# Lecture 6, 27 January 2026
# Storage allocation

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Programming Language Concepts
January–April 2026

# Scope

- Consider the following program block

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

   {
      int y = 3;
      x = x+2; y = x+y;
      print(x,y);
   }

   x = x+2; y = x+y;
   print(x,y);
}
```

Scope is lexical

dynamic

```
Outer y is hidden.
Updated y value is not propagated outside
4, 7

Outer y value and updated x value
6, 10
```

# Scope and Lifetime

- Scope – Region of text in which a declaration is visible
- Lifetime – Duration, at run-time, that a memory location is allocated for a specific declaration
- Consider the example below

```
{ int x = ...;
  { int y = ...;
    { int x = ...;
        ...
    }
  }
}
```

- Scope of outer x is the two outer blocks
- Scope of the inner x is the innermost block
- Lifetime of inner x is the time during which innermost block is active
- 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

- 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`

# static variables

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

```
public class A {
    static int howManyAs = 0;
    int id;
    public A(int id) {
        howManyAs += 1;
        this.id = id;
    }
}
```

per object

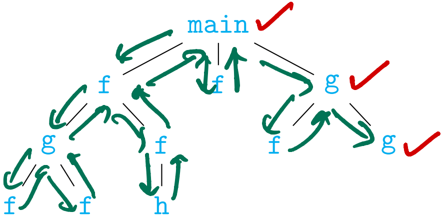
- The static variable howManyAs counts the number of instances of A created
- Lifetime of howManyAs spans the execution of the entire program
- Scope of howManyAs is limited to the class A

# Activation Record

- For local variables and function parameters, we need to store one copy for each function invocation (or activation)
- Activation record — collection of all data related to a function invocation
- Includes space for local variables, parameters, intermediate results, and some pointers

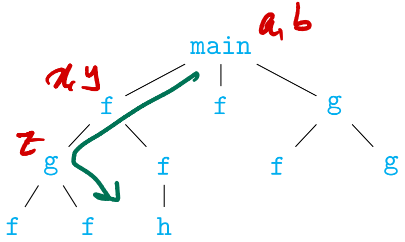
# Call graph

- A call graph helps us visualize the function calls during a program execution



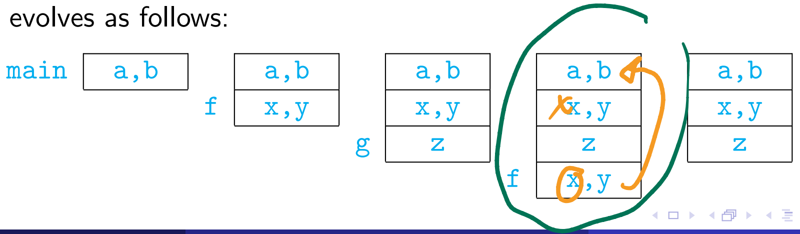

- The set of active function calls at any point of time lies on the path from the root to the right most leaf
- If f calls g, then g is completed before f
- Store the activation records on a stack
- Activation record is also called a stack frame

# Activation records on stack

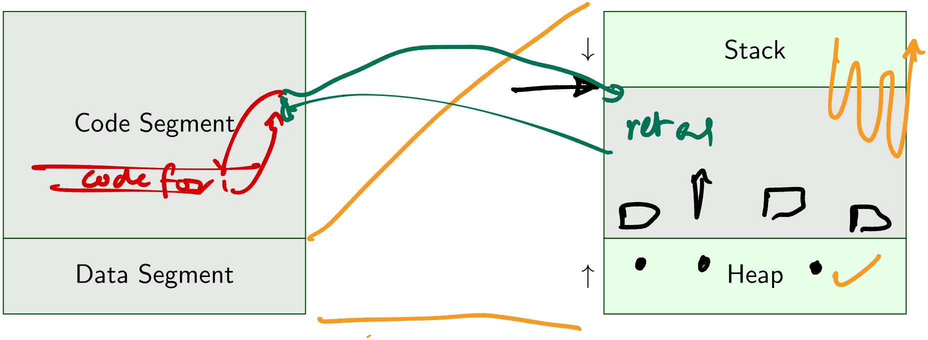



- Assume that `main` has local variables `a` and `b`, `f` has `x` and `y`, and `g` has `z`
- Place activation records on a stack — grows and shrinks as a program executes

- The stack evolves as follows:



# General layout of a program in memory



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

dynamic static

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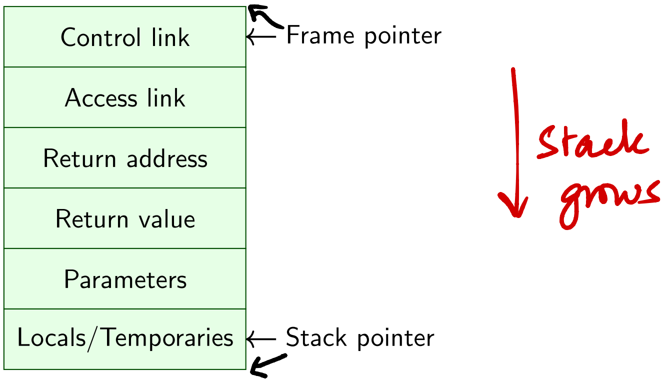
- Stores parameters, local variables, temporary variables used in running the function
- Various pointers — Control link, access link, return address
- System-wide pointers
  - Program counter — address of the next instruction to execute
  - Stack pointer — points to the top of the system stack
  - Frame 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

