Today's Topics

Last Time

- Semantics - the meaning of program structures
- Stack model of expression evaluation, the Expression Stack (ES)
- Stack model of automatic storage, the Run Stack (RS)

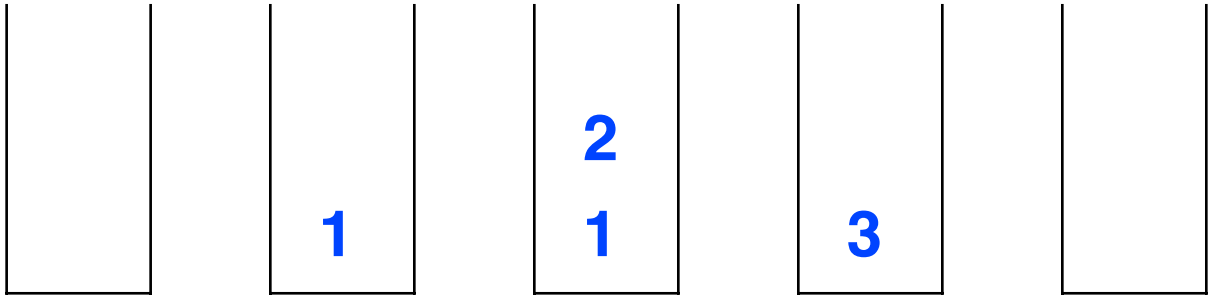
Today

- Managing the Run Stack, the Dynamic Pointer Stack
- Modelling visibility - Run Stack Display
- Lexical Level / Order Number addressing

Expression Stack (ES) Evaluation

```
x := 1 + 2
```

```
push 1
push 2
add
pop x
```




```
x := (5 + 7)*9
```

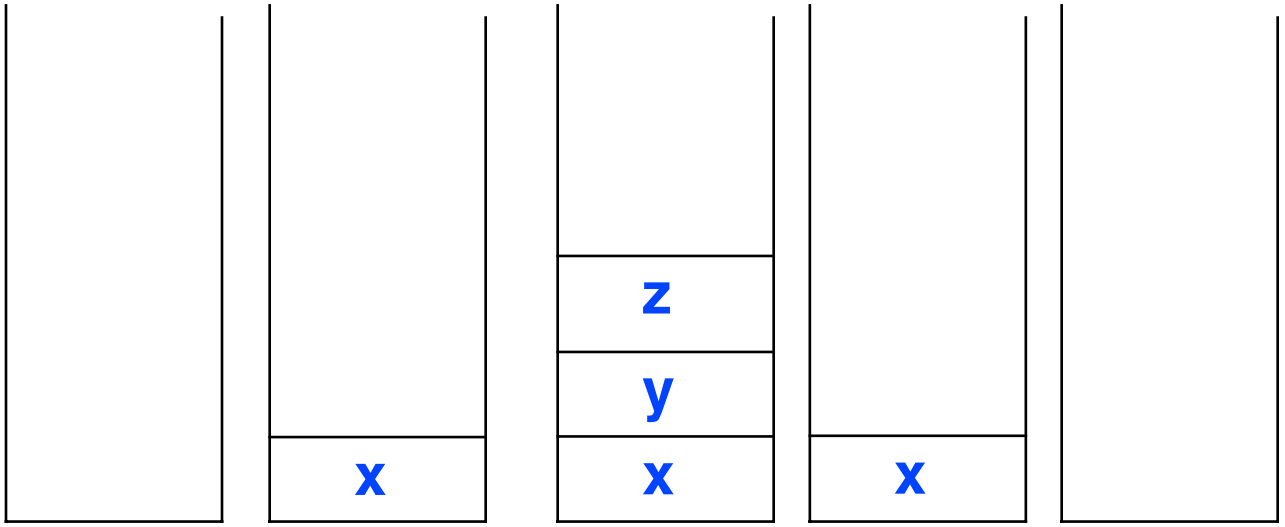
```
push 5
push 7
add
push 9
multiply
pop x
```

The Run Stack – Pascal Example

```
var x: integer;

procedure p;
   var y: integer;
       z: real;
end p;

p;
```

