Object Oriented Programming

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With thanks to Dr Robert Harle who designed this course and wrote the material.

Object Oriented Programming tries to help with scale

- Writing programs gets harder as the program gets bigger
- Today's programs are massive
- Object Oriented Programming is a style of programming
- The intention is to make it easier for your programming to scale

This course mixes concepts and practical skills

- Understand general concepts and examples in Java or C++
- Acquire practical skills of your own in Java

Pre-recorded videos for the lecture content

One concept per video

I've suggested a schedule to watch them but you can do what suits you

Objectives

- these are things you should be able to do by the end of the video
- e.g. "Give an example that demonstrates that fields are static polymorphic"

Quiz questions

- self-check that you didn't fall asleep!
- don't worry about submitting your answers at the end (if that pops up)

Suggested supervision work

- Three supervisions recommended for this course
- Suggested work on the course website
- Your supervisor might choose to vary this

Practical exercises

- You can only learn practical skills by practising them
- Practical exercises included in the supervision work
- Automated tests are provided using 'chime'

Use the discussion forum on Moodle

- Do not post your code or give answers
- If you need to include your code then please include a link to chime instead
- Answer your own question if you resolve it!
- Do not email me directly
  - I get a lot of email
  - Let others learn from your question

Assessment is through exam and take-home test

Two questions (choose one) on Paper 1

- Only material in the videos is examinable
- You are expected to master it and be able to apply it to new circumstances
- Links to additional material in the videos are not examinable

Take-home programming test

- 27 April 2021, 9:00am – 29 April 2021, 9:00am
- Examples are available on the course website
- No automated tests are provided - convince yourself you are right!

Books

OOP Concepts

- Java: How to Program by Deitel & Deitel
- Thinking in Java by Eckels
- Java in a Nutshell (O' Reilly) if you already know another OOP language
- Java specification book: http://java.sun.com/docs/books/jls/
- Design Patterns by Gamma *et al*.

My favourites

- Effective Java by Joshua Bloch
- Java Puzzlers by Joshua Bloch (this one is just for fun)

Resources

Course web page

- Slides
- Links to practical work
- Code from the videos
- Sample tripos questions
- Suggested supervision work

http://www.cl.cam.ac.uk/teaching/current/OOProg/

Resources

Moodle site “Computer Science Paper 1 (1A)”

- Watch for course announcements
- Videos
- Quick quizzes

Tasks with Chime

Objectives:

- Complete the whole process of solving a practical exercise on Chime
- Interpret a test coverage score

Practical work is on chime.cl.cam.ac.uk

- Selection of exercises roughly mapped to lectures
- I want to write more so let me know where you see holes
- Attempt to get a bit closer to what you would do in industry
  - Git version control system
  - Automated testing

Objectives

- To understand the workflow and tools to complete a practical exercise

We'd like to use your code for research

- Research into teaching and learning is important!
- We want your consent to use your code and share it with others
  - We will 'anonymise' it
- Consent is optional and it has no impact on your grades or teaching if you do not

Demo: Log into chime and opt-in/opt-out

We use git over SSH for version control

- Same setup as github and gitlab.developers.cam.ac.uk
- Generate an SSH key
- Put the **public** part of the key on chime

Demo: creating an SSH key and adding it to chime

Practical exercises are linked online

- Go to the course webpages to find links to the practical exercises
- Follow the link and start the task

Demo: starting a task

Software licensing and copyright

- Complicated area…
- The default is that if you write software you own the copyright and other people can't copy it
- We add licenses to make it clear what people can and can't do
- The initial code for the tasks is Apache 2 Licensed
- The system assumes your changes will be licensed the same...but they don't have to be
- Apache 2 License lets you do almost anything
  - Except remove or change the license

Demo: licenses on your code

Using an IDE is recommended!