```
int[] a;
  :
  :
a = new int [~~100~~ n];
```

# Activation record . . .



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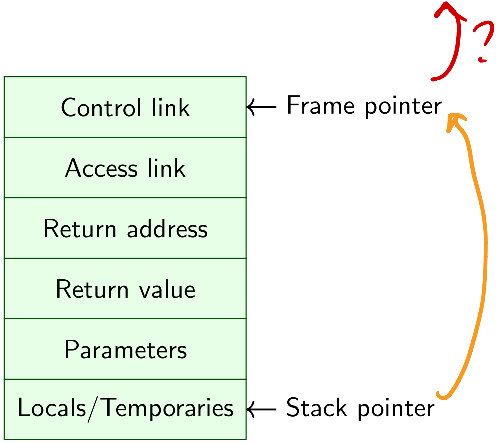


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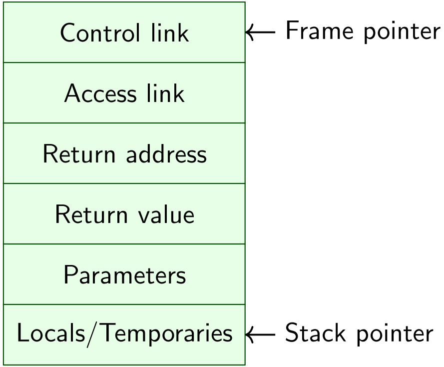


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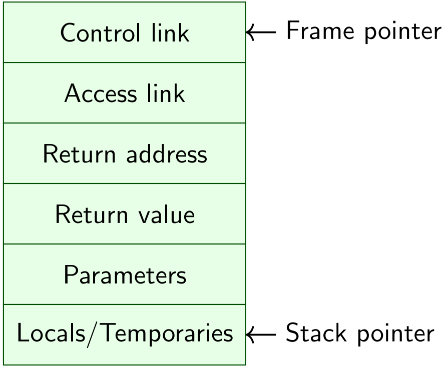


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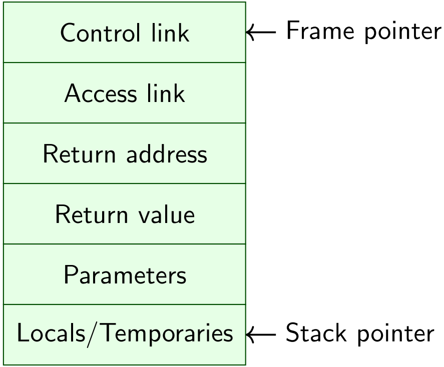


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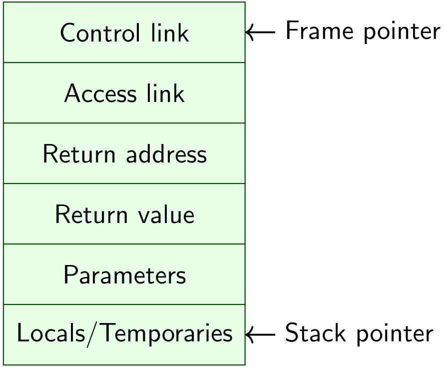


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- Temporaries are locations to store intermediate values

# 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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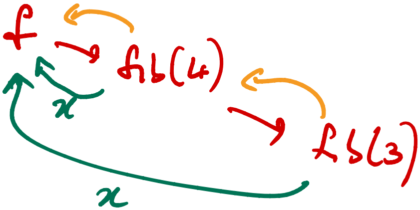

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- Need a new kind of link — access link pointing to “outer” activation record

# 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); ...
}
```

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

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instance var

constr.