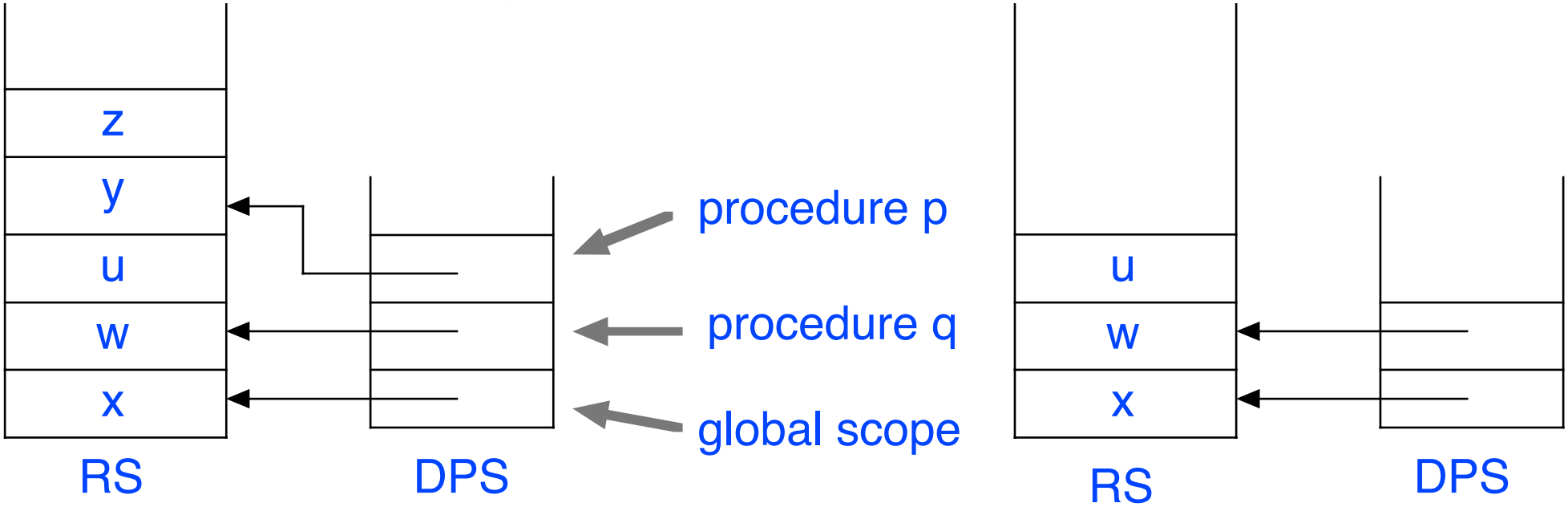


Managing the Run Stack

- We need to know how much to remove from the Run Stack when we exit each scope
- Scopes are nested, so this suggests another stack, the *Dynamic Pointer Stack* (DPS)
- The DPS has one entry for each scope that we enter, popped when we leave a scope
- The entry points to the bottom of the space allocated on the Run Stack for the scope
- When we leave a scope, use the top entry on the DPS to pop the RS before removing the element from the DPS

The Dynamic Pointer Stack - Example

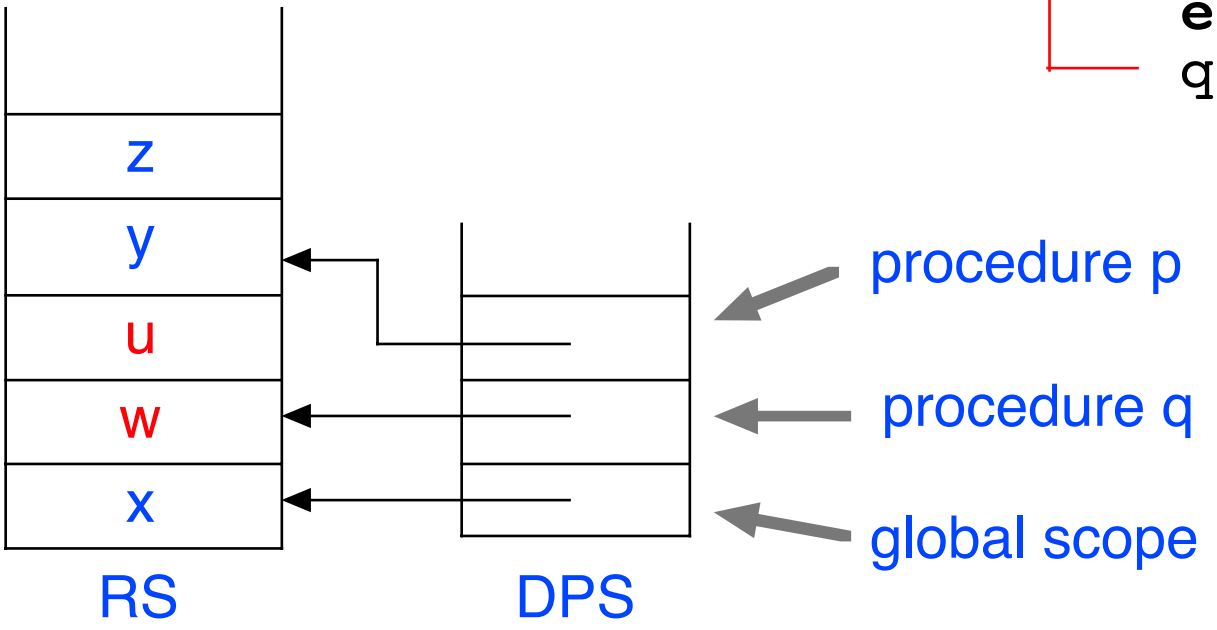
```
var x: integer;
procedure p;
   var y : integer;
       z : integer;
end p;
procedure q;
   var w : integer;
       u : integer;
   p;
end q;
q;
```



