EDAN65: Compilers, Lecture 10

Runtime systems

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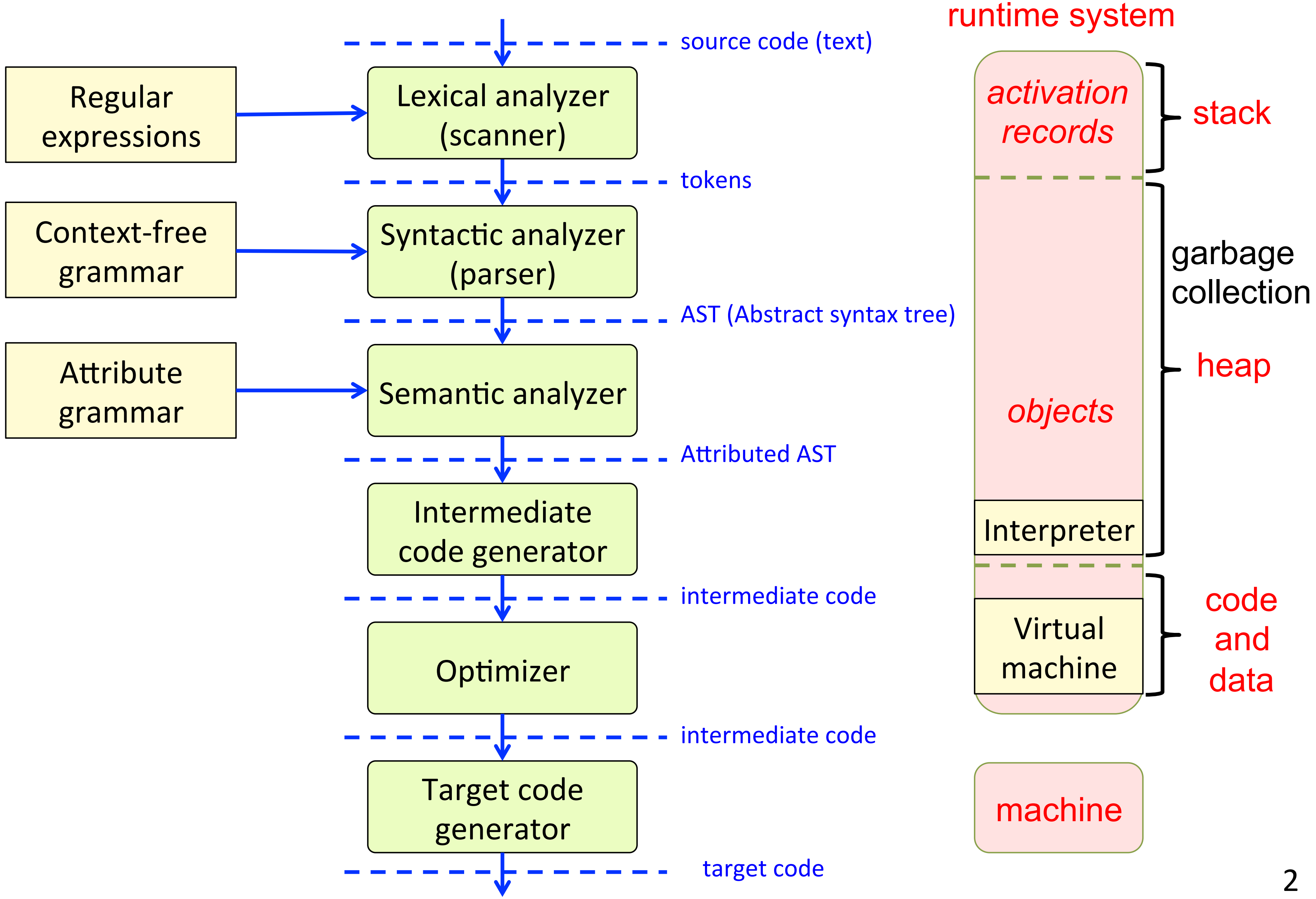
This lecture



Runtime systems

Organization of data

- Global/static data
- Activation frames (method instances)
- Objects (class instances)

Method calls

- Call and return
- Parameter transmission

Access to variables

- Local variables
- Non-local variables

Object-oriented constructs

- Inheritance
- Overriding
- Dynamic dispatch
- Garbage collection

The machine

Registers: 32 or 64 bits wide

r0	
r1	
...	
r31	

Typically a small number.
For example, 32 registers

Some have dedicated roles:
program counter, stack pointer, ...

Some are general purpose, for computations

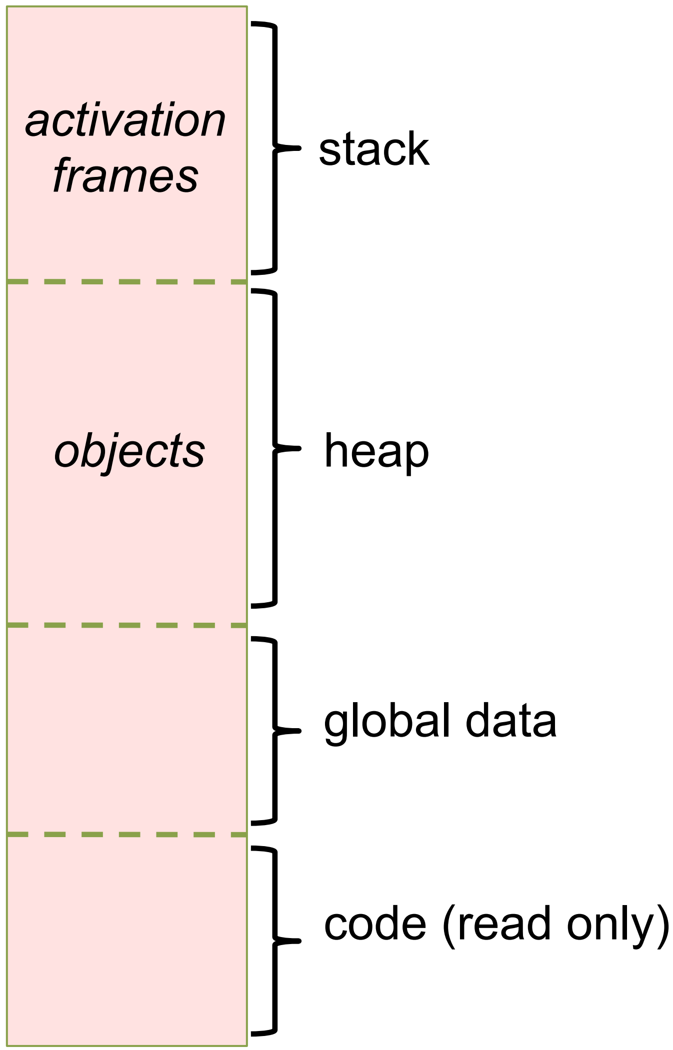
(Random Access) Memory: Typically byte adressed

