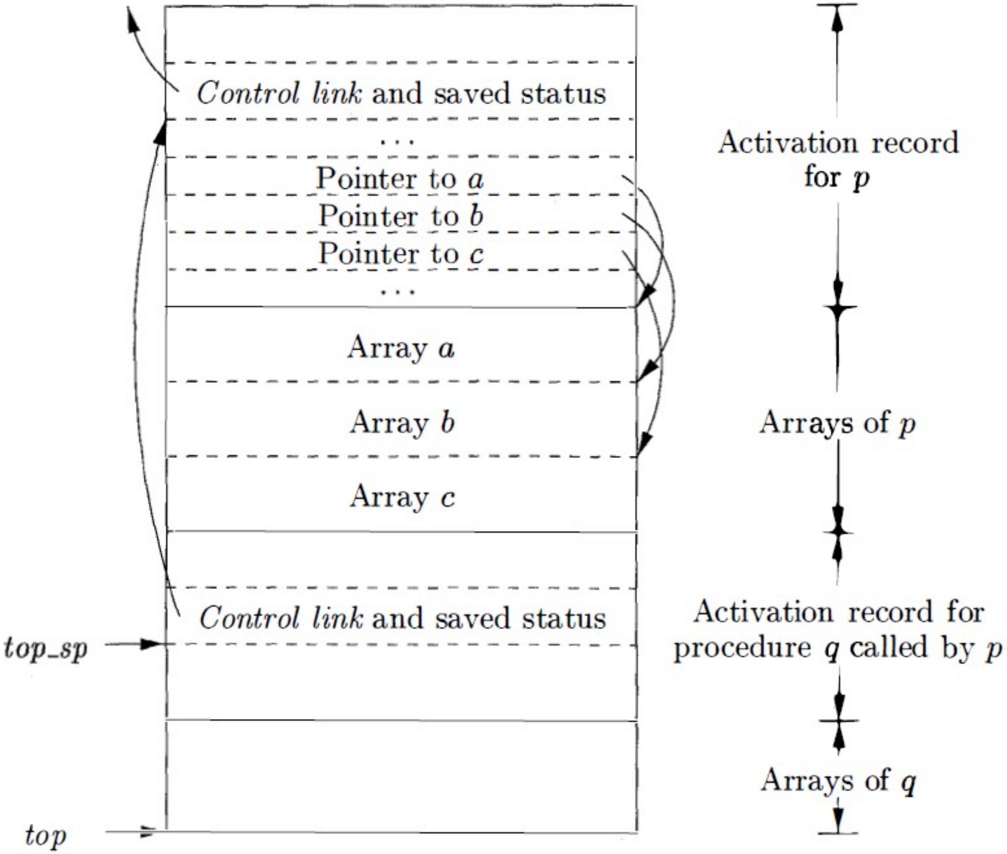
- Caller: eval actuals, allocate return address, temporaries, and local data, move top_sp
- Callee: save register values, initialize local variables

Return Sequence


...
Parameters and returned value
Control link
Links and saved status
Temporaries and local data
Parameters and returned value
Control link
Links and saved status
Temporaries and local data
top_sp
Caller's activation record
Caller's responsibility
Callee's activation record
Callee's responsibility

- Callee: place a return value, restore top_sp and other registers, jump back to caller's code.
- Caller: copy to returned value to its activation record.

