Names, Scopes, and Binding

Read: Scott, Chapter 3.1, 3.2 and 3.3.1, 3.3.2 and 3.3.6

Lecture Outline

- Notion of binding time
- Object lifetime and storage management

- An aside: Stack Smashing 101

- Scoping
  - Static scoping
  - Dynamic scoping

Scoping

- In most languages the same variable name can be used to denote different memory locations
- Scoping rules: map variable to location
- Scope: region of program text where a declaration is visible
- Most languages use static scoping
  - Mapping from variables to locations is made at compile time
- Block-structured programming languages
  - Nested subroutines (Pascal, ML, Scheme, etc.)
  - Nested blocks (C, C++ { … })

Static Scoping in Block Structured Programming Languages

- Also known as lexical scoping
- Block structure and nesting of blocks gives rise to the closest nested scope rule
  - There are local variable declaration within a block
  - A block inherits variable declarations from enclosing blocks
  - Local declarations take precedence over inherited ones
    - Hole in scope of inherited declaration
    - In other words, inherited declaration is hidden
- Lookup for non-local variables proceeds from inner to outer enclosing blocks

Example - Block Structured PL

```
main
    a, b, c: integer
    procedure P
        c: integer      main.a, main.b, P.c     main.P, P.S, main.R
        procedure S
            c, d: integer     main.a,main.b,S.c,S.d     main.P, P.S, S.R
            procedure R
            …                S.R,P.S,main.P
            end R
            R()
        end S
        R()
        S()
    end P
    procedure R
        a: integer       R.a, main.b, main.c     main.R, main.P
        … = a, b, c
    end R
    P()
end main
```

Nested block structure allows locally defined variables and subroutines

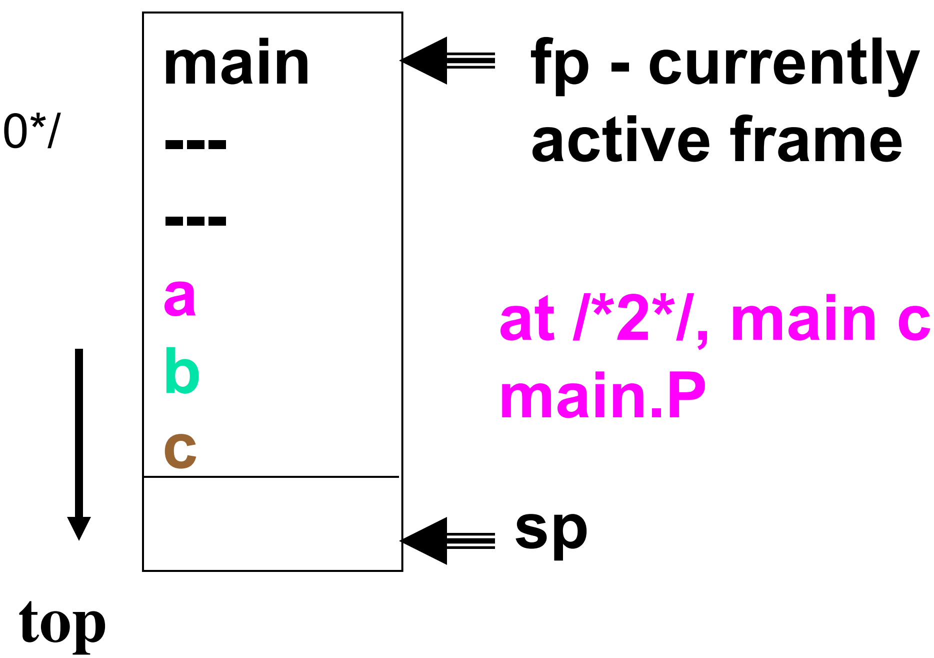
```
main
    a, b, c: integer
    procedure P
        c: integer
        procedure S
            c, d: integer
            procedure R
                …
            end R
            R()
        end S
        R()
        S()
    end P
    procedure R
        a: integer
        … = a, b, c
    end R
    P()
end main
```