0	
4	
8	
12	
16	
...	
2^{32}-4	

Very large – order of Gbyte.
Like a very big array.

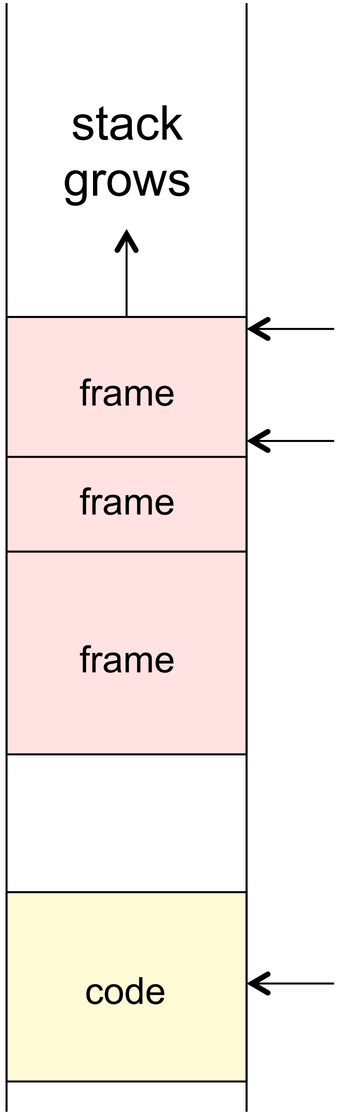
Typically divided into different segments:
global data, code, stack, heap.

Example memory segments



Stack of activation frames

The data for each method call is stored in an **activation frame**



Some dedicated registers:

SP – Stack Pointer. The top of the stack.

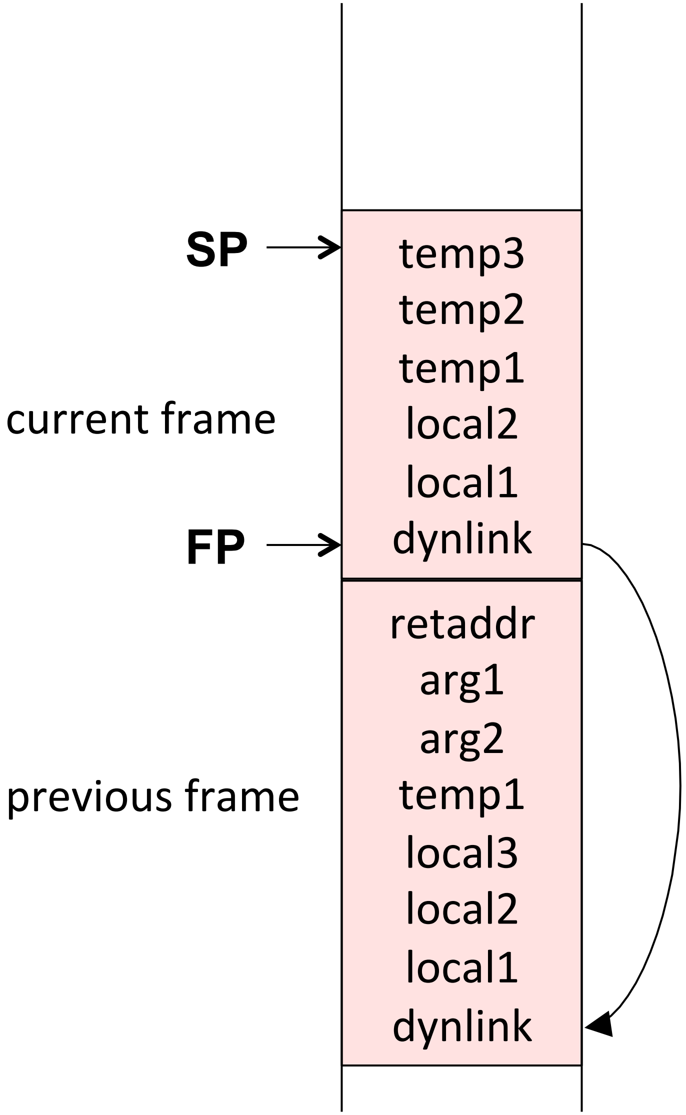
FP – Frame Pointer. The first word of the current frame

PC – Program counter. The currently executing instruction.