- I’ll use IntelliJ here but you can use whatever you like
- You only need the (free) ‘community edition’
- IntelliJ has built-in support for git but you can use the command line or other tools if you prefer
  - Sourcetree on Mac is really nice

Demo: cloning your task into a new project

Maven is a build system for Java

- In the pre-arrival course you built your code manually
- This doesn’t scale well
- Use a build system!
- There are many build systems for Java
  - All of them have strengths and weaknesses
  - We will use Maven in this course

Demo: Maven pom file and build

Be careful about what you check in

- Imagine you are working in a team on a shared code base
- Other engineers don’t want your IDE settings
- Or your temp files
- Or your class files
- Or personal information!!!
- We use .gitignore to tell git to ignore some files

Side-effects and void

Objectives:

- Write a method with a side-effect
- Write a method which does not return a value

Types of Languages

- Declarative - specify what to do, not how to do it. i.e.
  - E.g. HTML describes what should appear on a web page, and not how it should be drawn to the screen
  - E.g. SQL statements such as “select * from table” tell a program to get information from a database, but not how to do so
- Imperative – specify both what and how
  - E.g. “triple x“ might be a declarative instruction that you want the variable x tripled in value. Imperatively we would have “x=x*3” or “x=x+x+x”

Top 20 Languages 2016

Oct 2016	Oct 2015	Change	Programming Language	Ratings	Change
1	1		Java	18.799%	-0.74%
2	2		C	9.835%	-6.35%
3	3		C++	5.797%	+0.05%
4	4		C#	4.367%	-0.46%
5	5		Python	3.775%	-0.74%
6	8	↑	JavaScript	2.751%	+0.46%
7	6	↓	PHP	2.741%	+0.18%
8	7	↓	Visual Basic .NET	2.660%	+0.20%
9	9		Perl	2.495%	+0.25%
10	14	⇈	Objective-C	2.263%	+0.84%
11	12	↑	Assembly language	2.232%	+0.66%
12	15	↑	Swift	2.004%	+0.73%
13	10	↓	Ruby	2.001%	+0.18%
14	13	↓	Visual Basic	1.987%	+0.47%
15	11	⇊	Delphi/Object Pascal	1.875%	+0.24%
16	65	⇈	Go	1.809%	+1.67%
17	32	⇈	Groovy	1.769%	+1.19%
18	20	↑	R	1.741%	+0.75%
19	17	↓	MATLAB	1.619%	+0.46%
20	18	↓	PL/SQL	1.531%	+0.46%

Top 20 Languages 2016 (Cont)

Position	Programming Language	Ratings
21	SAS	1.443%
22	ABAP	1.257%
23	Scratch	1.132%
24	COBOL	1.127%
25	Dart	1.099%
26	D	1.047%
27	Lua	0.827%
28	Fortran	0.742%
29	Lisp	0.742%
30	Transact-SQL	0.721%
31	Ada	0.652%
32	F#	0.633%
33	Scala	0.611%
34	Haskell	0.522%
35	Logo	0.500%
36	Prolog	0.495%
37	LabVIEW	0.455%
38	Scheme	0.444%
39	Apex	0.349%
40	Q	0.303%

Top 20 Languages 2016 (Cont Cont)

41	Erlang	0.300%
42	Rust	0.296%
43	Bash	0.286%
44	RPG (OS/400)	0.273%
45	Ladder Logic	0.266%
46	VHDL	0.220%
47	Alice	0.205%
48	Awk	0.203%
49	CL (OS/400)	0.170%
50	Clojure	0.169%

Top 20 Languages 2016 (Cont Cont Cont)

The Next 50 Programming Languages

The following list of languages denotes #51 to #100. Since the differences are relatively small, the programming languages are only listed (in alphabetical order).

- (Visual) FoxPro, 4th Dimension/4D, ABC, ActionScript, APL, AutoLISP, bc, BlitzMax, Bourne shell, C shell, CFML, cg, Common Lisp, Crystal, Eiffel, Elixir, Elm, Forth, Hack, Icon, IDL, Inform, Io, J, Julia, Korn shell, Kotlin, Maple, ML, MQL4, MS-DOS batch, NATURAL, NXT-G, OCaml, OpenCL, Oz, Pascal, PL/I, PowerShell, REXX, S, Simulink, Smalltalk, SPARK, SPSS, Standard ML, Stata, Tcl, VBScript, Verilog

ML as a Functional Language

- **Functional** languages are a subset of declarative languages
  - ML is a functional language
  - It may appear that you tell it how to do everything, but you should think of it as providing an explicit example of what should happen
  - The compiler may optimise i.e. replace your implementation with something entirely different but 100% equivalent.

```
let rec factorial n =
  match n with
    | 0 -> 1
    | 1 -> 1
    | n -> n * (factorial (n – 1));
```