Rule: a variable is visible if it is declared in its own block or in a textually surrounding block **and** it is not 'hidden' by a binding in a closer block (i.e., there is no hole in scope)

Example with Frames

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

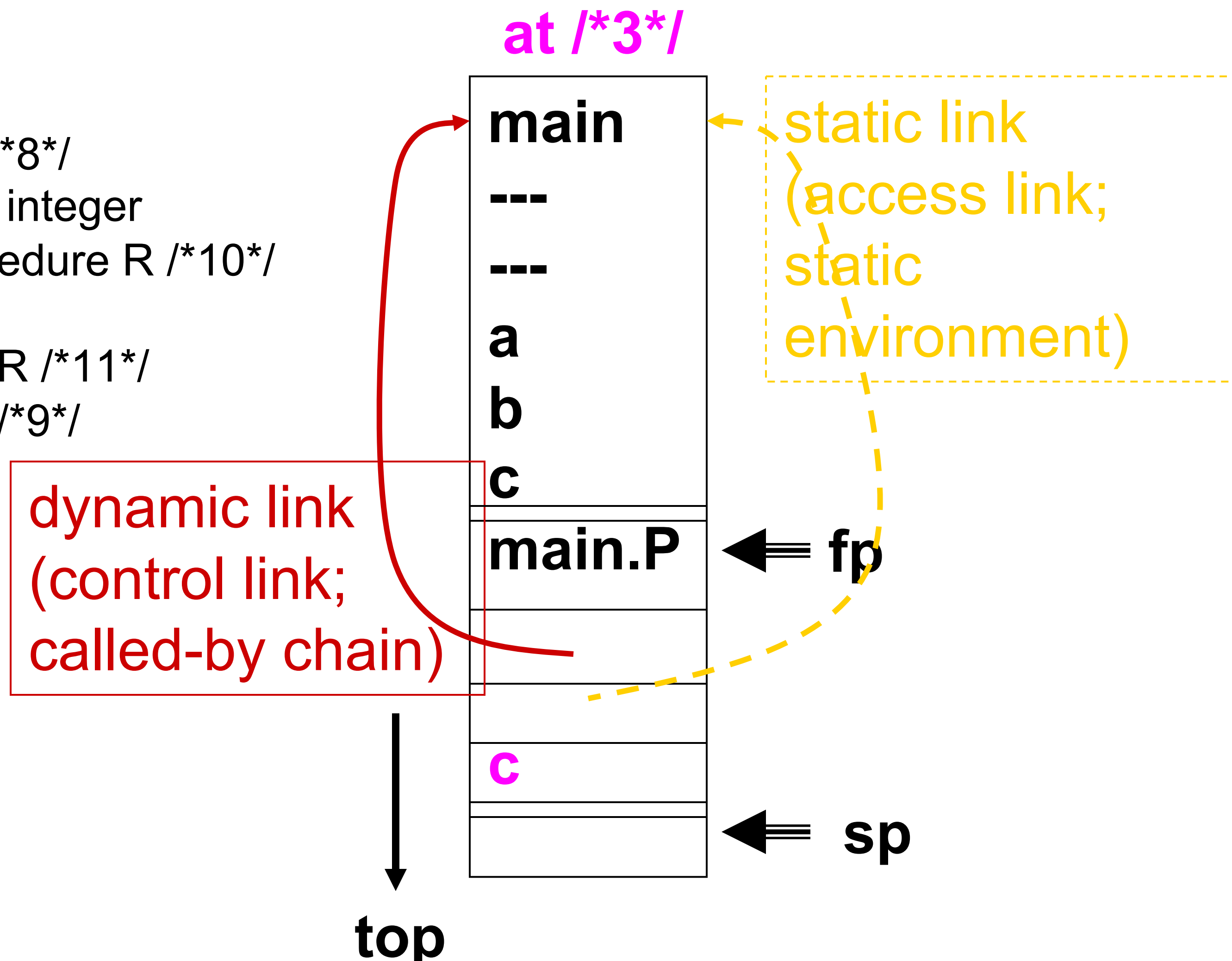
at /*1*/



at /*2*/, main calls main.P

Example

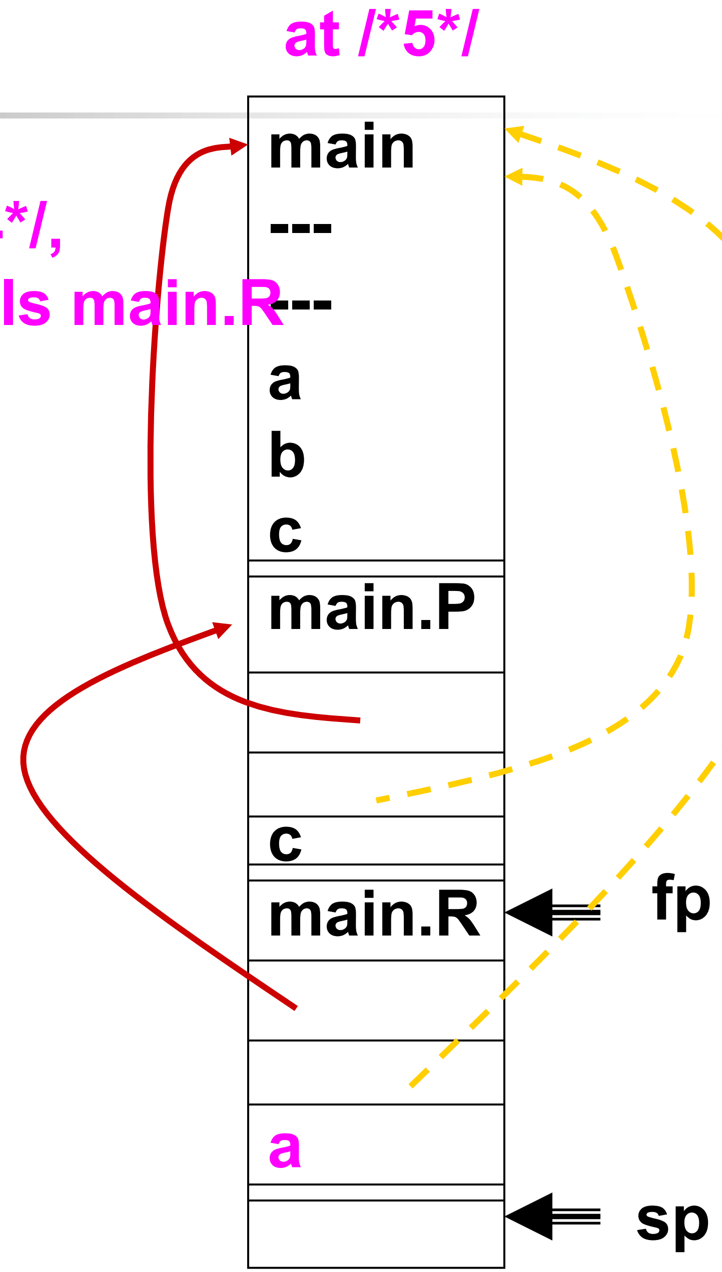
```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```



Example

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