Synonyms:
activation record
activation
stack frame
frame

Swedish:
aktiveringspost

Example frame layout



temps: Temporary variables

locals: Local variables

dynlink: Dynamic link – points to frame of calling method

retaddr: Saved PC - where to jump at return

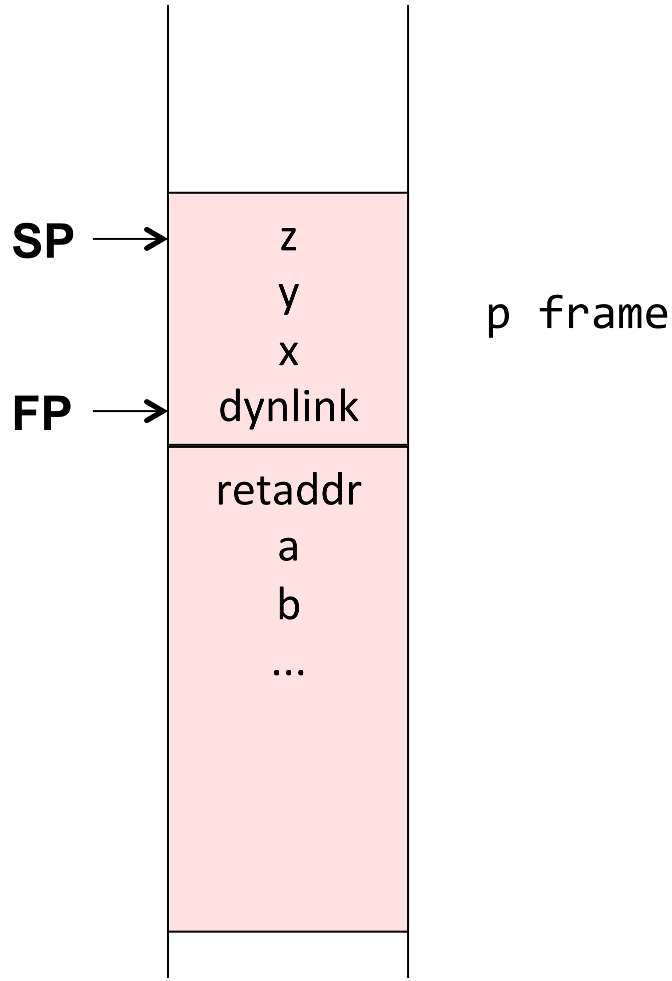
args: Arguments to current frame.

The calling method pushes arguments on the stack.
The return value is placed in a register.

Frame pointer

Used for accessing arguments and variables in the frame

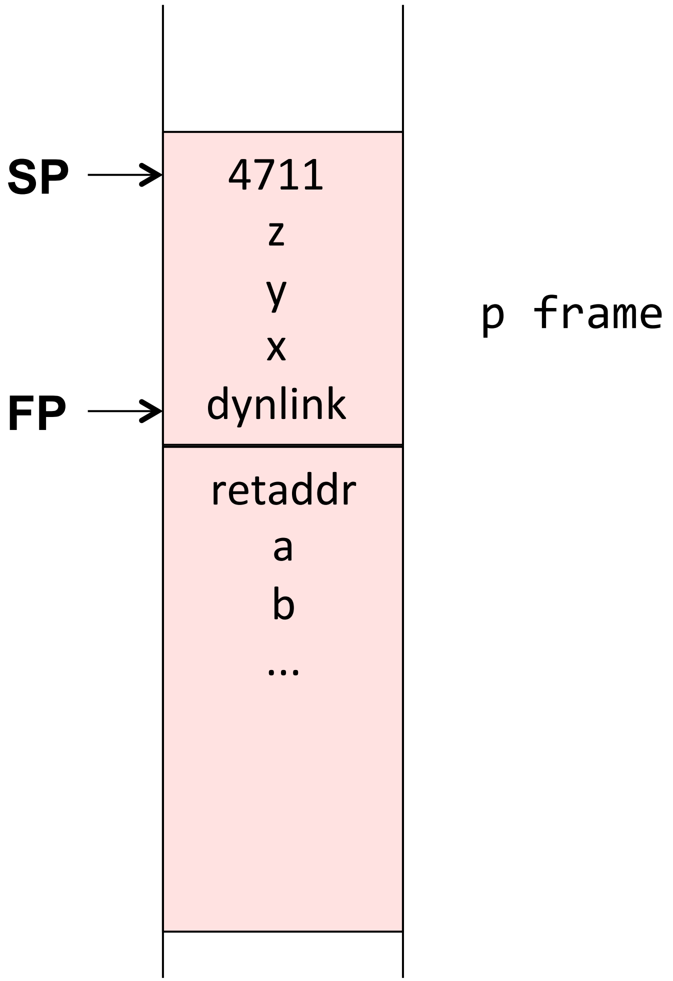
```
void p(int a, int b) {
  int x = 1;
  int y = 2;
  int z = 3;
  ...
}
```



Stack pointer

Used for growing the stack, e.g., at a method call

```
void p(int a, int b) {
  int x = 1;
  int y = 2;
  int z = 3;
  q(4711);
}
```



The argument 4711 is pushed on the stack before calling q

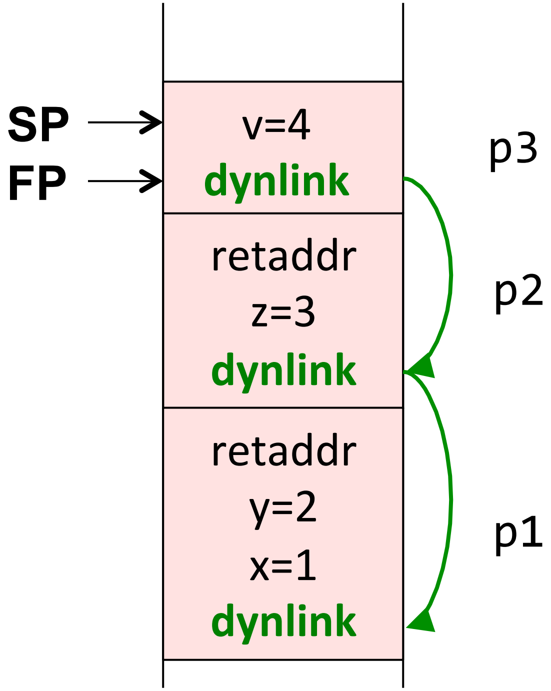
Dynamic link

Points to the frame of the calling method

```
void p1() {
  int x = 1;
  int y = 2;
  p2();
}

void p2() {
  int z = 3;
  p3();
}

void p3(){
  int v = 4;
}
```