Variable Length Data



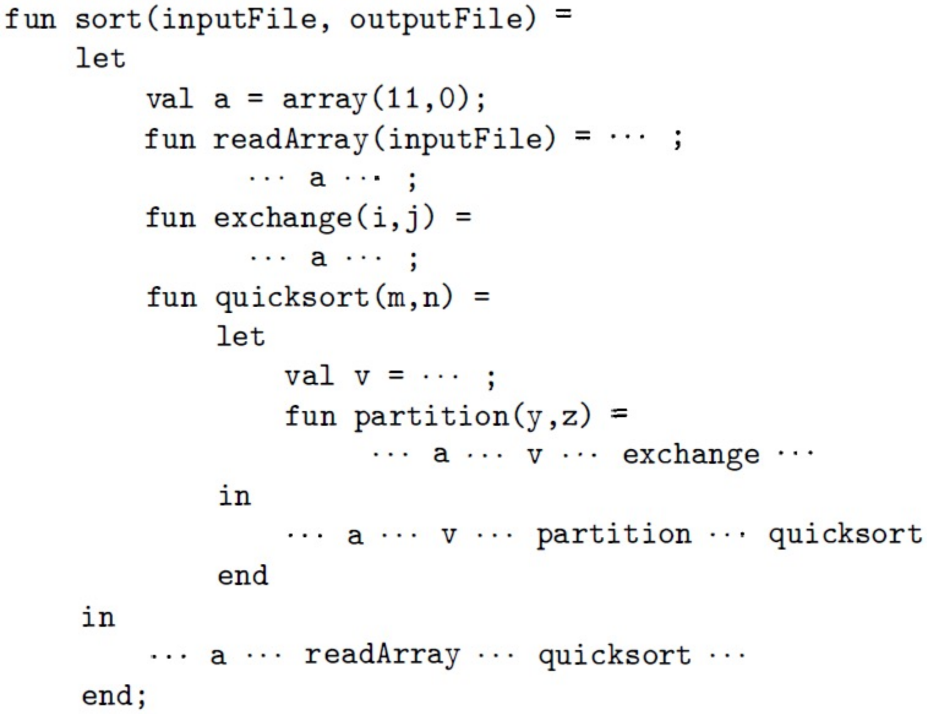
Control link and saved status
...
Pointer to *a*
Pointer to *b*
Pointer to *c*
...
Array *a*
Array *b*
Array *c*
Control link and saved status
top_sp
top
Activation record for *p*
Arrays of *p*
Activation record for procedure *q* called by *p*
Arrays of *q*

When data size is unknown at the compile time

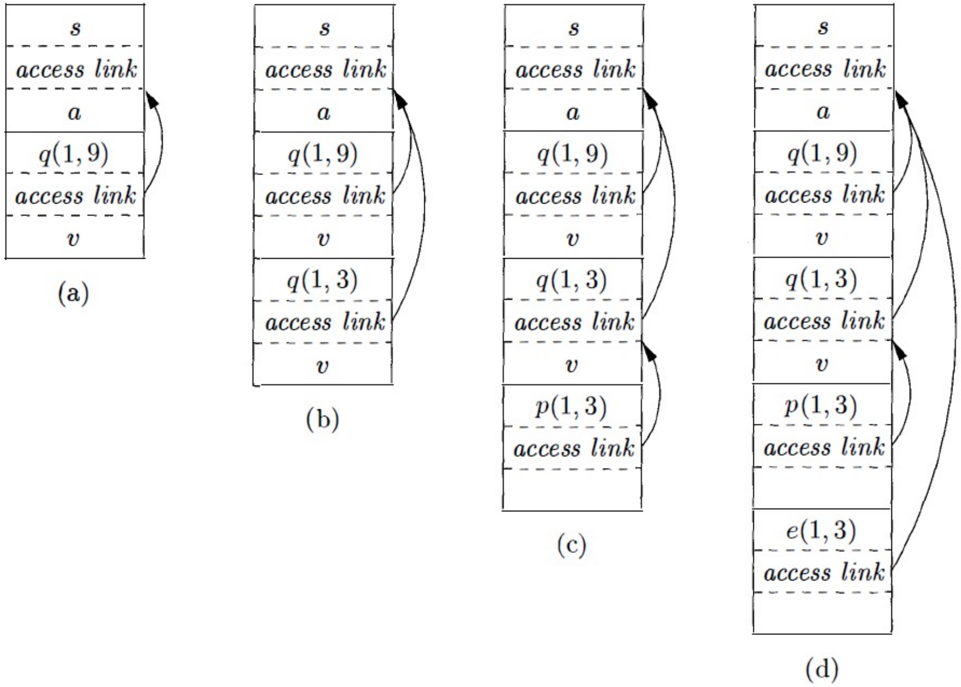
- E.g. Array size is passed by the parameter

Activation record has pointers to actual arrays

Nested Procedures (Quicksort in ML)