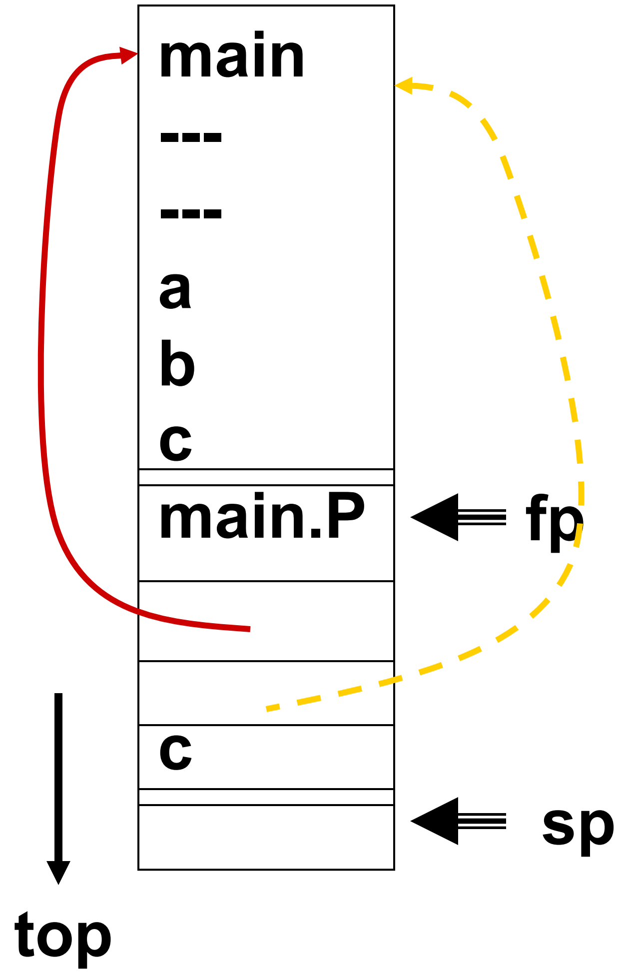
at /*4*/,
P calls main.R



Example

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

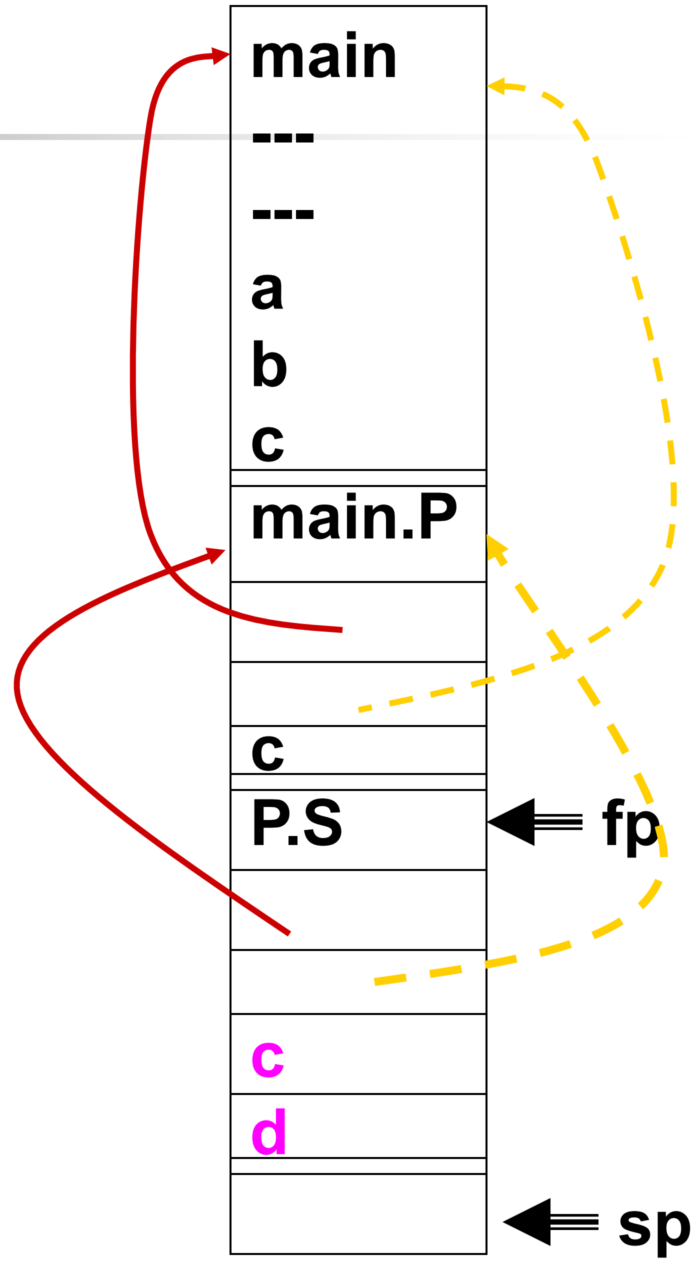
at /*6*/ main.R exits
sp ← fp
fp ← old fp
in main.R's frame



Example