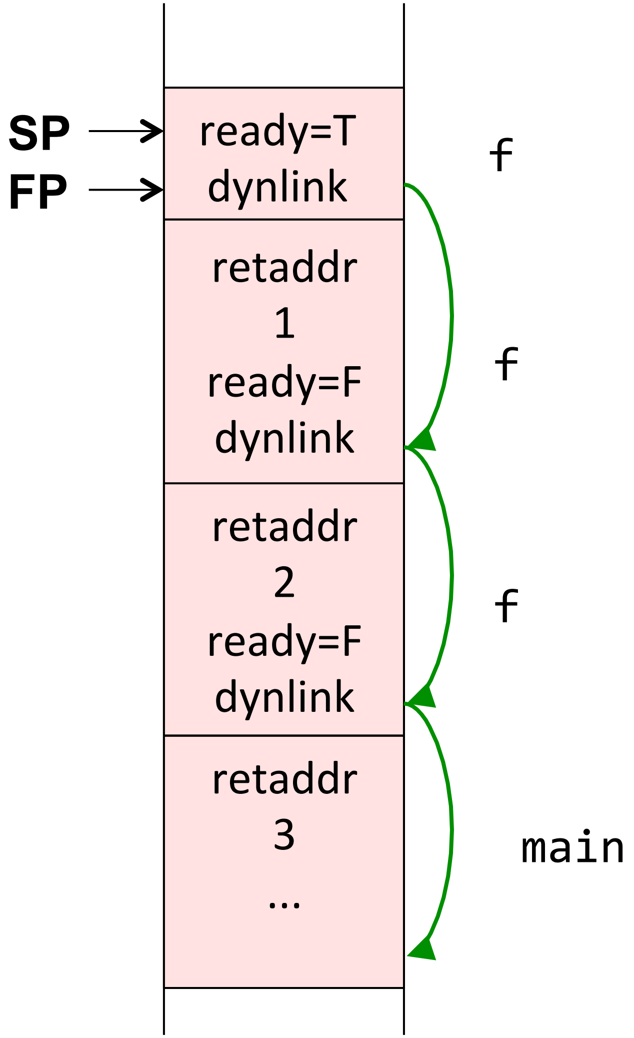
Used for restoring FP when returning from a call.

Recursion

Several activations of the same method

```
int f(int x) {
  bool ready = x <= 1;
  if (ready)
    return 1;
  else
    return x * f(x-1);
}
```

```
void main() {
  ...
  f(3);
  ...
}
```



Nested methods

Static link – a hidden argument that points to the frame of the enclosing method.
Makes it possible to access variables in enclosing methods.

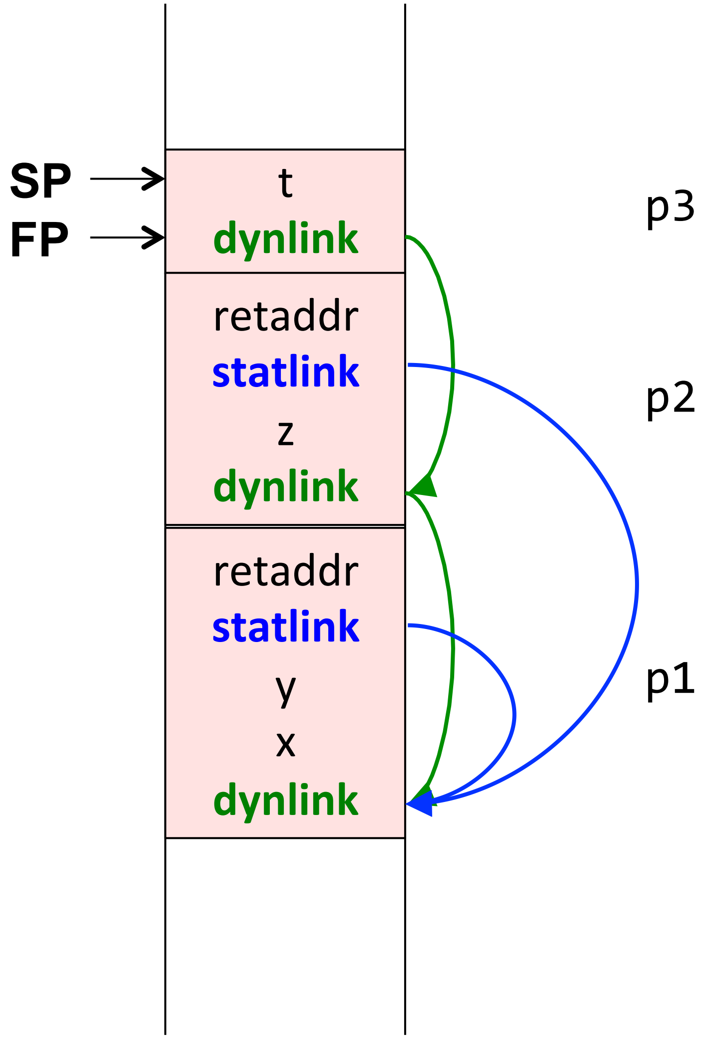
```
void p1() {
  int x = 1;
  int y = 2;

  void p2() {
    int z = y+1;
    p3();
  }

  void p3(){
    int t = x+3;
  }

  p2(); y++;
}
```

The methods are *nested.*
Supported in Algol, Pascal, Python,
but not in C, Java...



