Storage allocation

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Programming Language Concepts

Lecture 5, 28 January 2025

Variables, functions and storage

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- Compiler creates a map from variables to memory addresses

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  - Complexities introduced by recursion
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  - Need a way to keep track of all copies of a local `x`
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- Scope and lifetime of variables

Scope

- Consider the following program block

```
{
  int x = 2;
  int y = 4;

  {
    int y = 3;
    x = x+2; y = x+y;
    print(x,y);
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Updated y value is not propagated outside
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Updated y value is not propagated outside
4, 7

Outer y value and updated x value
6, 10

for (int i=0. — i++;) {

int i=4 X

A[i]   i = i*4;

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Scalars

Scope $\subseteq$ Lifetime

x is not in scope

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- Lifetime of outer `x` is the time during which outermost block is active (includes the lifetime of inner `x`)

static variables

- static variables are associated with a class as a whole
- Do not require instantiation of objects

static functions

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- The `static` variable `howManyAs` counts the number of instances of `A` created
- Lifetime of `howManyAs` spans the execution of the entire program
- Scope of `howManyAs` is limited to the class `A`

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- Activation record — collection of all data related to a function invocation
- Includes space for local variables, parameters, intermediate results, and some pointers

return val

Call graph

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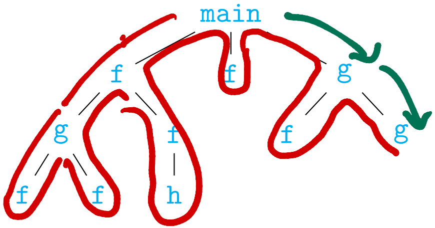

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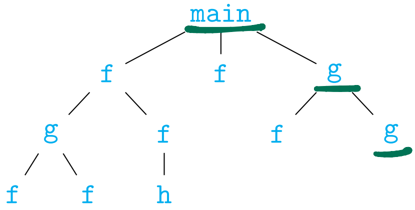

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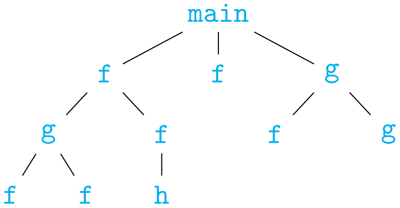

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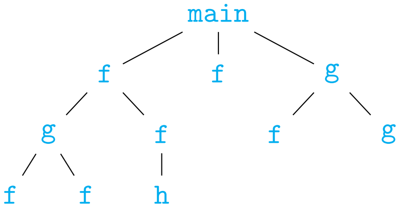