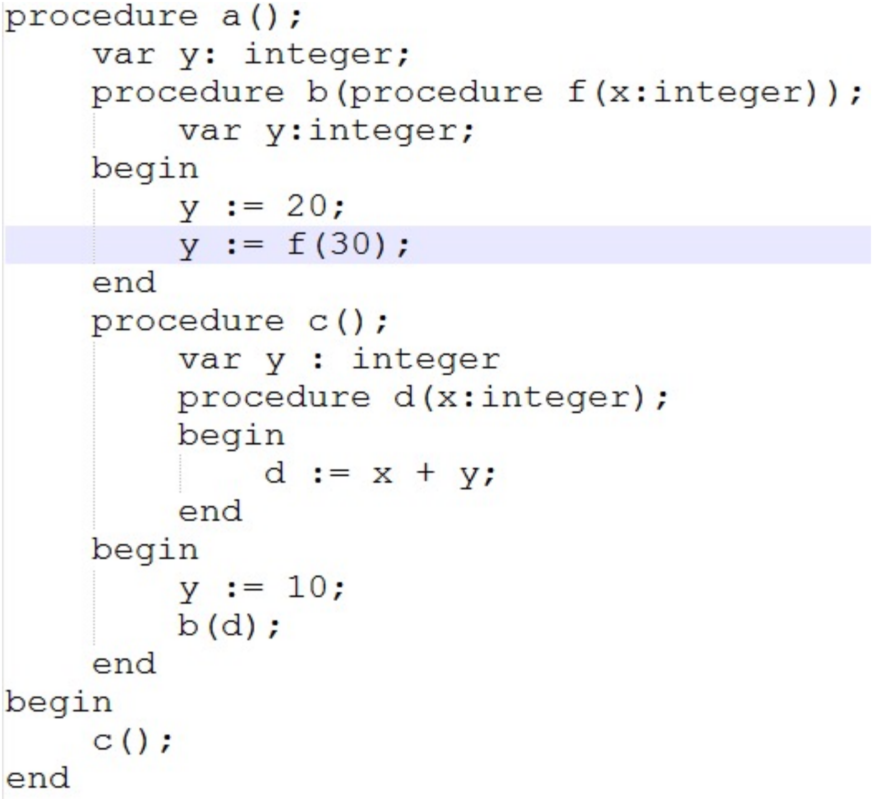
```
fun sort(inputFile, outputFile) =
    let
        val a = array(11,0);
        fun readArray(inputFile) = ··· ;
              ··· a ··· ;
        fun exchange(i,j) =
              ··· a ··· ;
        fun quicksort(m,n) =
            let
                val v = ··· ;
                fun partition(y,z) =
                    ··· a ··· v ··· exchange ···
            in
                ··· a ··· v ··· partition ··· quicksort
            end
    in
        ··· a ··· readArray ··· quicksort ···
    end;
```



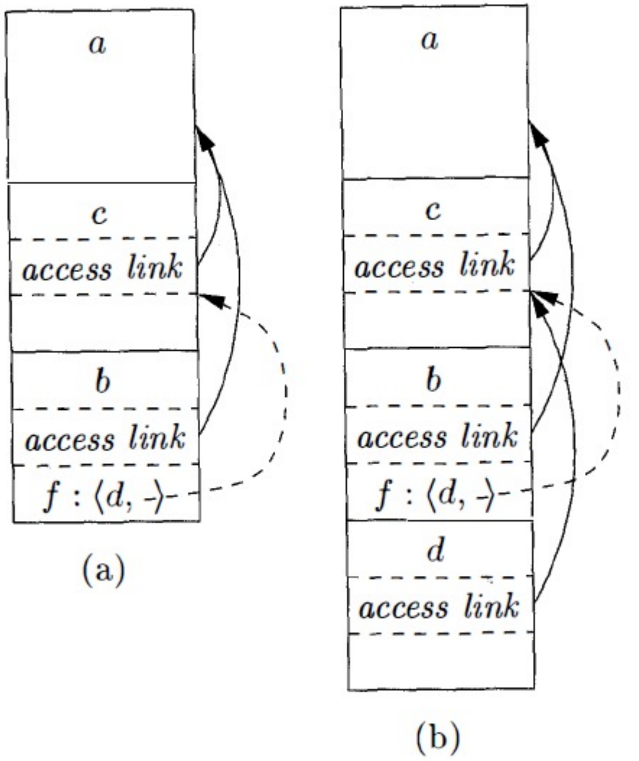
(a) (b) (c) (d)