Variable Visibility

- The compiler must implement variable visibility - some variables are still "live" (in memory), but are not currently accessible
- At the execution point shown in our example, procedure *p* must not be able to access *w* and *u*, but must be able to access *x*

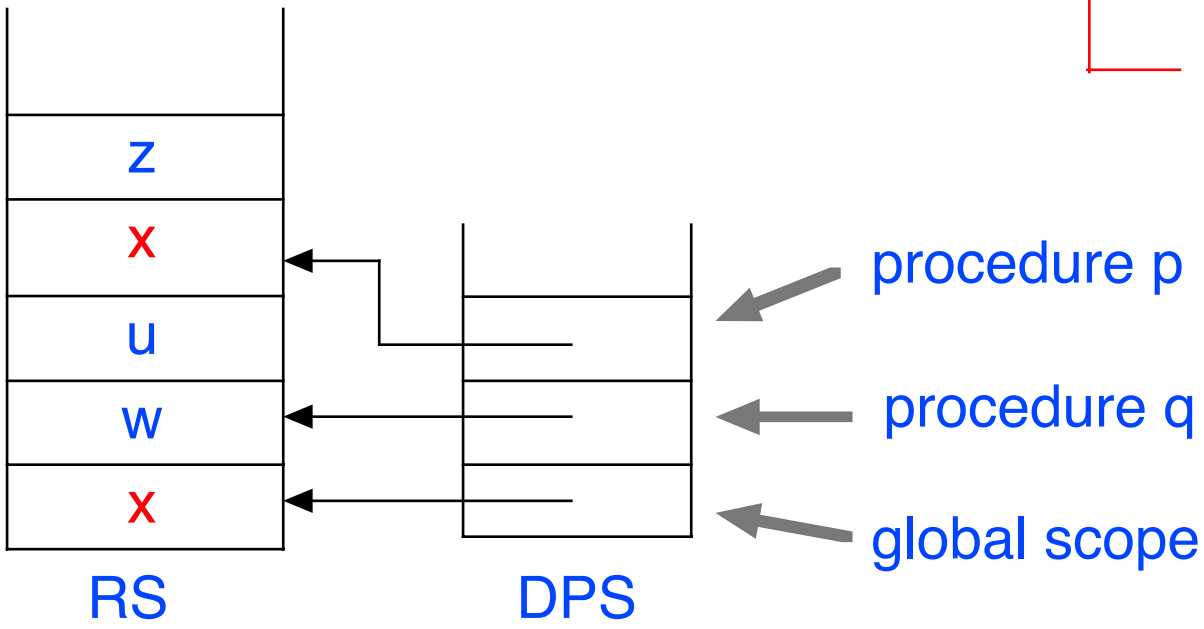
```
var x: integer;
procedure p;
   var y : integer;
       z : integer;
end p;
procedure q;
   var w : integer;
       u : integer;
   p;
end q;
q;
```



Variable Visibility

- There may also be more than one variable with the same name on the RS, due to either
  - Recursion (multiple instances of the same variable), or
  - Masking (variable with the same name in an inner scope).

```
var x: integer;
procedure p;
   var x : integer;
       z : integer;
end p;
procedure q;
   var w : integer;
       u : integer;
   p;
end q;
q;
```



Variable Visibility

- Our Run Stack model of scopes and variables must account for both these problems, so that the compiler properly implements the language
- The points can be summarized as:
  - Given a variable name,
    - Is a variable of that name currently visible?
    - If so, which one of that name is currently accessible?
    - And where is that one on the RS?
- Or more succcintly, what is the RS position (memory address) of the currently visible variable of a given name?
- We will attack this problem by refining the RS model to include the concept of *lexical levels*