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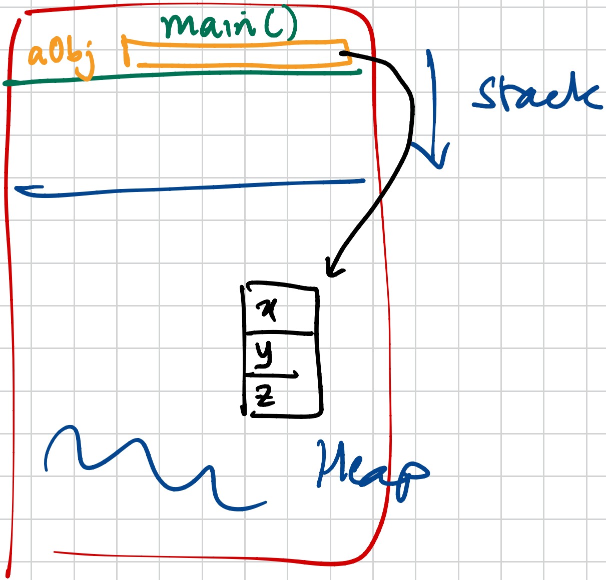
- `aObj` itself has pointers to the class definition
- The AR for `f` has a pointer to an array stored on heap


main()
aObj
Stack
x
y
z
Heap

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    - Unstructured
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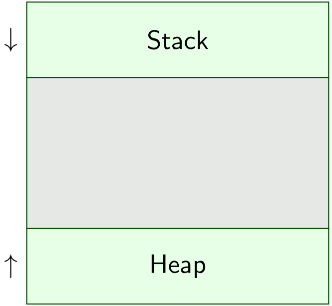
"Stack overruns heap"



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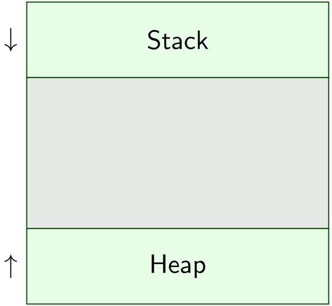
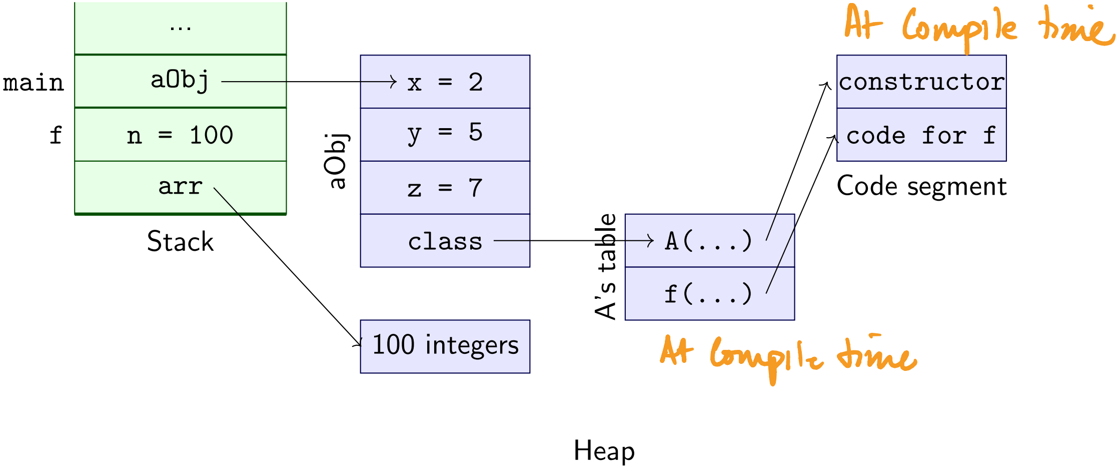
- Consist of chunks of allocated and unallocated memory