Access Links

Procedure Parameters

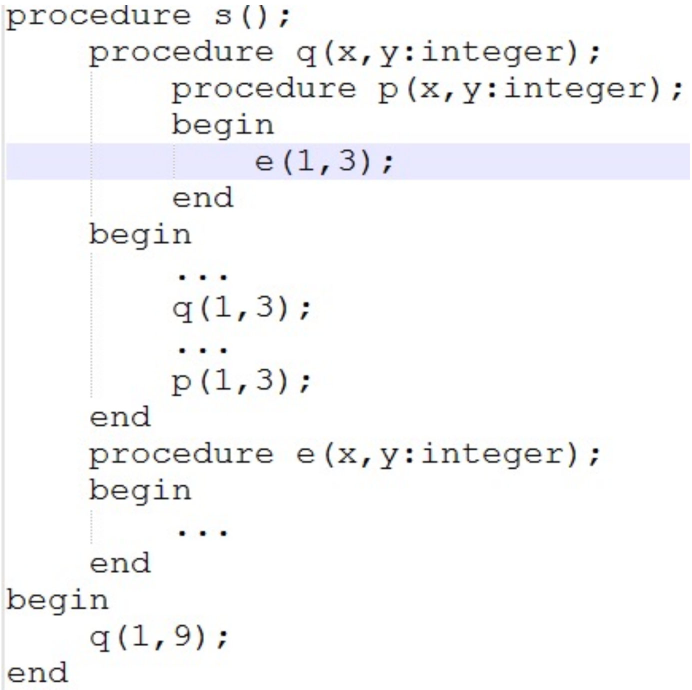


```
procedure a();
    var y: integer;
    procedure b(procedure f(x:integer));
        var y:integer;
    begin
        y := 20;
        y := f(30);
    end
    procedure c();
        var y : integer
        procedure d(x:integer);
        begin
            d := x + y;
        end
    begin
        y := 10;
        b(d);
    end
begin
    c();
end
```

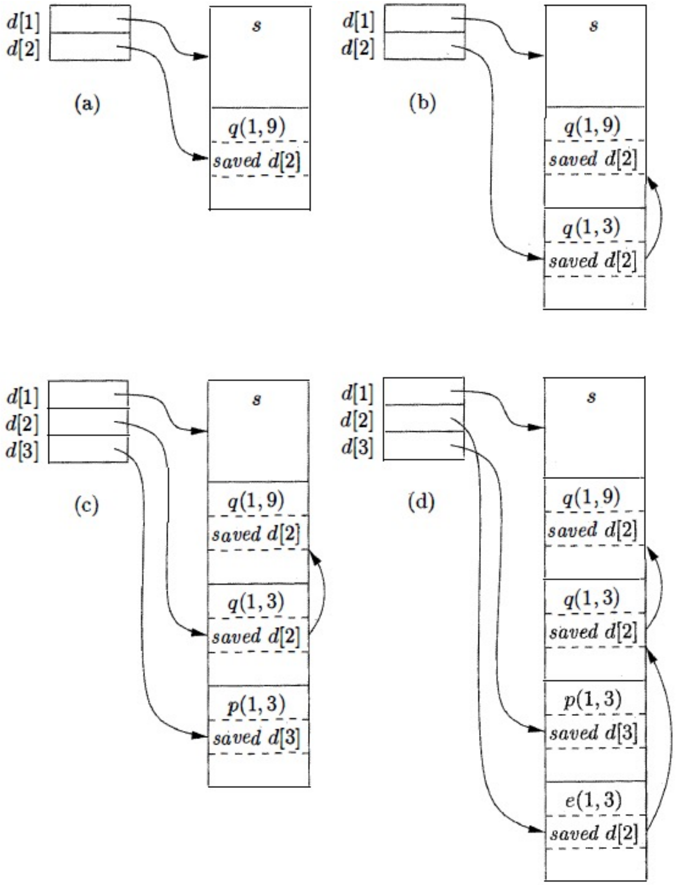


- Caller needs to pass the access link along with the procedure parameter

Displays



```
procedure s();
    procedure q(x,y:integer);
        procedure p(x,y:integer);
        begin
            e(1,3);
        end
    begin
        ...
        q(1,3);
        ...
        p(1,3);
    end
    procedure e(x,y:integer);
    begin
        ...
    end
begin
    q(1,9);
end
```



When a new activation record for a procedure at nesting depth i is set up

1. Save the value of d[i] in the new activation record
2. Set d[i] to point to the new activation record

When the activation ends, d[i] is reset to the saved value

Parameter Passing

Call-by-value

- Formal parameters are treated like a local variable
- Caller evaluates the actual parameters and places their r-values in the formal parameters.