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

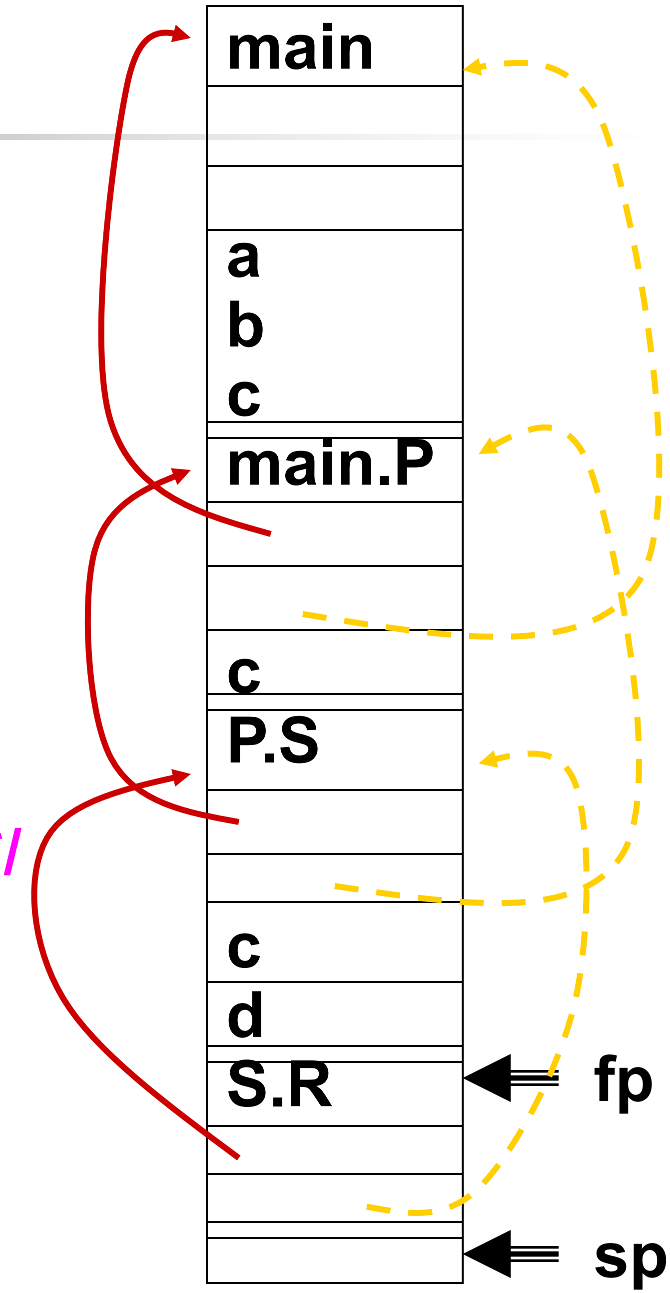
at /*7*/,
P calls P.S;
at /*8*/:



Example

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

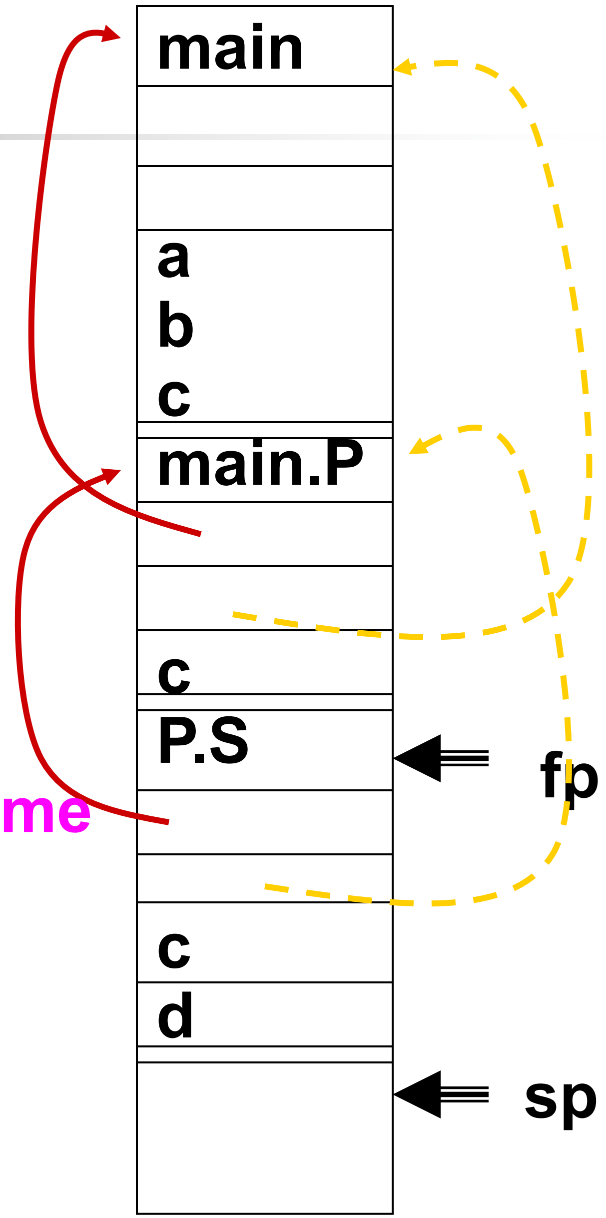
at /*9*/ S calls in S.R; at /*10*/



Example