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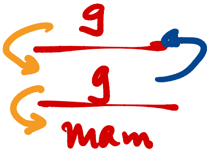

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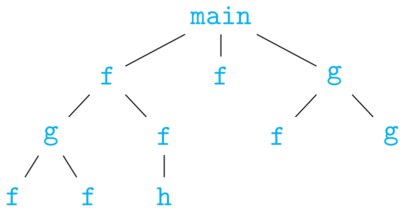

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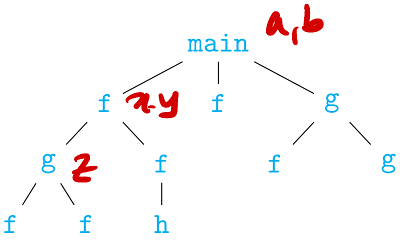
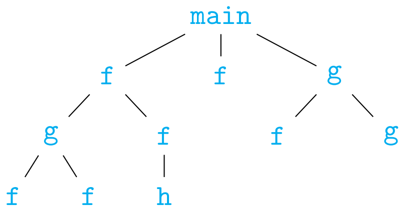
- Activation record is also called a stack frame

Activation records on stack



- Assume that `main` has local variables `a` and `b`, `f` has `x` and `y`, and `g` has `z`

Activation records on stack



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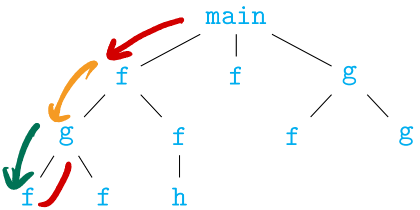

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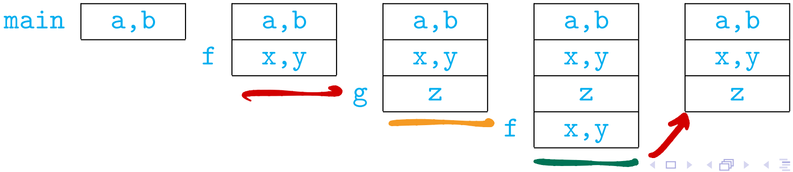
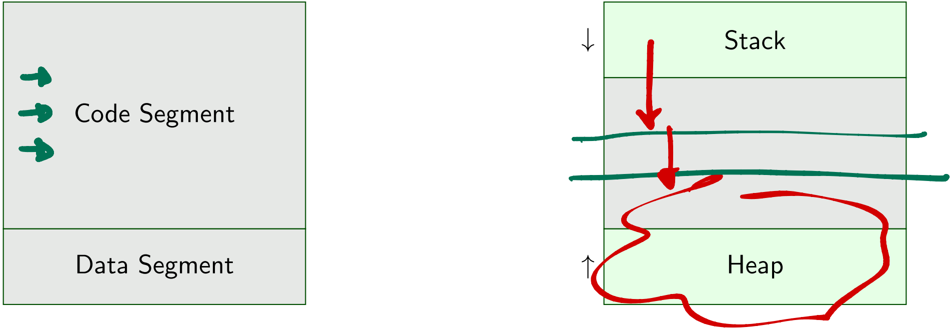
- The stack evolves as follows:



General layout of a program in memory



"Stack overruns heap" - -

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- Various pointers — Control link, access link, return address

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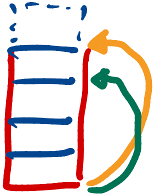
- Stores parameters, local variables, temporary variables used in running the function
- Various pointers — Control link, access link, return address
- System-wide pointers
  - Program counter — address of the next instruction to execute
  - Stack pointer — points to the top of the system stack
  - Frame pointer — points to the start of the topmost frame on stack
  - Data in topmost frame accessed via offsets from the frame pointer or stack pointer — offsets can computed at compile time



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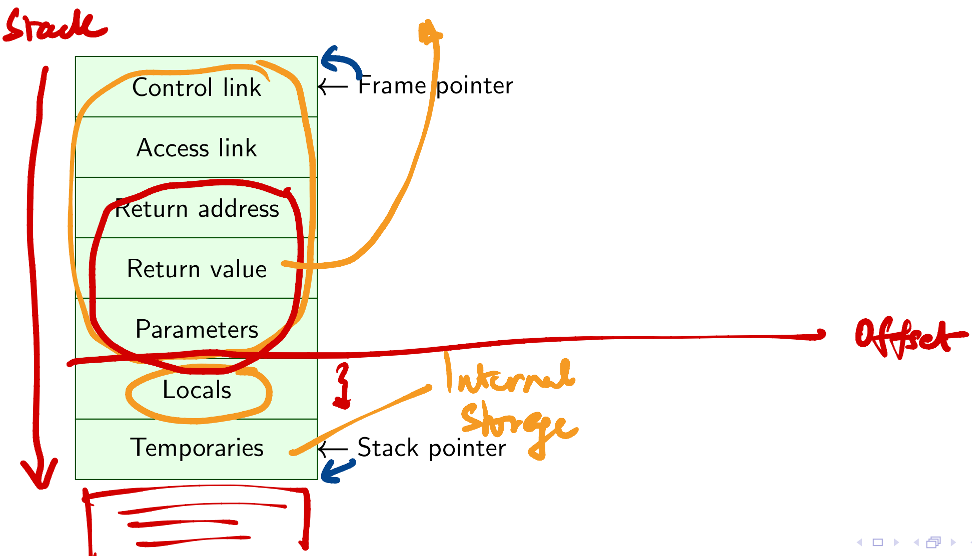

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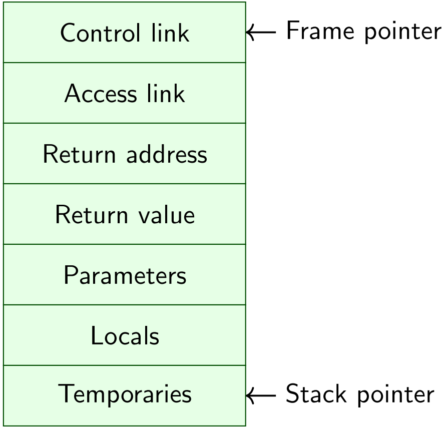

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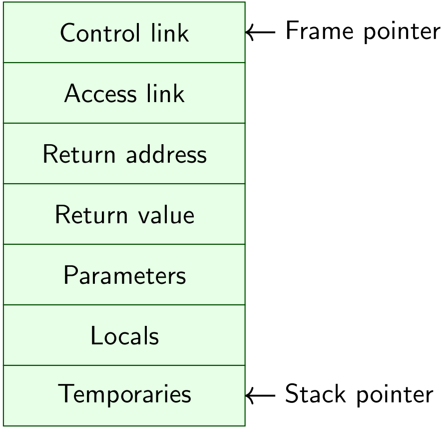

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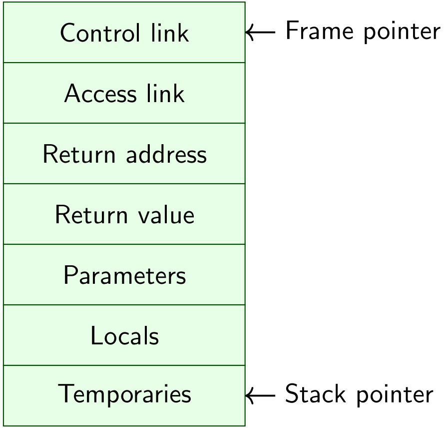

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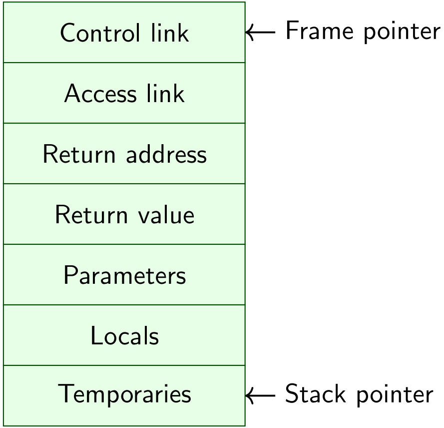

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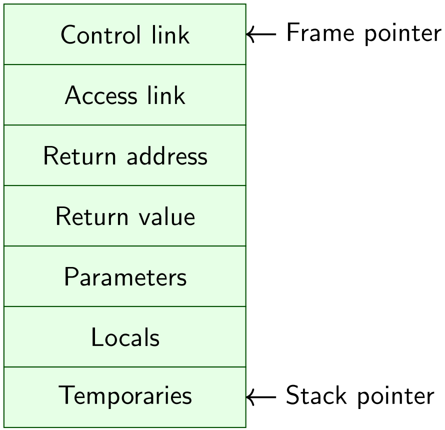

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- Temporaries are locations to store intermediate values

Access links