Lexical Levels

- A *lexical level* is a level number assigned to each scope based on its static nesting depth (the depth of the scope in the actual source text of the program)

```
0 |     var x: integer;
  |     procedure p;
  | 1 |   var y: integer;
  |   |       z: integer;
  |   |   procedure q;
  |   | 2 |   var w: integer;
  |   |   end q;
  |   |   procedure r;
  |   | 2 |   var u : integer;
  |   |   end r;
  |     end p;
```

```
0 |   int x;
  |   void main() {
  | 1 |   int y,
  |   |       z;
  |   |   {
  |   | 2 |   int w;
  |   |   }
  |   |   {
  |   | 2 |   int u;
  |   |   }
  |   }
```

Lexical Level, Order Number Addressing

- Each variable in a scope is given an *order number* (ON) which is the sequence number of its declaration in the scope - the first declared variable in a scope is number 0, the second is 1, and so on
- The ordered pair (LL,ON), consisting of a lexical level LL and an order number ON, refers to *"the currently visible variable with order number ON at lexical level LL"* - uniquely identifies each visible variable
- Referring to variables in this way is called *Lexical Level, Order Number Addressing*

Lexical Level, Order Number Addressing

- In our example:

x	(0,0)
y	(1,0)
z	(1,1)
w	(2,0)
u	(2,0)

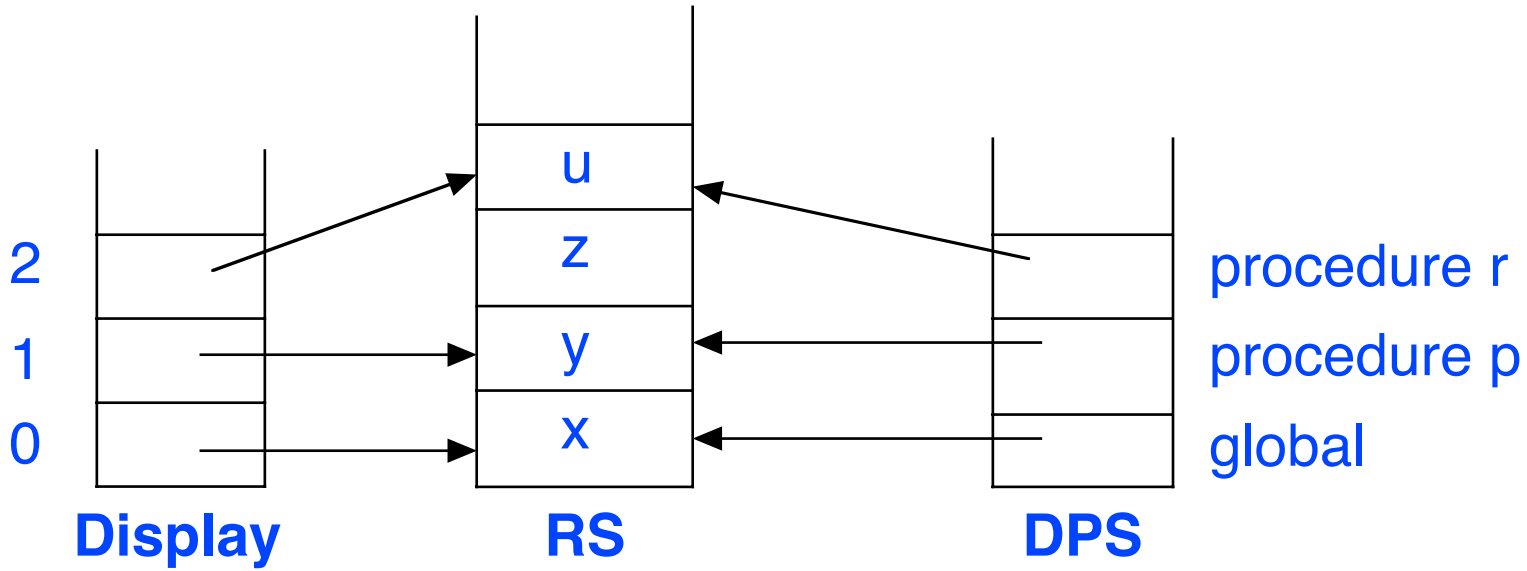
Note both *w* and *u* same!

```
0 |     var x: integer;
  |     procedure p;
1 |       var y: integer;
  |           z: integer;
  |       procedure q;
2 |         var w: integer;
  |       end q;
  |       procedure r;
2 |         var u : integer;
  |       end r;
  |   end p;
```