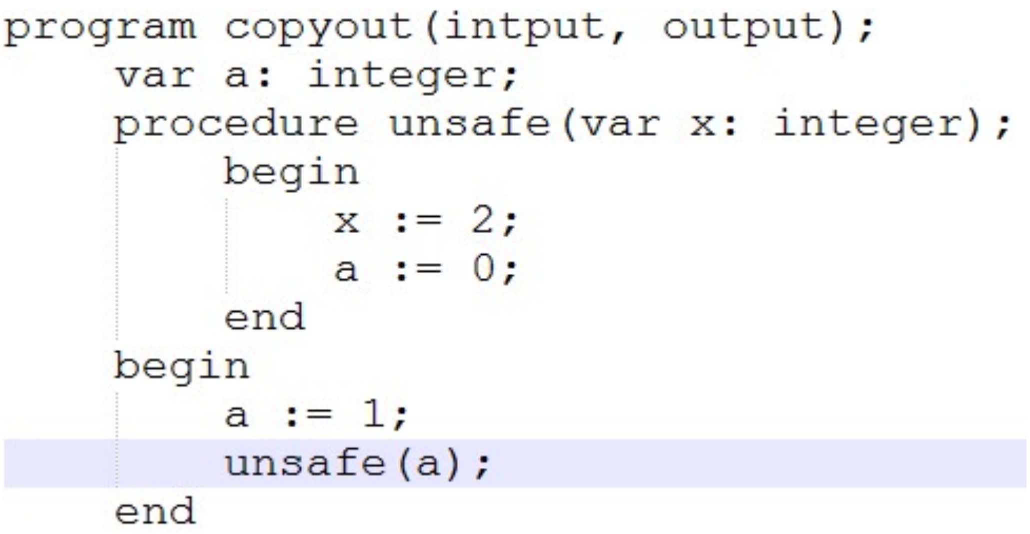
Call-by Reference

- If an actual parameter is a name or an expression having an l-value, the l-value is passed
- If an actual parameter does not have l-value (like 1+2), then the parameter is evaluated in a new location and the address of the location is passed.

Parameter Passing

Copy-Restore

- During the calling sequence, the r-values of actual parameters are passed like call-by-value.
- During the return sequence, for the actual parameters with l-values, the updated values are copied.

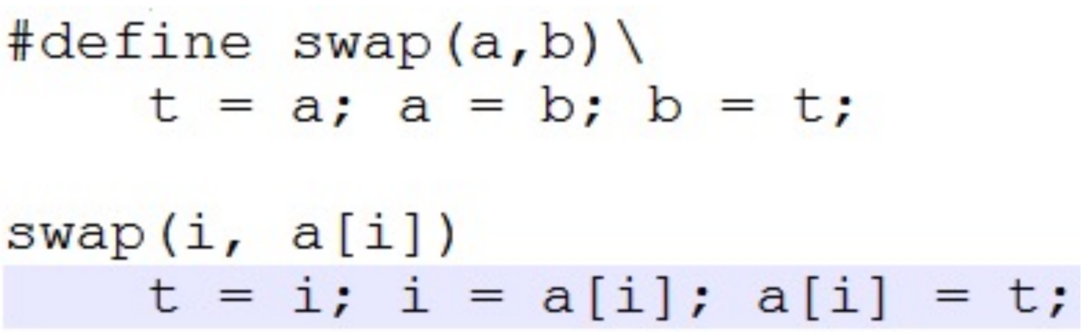


```
program copyout(intput, output);
    var a: integer;
    procedure unsafe(var x: integer);
        begin
            x := 2;
            a := 0;
        end
    begin
        a := 1;
        unsafe(a);
    end
```

Parameter Passing

Call-by-Name

- Procedure is treated as if it were a macro
- Local variables of called procedure are systematically renamed into a distinct new name.
- Actual parameters are surrounded by parenthesis if necessary.



```
#define swap(a,b)\
     t = a; a = b; b = t;

swap(i, a[i])
     t = i; i = a[i]; a[i] = t;
```

Questions?