Objects and methods

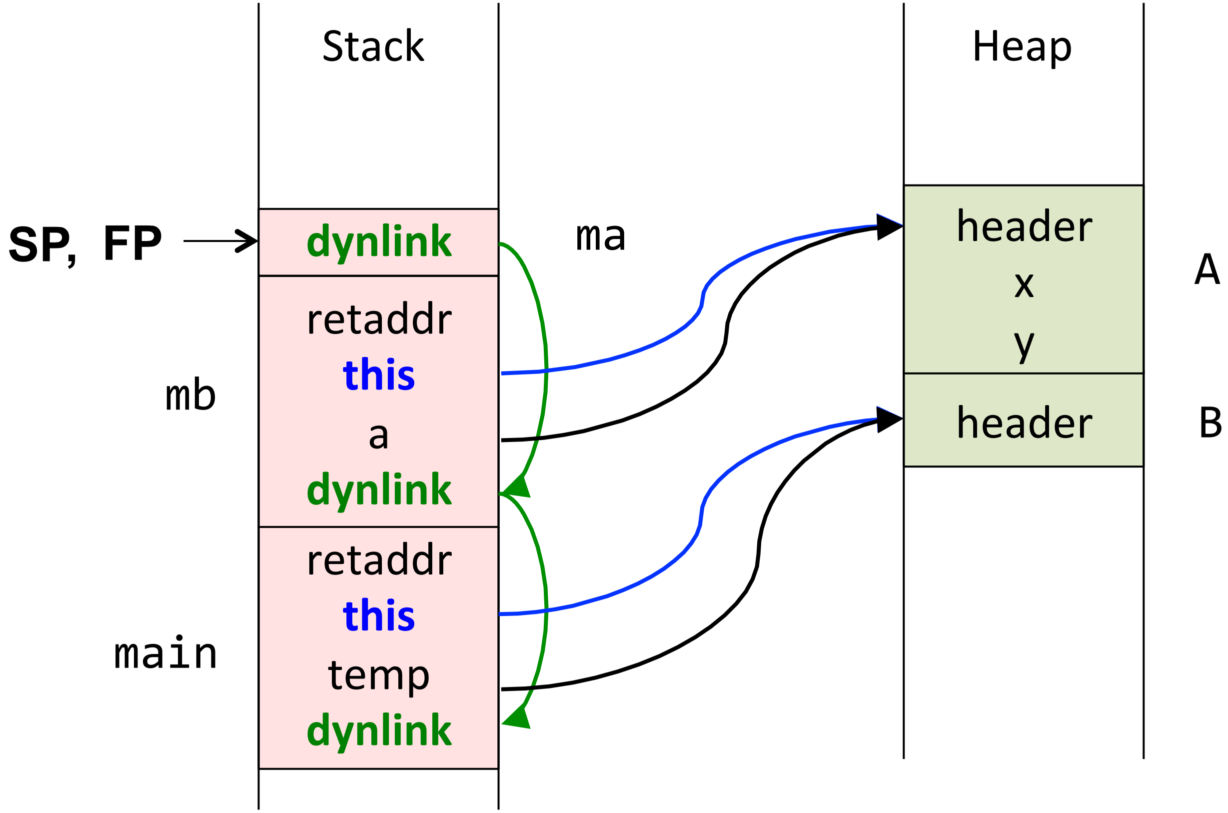
This pointer – a hidden argument. Corresponds to the static link.
Makes it possible to access fields in the object.

```
class A {
  int x = 1;
  int y = 2;

  void ma() {
    x = 3;
  }
}
```

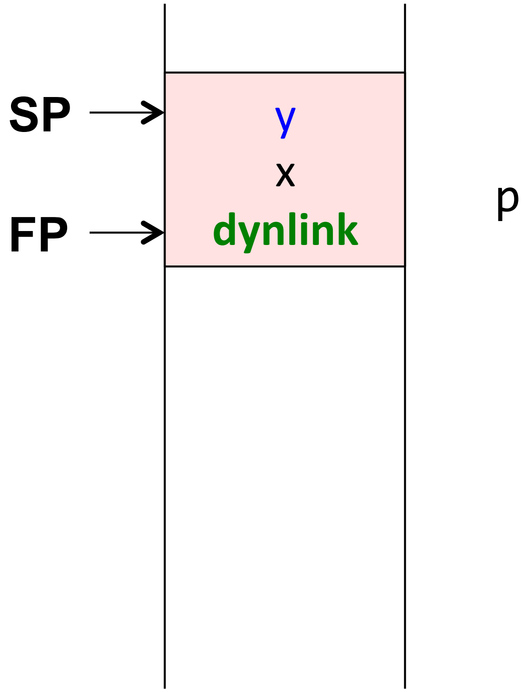
```
class B {
  void mb() {
    A a = ...;
    a.ma();
  }
}
```

```
void main() {
  new B().mb();
}
```



Access to local variable

```
void p() {
  int x = 1;
  int y = 2;
  y++;
  ...
}
```



Assume each word is 8 bytes.

The compiler computes addresses relative to FP:

var	offset	address
x	1	FP-1*8
y	2	FP-2*8

Typical assembly code for y++

```
SUB   FP  16  R1     // Compute address of y, place in R1
LOAD  R1  R2         // load value of y into R2
INC   R2             // increment R2
STORE R2  R1         // store new value into y
```

Computing offsets for variables

```
void p() {
  boolean f1 = true;
  int x = 1;
  boolean f2 = false;
  if (...) {
    int y = 2;
    ...
  }
  else {
    int z = 3;
    ...
  }
  ...
}
```

The compiler can reorder variables in the activation to make efficient use of the space.

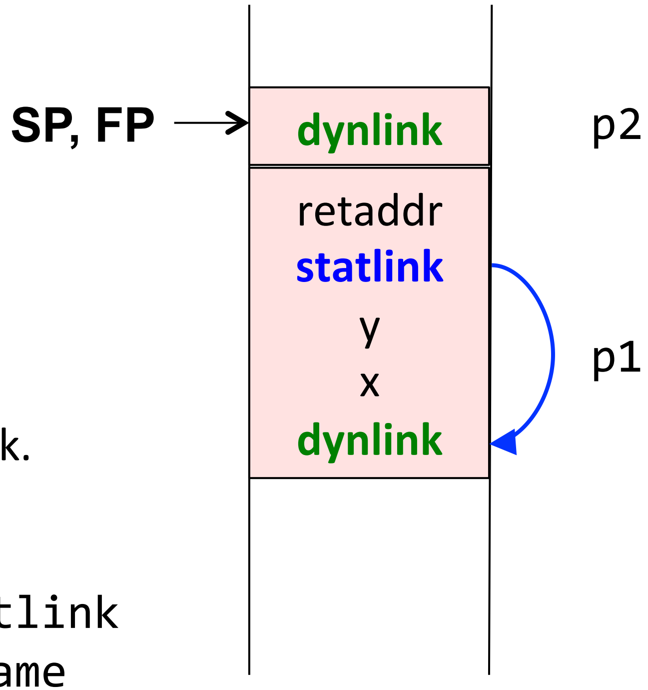
y and z have disjoint lifetimes.
They could share the same memory cell.

The booleans could be stored in consecutive bytes, or bits.