- In our abstract machine model, all variables are accessed through the their (LL,ON) address
- We will arrange that at any given time, each (LL,ON) address refers to only one variable
- If two variables have the same (LL,ON) pair, then at any given time in execution, the model will arrange that the currrently visible one is the one referenced by (LL,ON)

Lexical Level Representation

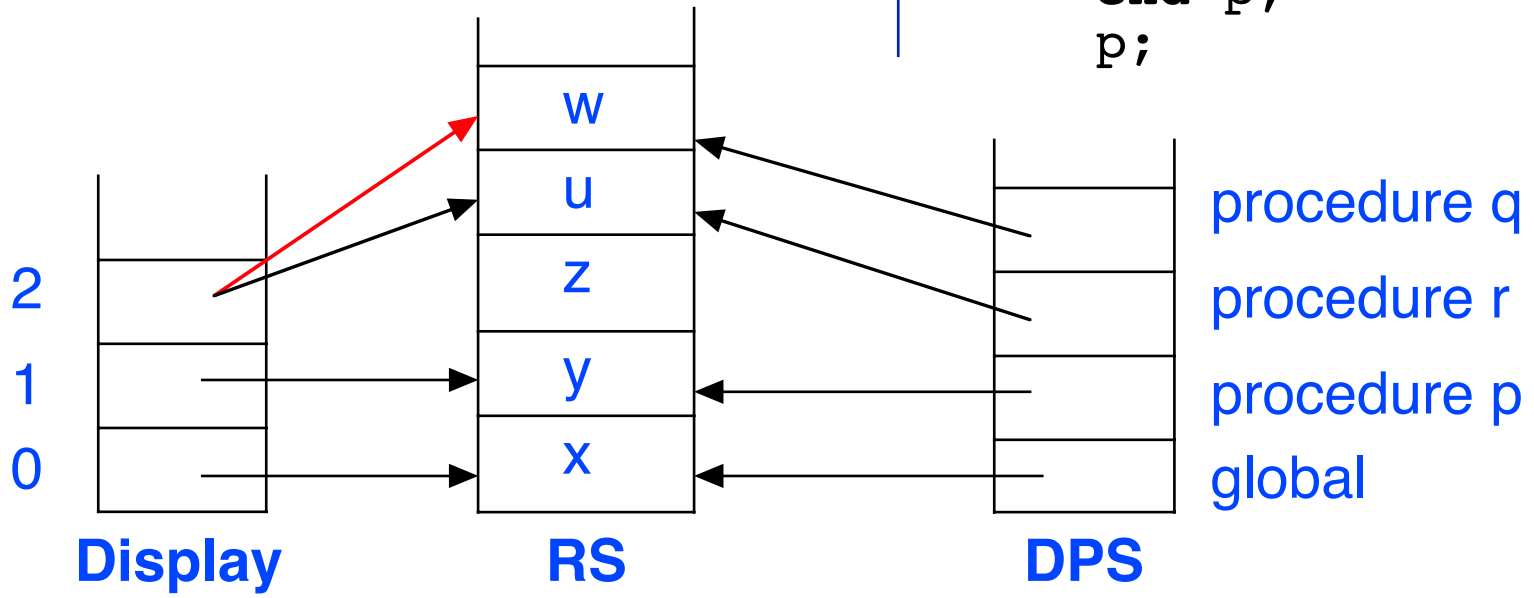
- Lexical Levels are modeled in the abstract machine using another stack-like structure called the *Display*
- The Display keeps track of the currently active scope at each LL
- For (LL,ON) addressing to work, we must maintain (i.e., keep current during execution) the Display
- On entry to a scope at lexical level LL, we must set Display[LL] to point to the base of the new scope's RS space (its "stack frame")
- On exit from a scope at lexical level LL, we must reset Display[LL] to point to the base of the previous scope that was at that level



Lexical Level Representation

- Example: on entry to *q*, must set Display[2] to the RS space for *q*
- On exit from *q*, must reset Display[2] to the RS space for *r*