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

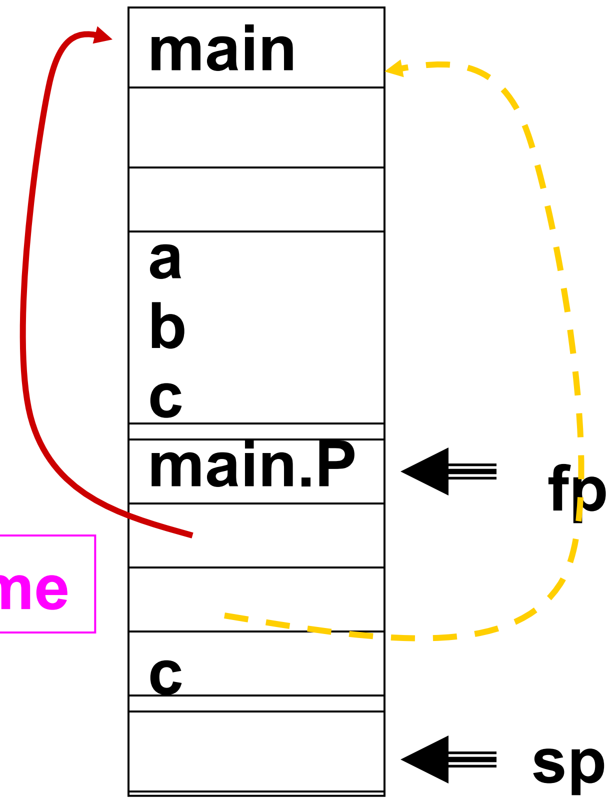
/*11*/ pop S.R’s frame



Example

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

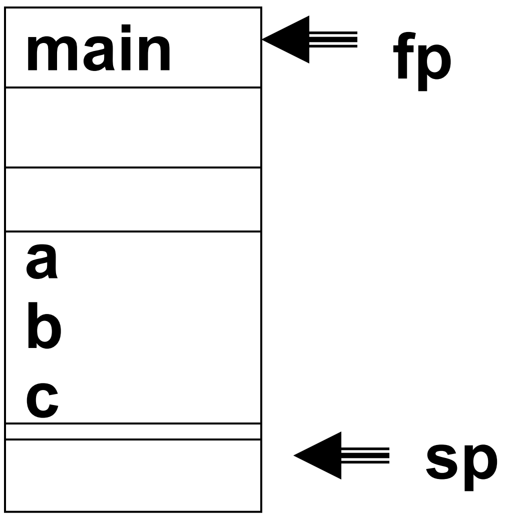
/*12*/pop S’s frame



Example