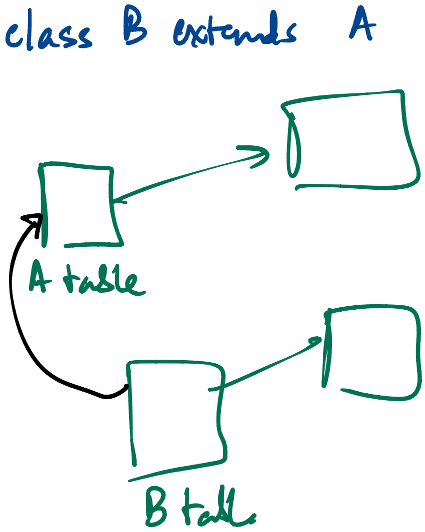


# Stack and heap



# Overriding, inheritance etc.

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



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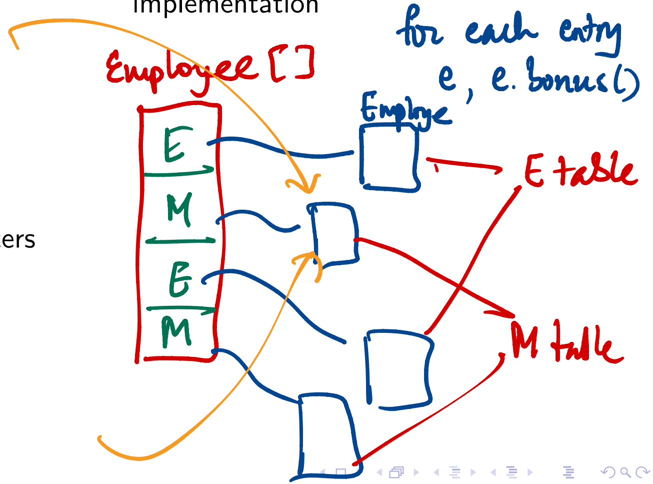

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- Runtime polymorphism has a simple implementation
- Consider an array of `Shape`, each element being an instance of a subclass
- Elements of the array are pointers to objects
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- Calling `perimeter` on each element of the array runs the code pointed to by the appropriate subclass table

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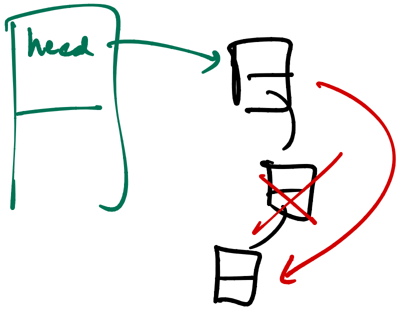

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- Allocated data might no longer have a reference from the stack (direct or indirect)
- This is called garbage – waste of memory

# Explicit memory management

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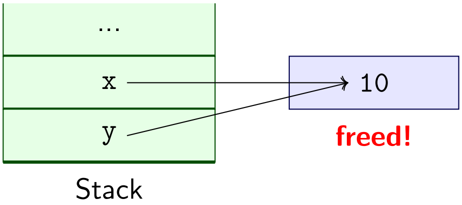
- Older languages expect programmer to manage memory
- malloc / free in C, new / delete in C++
- free / delete tells the system to take back ownership of memory locations from the program – deallocation
- Can cause the problem of dangling pointers – pointers to deallocated variables

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

← 2 pointers, same location

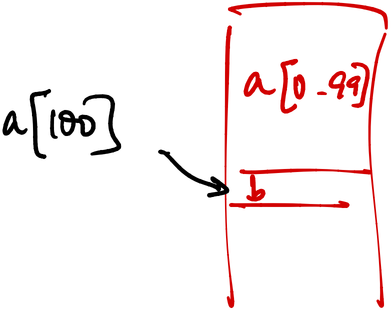


# Garbage

- Dangling pointers are a serious problem!
- Accessing a deallocated location could give arbitrary results
- Huge security risk!
- Garbage is not so serious, but wastes resources!
- Can happen even with explicit deallocation

int a[100]
int b

ALIASING



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int *x = malloc(sizeof(int));
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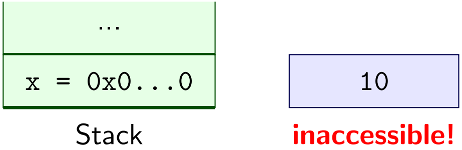

# Java / Python → Garbage Collection

Stop execution

Follow all variables from stack &
mark all heap in use

Mark everything else as unused