```
func f {
    int x = 0;
    int fib(int n) {
        if n <= 1 then return n;
        else {
            x += 1;
            return fib(n-1) + fib(n-2);
        }
    }
    print(fib(4));
}
```

- Count the number of additions in `fib(4)`

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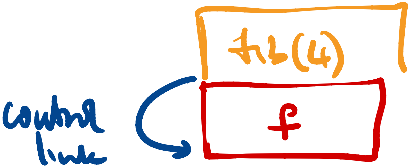

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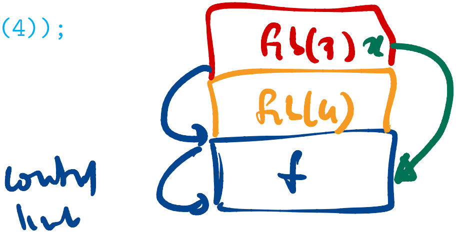

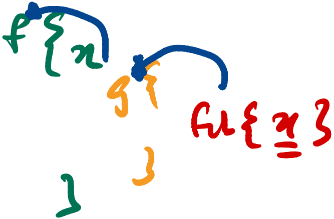

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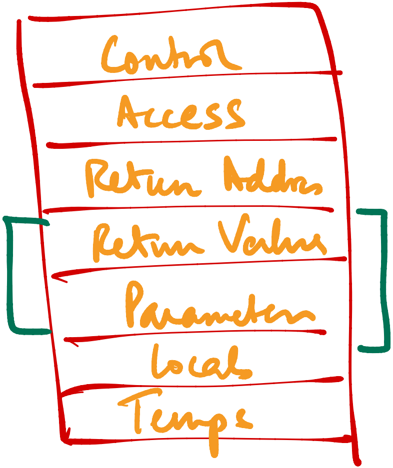
- But `fib(3)` is called by `fib(4)`, so control link cannot be used to access `x`
- Need a new kind of link — access link pointing to "outer" activation record



Call by value

Call by reference

m=7

fact(m)

n=m