```
main
    a, b, c: integer /*1*/
    procedure P    /*3*/
        c: integer
        procedure S /*8*/
            c, d: integer
            procedure R /*10*/
            …
            end R /*11*/
            R()  /*9*/
        end S /*12*/
        R() /*4*/
        S() /*7*/
    end P /*13*/
    procedure R /*5*/
        a: integer
        … = a, b, c
    end R /*6*/
    P() /*2*/ …
end main /*14*/
```

at /*13*/



/*13*/ pop P's frame
/*14*/ pop main's frame
so that sp ← fp

Static Link vs. Dynamic Link

- Static link for a frame of subroutine P points to the most recent frame of P's lexically enclosing subroutine
  - Bookkeeping required to maintain the static link
  - If subroutine P is enclosed *k*-levels deep from main, then the length of the static chain that begins at a frame for P, is *k*
  - To find non-local variables, follow static chain
- Dynamic link points to the caller frame, this is essentially old fp stored on frame

Observations

- Static link of a subroutine P points to the frame of the most recent invocation of subroutine Q, where Q is the lexically enclosing subroutine of P
  - Used to implement static scoping using a *display*

- Dynamic link may point to a different subroutine's frame, depending on where the subroutine is called from

An Important Note!

- For now, we assume languages that do not allow subroutines to be passed as arguments or returned from other subroutines, i.e., subroutines (functions) are third-class values
  - When subroutines (functions) are third-class values, it is guaranteed the static reference environment is on the stack
  - I.e., a subroutine cannot outlive its reference environment

An Important Note!

- Static scoping rules become more involved in languages that allow subroutines to be passed as arguments and returned from other subroutines, i.e., subroutines (functions) are first class values

- We will return to scoping later during our discussion of functional programming languages

Dynamic Scoping

- Allows for local variable declaration
- Inherits non-local variables from subroutines that are live when current subroutine is invoked
  - Use of variable is resolved to the declaration of that variable in the most recently invoked and not yet terminated frame. I.e., lookup proceeds from closest predecessor on stack to furthest
  - (old) Lisp, APL, Snobol, Perl

Example