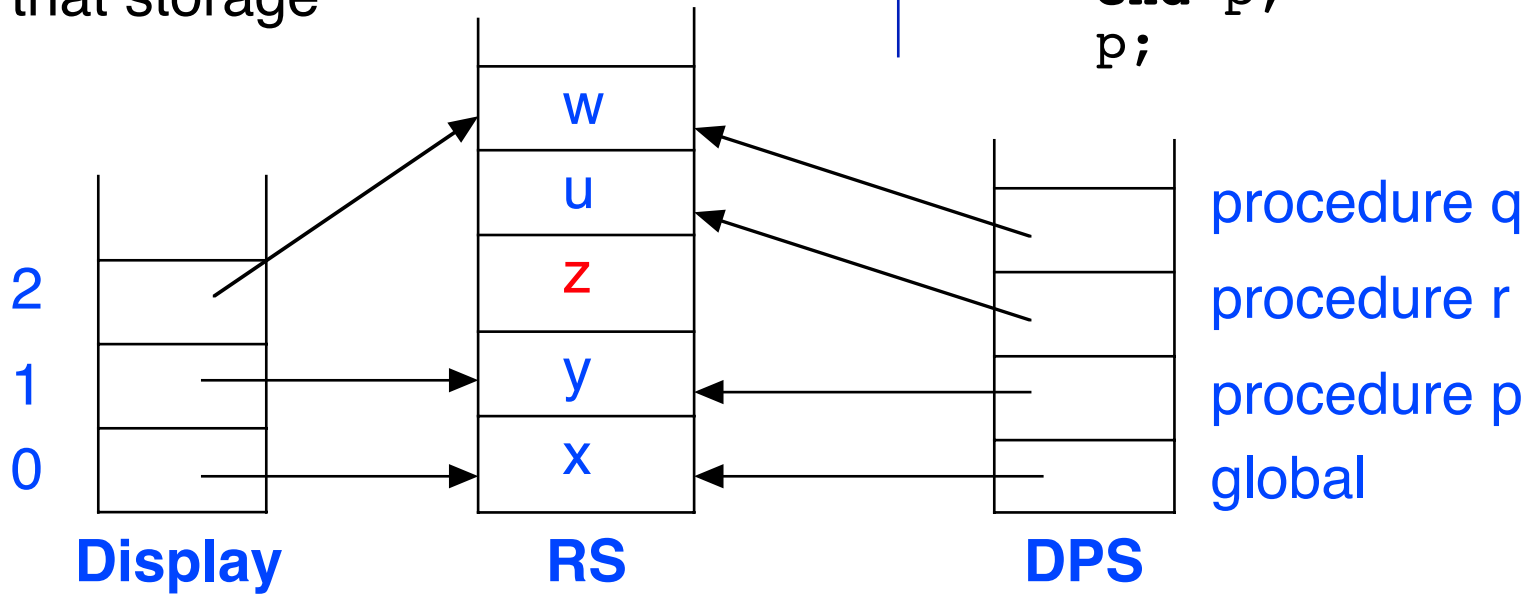
```
0   var x: integer;
    procedure p;
1     var y: integer;
          z: integer;
      procedure q;
2       var w: integer;
      end q;
      procedure r;
2       var u : integer;
        q;
      end r;
      r;
    end p;
    p;
```



(LL,ON) Address Calculation

- At run time, the address of a variable in the Run Stack is computed from its (LL,ON)
- RS [Display [LL] + ON] is the storage for variable (LL,ON)
- Display [LL] is the *base* of the storage for the scope, and ON is the *displacement* of the particular variable within that storage

```
0                var x: integer;
                 procedure p;
1                  var y: integer; 1,0
                       z: integer; 1,1
                   procedure q;
2                    var w: integer;
                   end q;
                   procedure r;
2                    var u : integer;
                     q;
                   end r;
                   r;
                end p;
                p;
```



Addressable Variables

- In our abstract machine model, all variables are referred to using (LL,ON) addressing
- Example: for expression z+x

```
push (1,1)      push value of RS [Display[1] + 1] on ES
push (0,0)      push value of RS [Display[0] + 0] on ES
add
```

- Variables not in visible scopes are not addressable on the RS (i.e., there is no (LL,ON) way to refer to them)
  - If they are in internal scopes (i.e. a higher lexical level) then there is not yet an entry for their LL in the Display
  - If they are in sibling scopes (at the same or lower lexical level) then their (LL,ON) address is masked by the addresses of the variables in the current scope
  - This also handles the problem of which instance of a variable is visible when we have recursive procedures

Summary

Modelling Scopes and Visibility

- Managing the Run Stack, the Dynamic Pointer Stack
- The Run Stack Display
- (LL,ON) addressing

Next Time

- Maintaining the Display
- Modelling procedure call / return, parameter passing, functions