```
fact(n) {

    n=n-1

}
```

Dynamic allocation

```
class A {
    int x, y, z;
    A(x,y,z) {
        this.x = x; ...
    }
    public int f(int n) {
        int arr[n]; ...
    }
}
main {
    A aObj(2,5,7);
    aObj.f(100); ...
}
```

Constr

fn

new array

- Functions can handle complex data types – arrays / classes, . . .

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- `aObj` itself has pointers to the class definition
- The AR for `f` has a pointer to an array stored on heap

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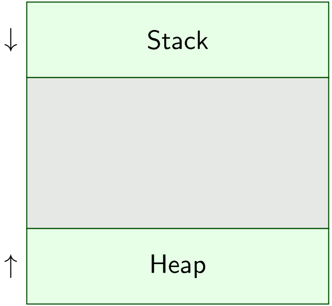

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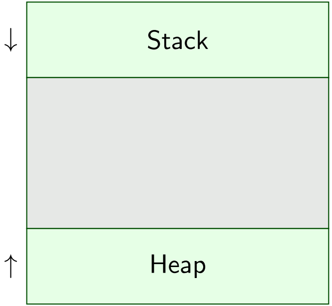
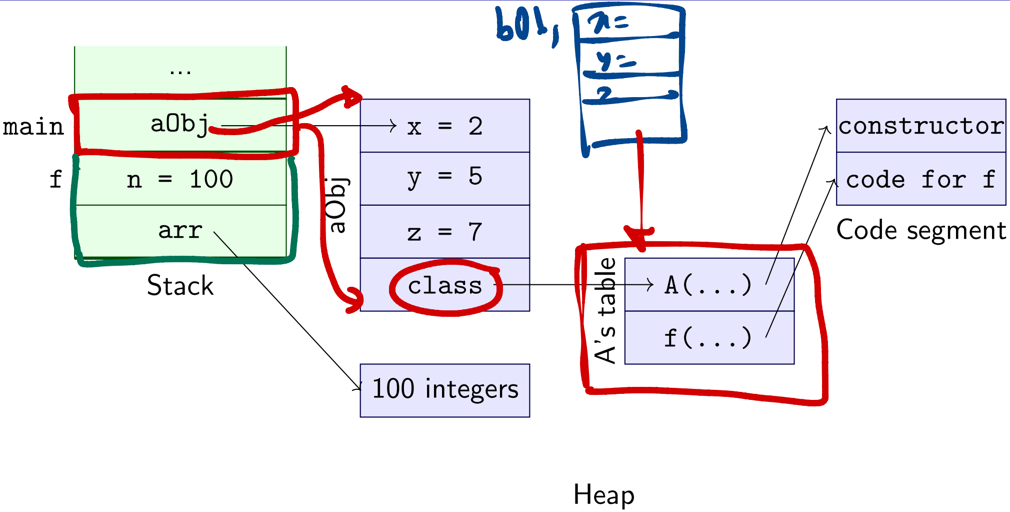
- Consist of chunks of allocated and unallocated memory



Stack and heap

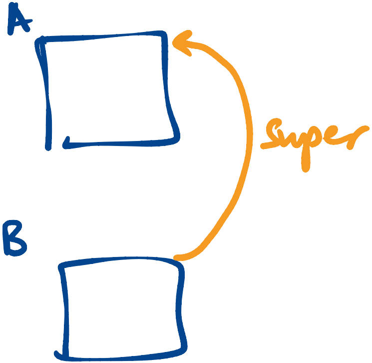


Overriding, inheritance etc.

- Table for each class has a pointer to table for superclass

class A

class B extends A



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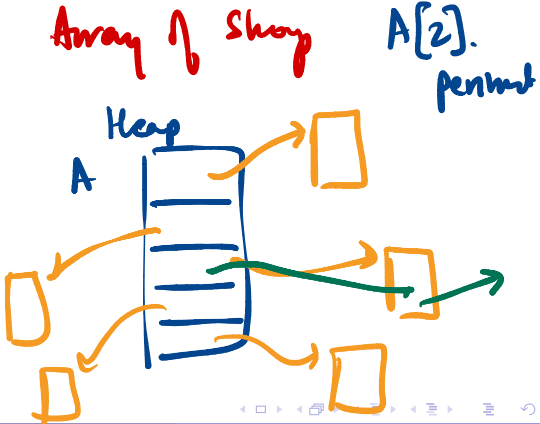
- Runtime polymorphism has a simple implementation



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- Consider an array of `Shape`, each element being an instance of a subclass
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- Calling `perimeter` on each element of the array runs the code pointed to by the appropriate subclass table

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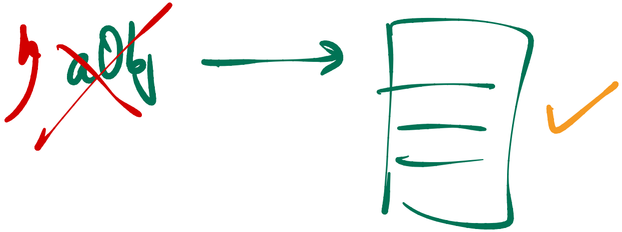

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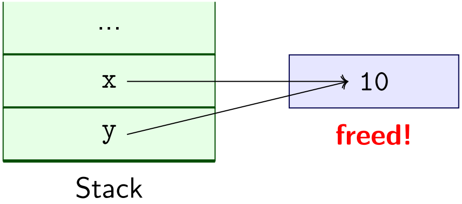
- Can cause the problem of dangling pointers – pointers to deallocated variables

```
int *x = malloc(sizeof(int));
*x = 10;
y = x;
free(x);
```



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```
int *x = malloc(sizeof(int));
*x = 10;
x = NULL;
```