```
main
    procedure Z
        a: integer
        a := 1
        Y()
        output a
    end Z
    procedure W
        a: integer
        a := 2
        Y()
        output a
    end W
    procedure Y
        a := 0 /*1*/
    end Y
    Z()
    W()
end main
```

Which a is modified at /*1*/ under dynamic scoping? Z.a or W.a or both?

Example

```
main
    procedure Z
        a: integer
        a := 1
        Y()
        output a
    end Z
    procedure W
        a: integer
        a := 2
        Y()
        output a
    end W
    procedure Y
        a := 0; /*1*/
    end Y
    Z()
    W()
end main
```

main calls Z,
Z calls Y,
Y sets Z.a to 0.

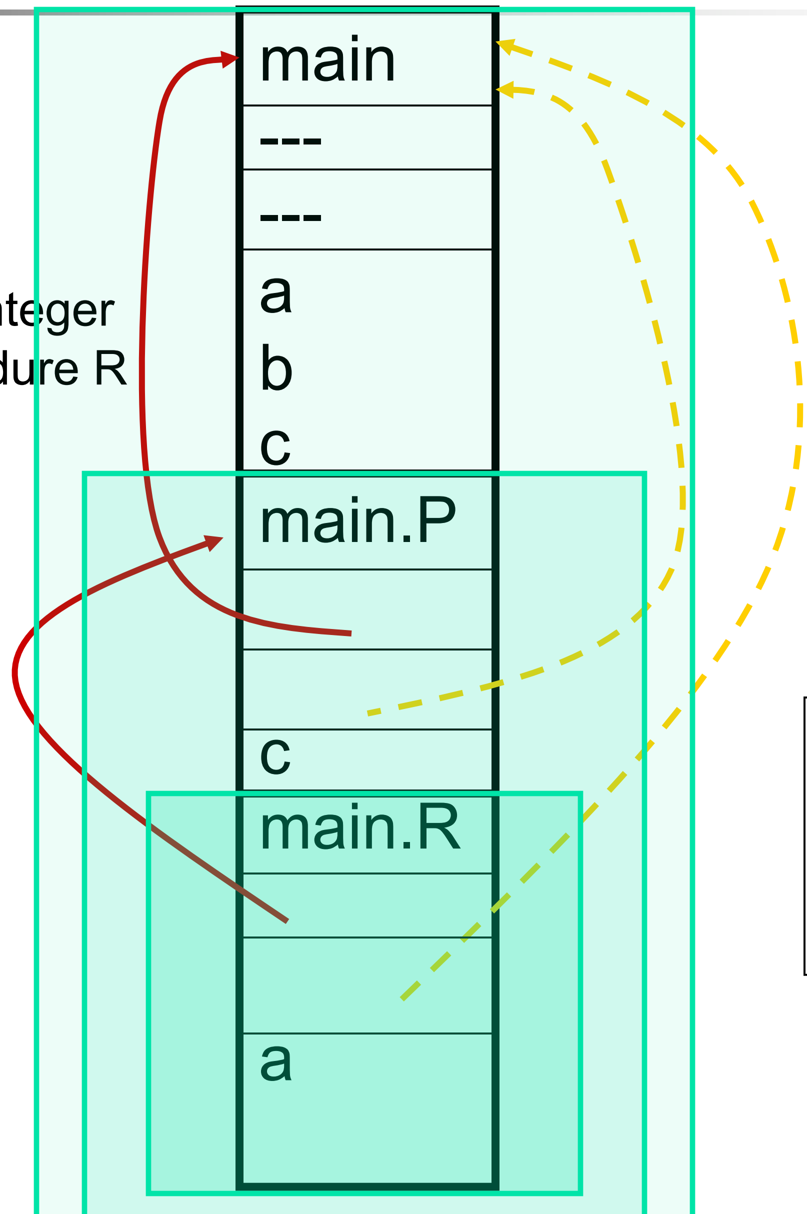
Example

```
main
    procedure Z
        a: integer
        a := 1
        Y()
        output a
    end Z
    procedure W
        a: integer
        a := 2
        Y()
        output a
    end W
    procedure Y
        a := 0; /*1*/
    end Y
    Z()
    W()
end main
```

main calls W,
W calls Y,
Y sets W.a to 0.

Static vs. Dynamic Scoping

```
main
    a, b, c: integer
    procedure P
        c: integer
        procedure S
            c, d: integer
            procedure R
            …
            end R
            R()
        end S
        R()
        S()
    end P
    procedure R
        a: integer
        … = a, b, c
    end R
    P()
end main
```



Static Scoping:
- a bound to R.a,
- b to main.b,
- c to main.c

Dynamic Scoping:
- a bound to R.a,
- b to main.b,
- c to P.c

Dynamic Scoping

- Dynamic scoping is considered a bad idea. Why?

- More on static and dynamic scoping to come!

The End