...

Access to non-local variable

```
void p1() {
  int x = 1;
  int y = 2;
  void p2() {
    x++;
  }
  p2();
}
```



The compiler knows that x is declared in the enclosing block.

Follow the static link once to get to the enclosing frame

```
ADD   FP  16  R1  // Compute address of statlink
LOAD  R1  R2      // Get address to p1's frame

SUB   R2  8   R3  // Compute the address of x
LOAD  R3  R4      // Load y into R4
INC   R4          // Increment
STORE R4  R3      // Store the new value to memory
```

For deeper nesting, follow multiple static links.

Method call

```
void p1() {
  int x, y, z;
  ...
  z = p2(x+1, y*2);
  ...

}
```

```
int p2(int a, int b) {
  ...
  ...
  ...
  return ...
  ...
}
```

1. Transfer arguments and call:
   Push the arguments. Push the return address. Jump to the called method.

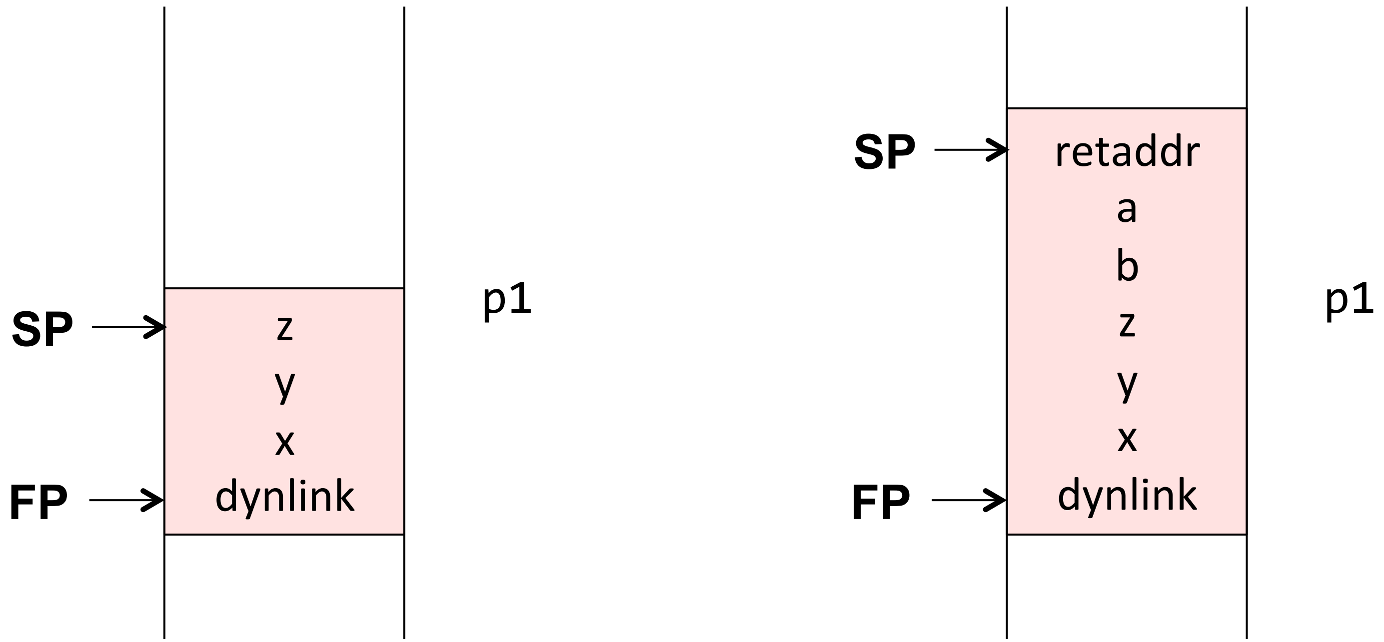
2. Allocate new frame:
   Push FP and move FP.
   Move SP to make space for local variables.

3. Run the code for p2.

4. Save the return value in a register.
   Deallocate the frame: Move SP back. Move FP back. Pop FP.
   Pop return address and jump to it.

5. Pop arguments. Continue executing in p1.

Step 1: Transfer arguments and call.



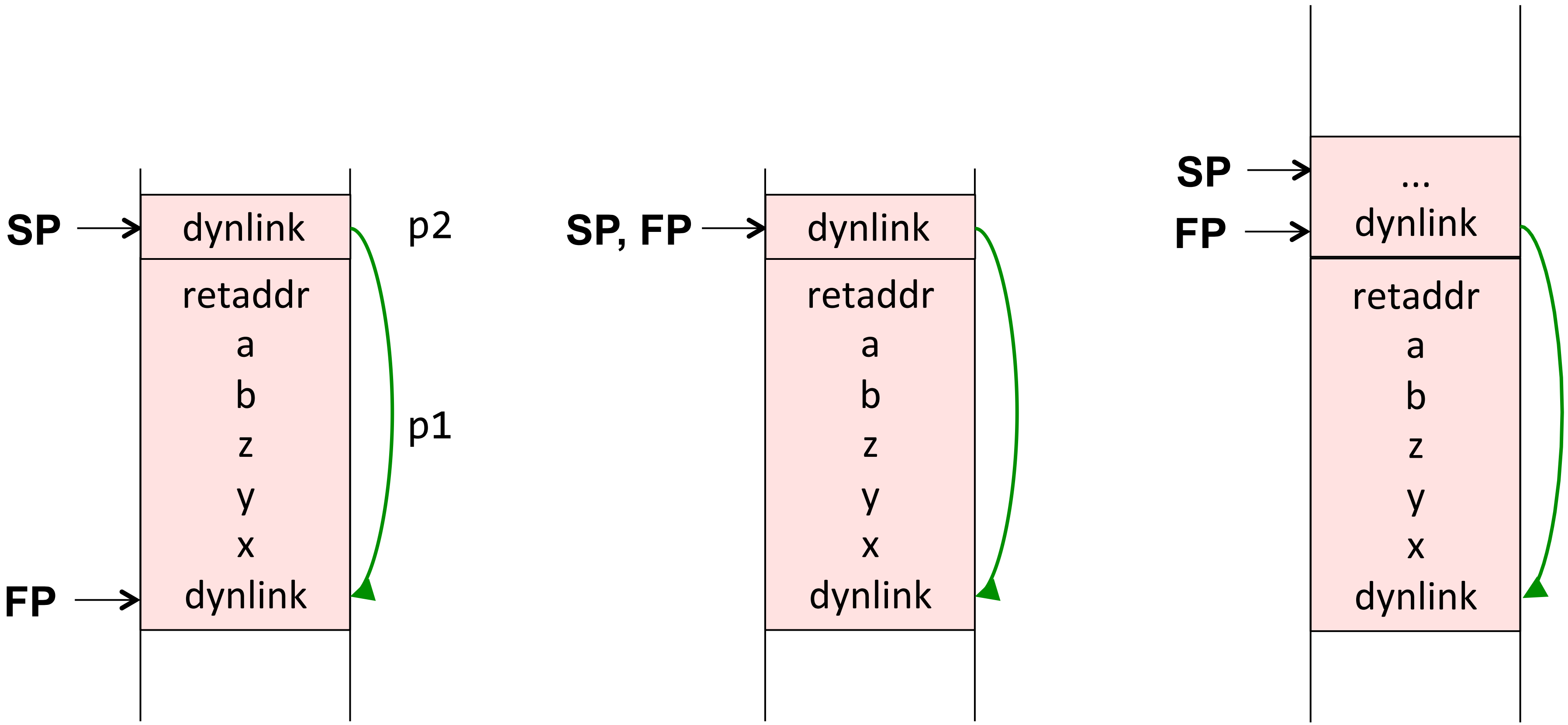
Transfer arguments:

- Push the arguments on the stack

Do the call:

- Compute the return address (e.g., PC+2*8) and push it on the stack.
- Jump to the code for p2.
  (Usually an instruction "CALL p2" accomplishes these two things.)

Step 2: Allocate the new frame

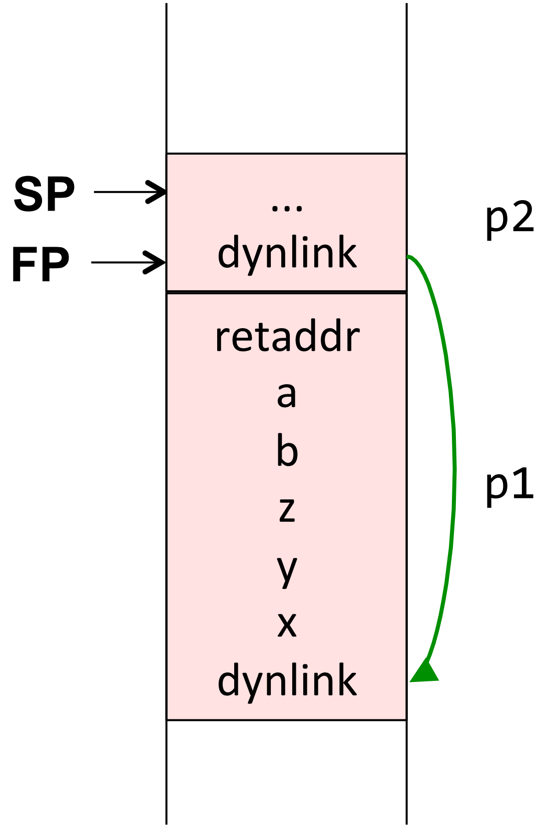


push the dynamic link (current FP)

set FP to the new frame

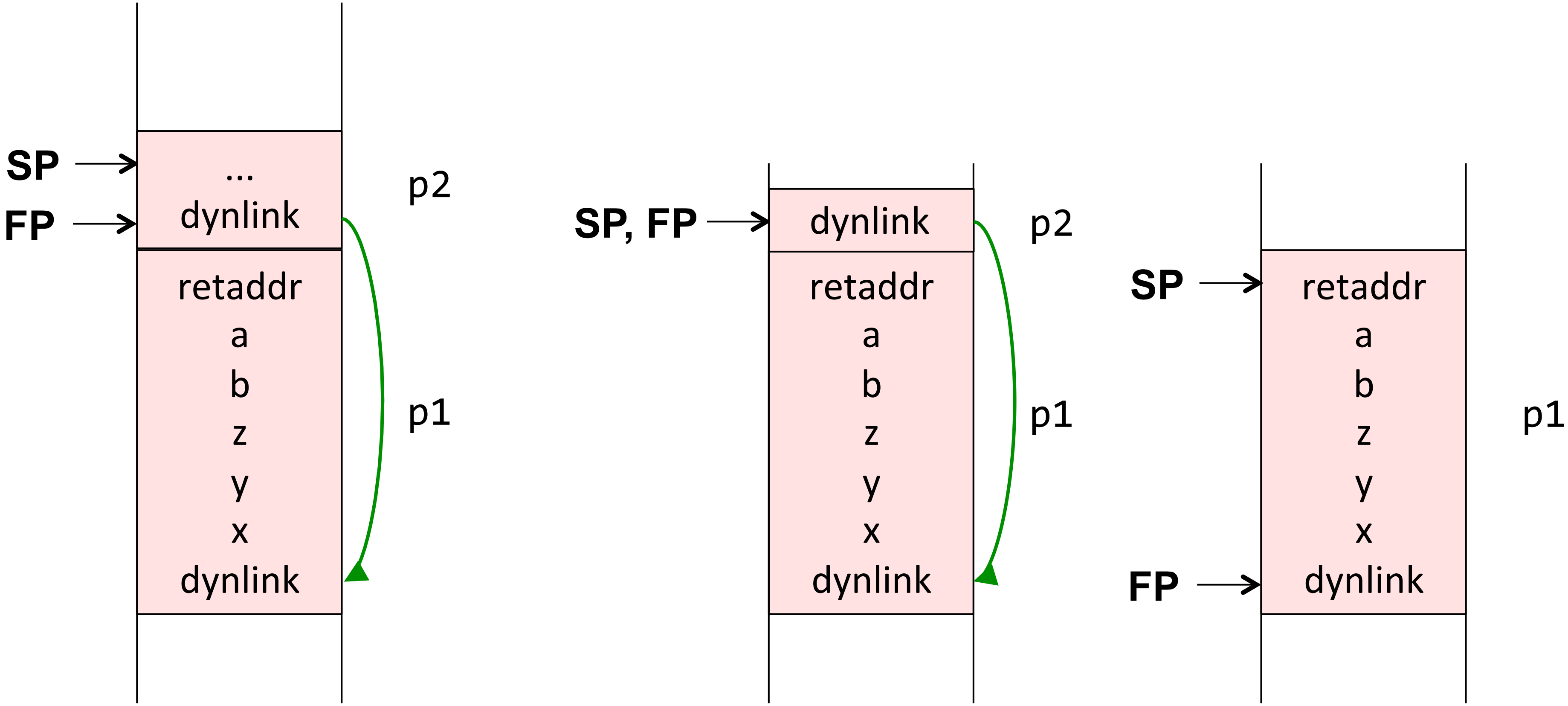
move SP to allocate space for new locals

Step 3: Run the code for p2



run the code for p2

Step 4: Deallocate and return



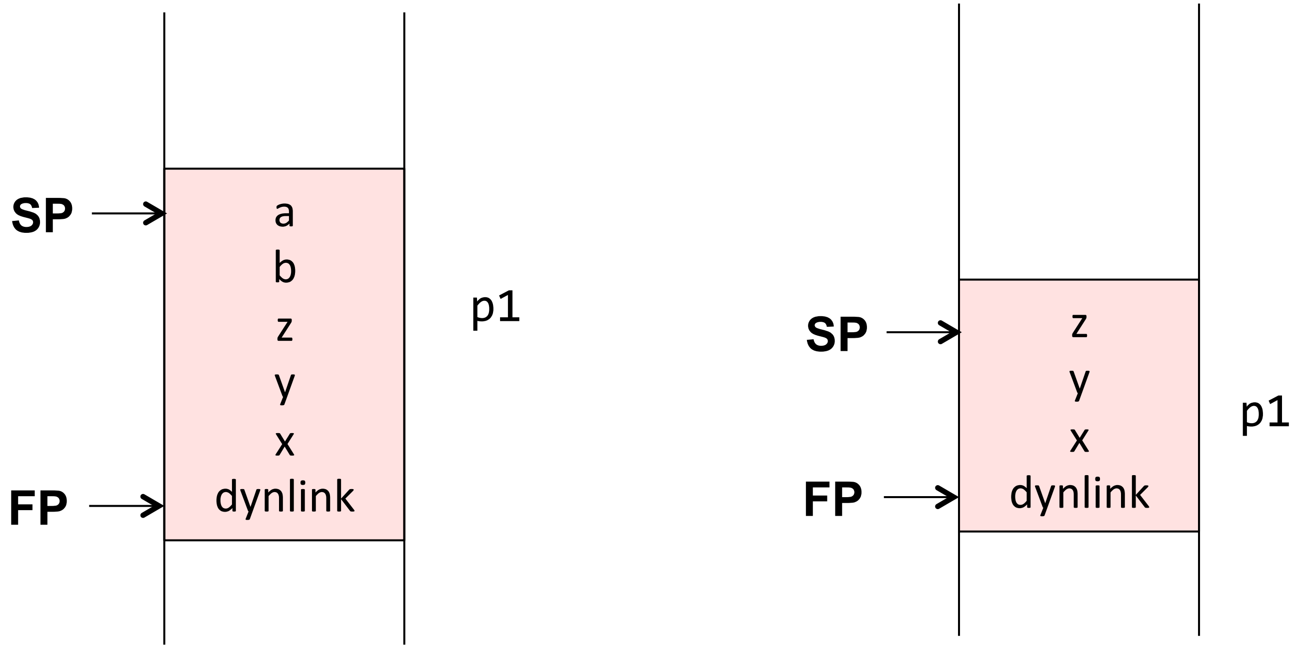
Store the return value in a register.

Deallocate locals: Move SP back to FP.

Pop FP and set FP to old value (dynlink)

Then pop the return address and jump to it.
(Usually an instruction "RET" does this.)

Step 5: Continue executing in p1



- Pop the arguments
- Continue executing in p1

What the compiler needs to compute

For uses of locals and arguments

- The offsets to use (relative to the Frame Pointer)

For methods

- The space needed for local declarations and temporaries.
  (Or use push/pop for allocation/deallocation.)

If nested methods are supported

- The number of static levels to use for variable accesses (0 for local vars)
- The number of static levels to use for method calls (0 for local methods)

Registers typically used for optimization

Store data in registers instead of in the frame:

- The return value
- The *n* first arguments
- The static link
- The return address

If a new call is made, these registers must not be corrupted!

Calling conventions:
Conventions for how arguments are passed, e.g., in specific registers or in the activation record.
Conventions for which registers must be saved (as temps) by caller or callee:

Caller-save register: The caller must save the register before calling.

Callee-save register: The called method must save these registers before using them, and restoring them before return.

Many different variants on activation frames

Stack pointer: Point to first empty word, or last used word?
Arguments: Treat them as part of the calling or called frame?
Argument order: Forwards or backwards order in the frame?
Direction: Let the stack grow towards larger or smaller addresses?
Allocate space for vars and temps: In one chunk, or push one var at a time.
...

Machine architectures often have instructions supporting a specific activation record design. E.g., dedicated FP and SP registers, and CALL, RETURN instructions that manipulate them.

Summary questions

- What is the difference between registers and memory?
- What typical segments of memory are used?
- What is an activation frame?
- Why are activation frames put on a stack?
- What are FP, SP, and PC?
- What is the static link? Is it always needed?
- What is the dynamic link?
- What is meant by the return address?
- How can local variables be accessed?
- How can non-local variables be accessed?
- How does the compiler compute offsets for variables?
- What happens at a method call?
- What information does the compiler need to compute in order to generate code for accessing variables? For a method call?
- What is meant by ”calling conventions”?