Function Side Effects

- Functions in imperative languages can use or alter larger system state → *procedures*

Maths: m(x,y) = xy

ML: fun m(x,y) = x*y;

Java:

```
int y = 7;
int m(int x) {
        y=y+1;
        return x*y;
}
```

Side effect

void Procedures

- A void procedure returns nothing:

```
int count=0;

void addToCount() {
  count=count+1;
}
```

count+=1   count++   ++count

Void is not quite the same as unit in ML

Control flow

Objectives:

- Use if, for, while, do-while, recursion, case, break and labels in your own programs

Control Flow: Looping

for(*initialisation; termination; increment* **)**

```
for (int i=0; i<8; i++) ...

int j=0;  for(; j<8; j++) ...

for(int k=7;k>=0; j--) ...
```

Demo: printing the numbers from 1 to 10

while(*boolean_expression* **)**

```
int i=0;  while (i<8) { i++; ...}

int j=7; while (j>=0) { j--; ...}
```

Control Flow: Branching I

- Branching statements interrupt the current control flow
- **return**
  - Used to return from a function at any point

```
boolean linearSearch(int[] xs, int v) {
   for (int i=0;i<xs.length; i++) {
      if (xs[i]==v) return true;
   }
   return false;
}
```

Control Flow: Branching II

- Branching statements interrupt the current control flow
- **break**
  - Used to jump out of a loop

```
boolean linearSearch(int[] xs, int v) {
    boolean found=false;
    for (int i=0;i<xs.length; i++) {
        if (xs[i]==v) {
                found=true;
                break;   // stop looping
        }
    }
    return found;
}
```

Control Flow: Branching III

- Branching statements interrupt the current control flow
- **continue**
  - Used to skip the current iteration in a loop

```
void printPositives(int[] xs) {

   for (int i=0;i<xs.length; i++) {
      if (xs[i]<0) continue;
      System.out.println(xs[i]);
   }
}
```

Immutable values, returning and printing

Objectives:

- Write a function that returns a result
- Write a function that prints a result
- Store the result of an assignment expression
- Identify statements and expressions in Java

Immutable to Mutable Data

ML

```
- val x=5;
> val x = 5 : int
- x=7;
> val it = false : bool
- val x=9;
> val x = 9 : int
```

ML is a language of expressions

Java is a language of statements and expressions

Java

Evaluates to the value 7 with type int

```
int x=5;
x=7;

int x=9;
for(int i=0;i<10;i++) {
  System.out.println(i);
}
```

Does not evaluate to a value and has no type

Demo: returning vs printing

Primitive types

Objectives:

- List the primitive types and the range of data they store
- Identify when a cast is a widening or a narrowing transformation
- Give an example of how data can be lost through a narrowing transformation

Types and Variables

- Java and C++ have limited forms of type inference

```
var x = 512;
int y = 200;
int z = x+y;
```

- The high-level language has a series of *primitive* (built-in) types that we use to signify what's in the memory
  - The compiler then knows what to do with them
  - E.g. An "int" is a primitive type in C, C++, Java and many languages. In Java it is a 32-bit signed integer.
- A variable is a name used in the code to refer to a specific instance of a type
  - x,y,z are variables above
  - They are all of type int

E.g. Primitive Types in Java

- “Primitive” types are the built in ones.
  - They are building blocks for more complicated types that we will be looking at soon.
- boolean – 1 bit (true, false)
- char – 16 bits
- byte – 8 bits as a signed integer (-128 to 127)
- short – 16 bits as a signed integer
- int – 32 bits as a signed integer
- long – 64 bits as a signed integer
- float – 32 bits as a floating point number
- double – 64 bits as a floating point number

Widening
Vs
Narrowing

Demo: int → byte overflow

Overloading and protoypes

Objectives:

- State the rules in Java for overloading
- Recognise the terms: prototype and signature

Overloading Functions

- Same function name
- Different arguments
- Possibly different return type

```
int myfun(int a, int b) {…}
float myfun(float a, float b) {…}
double myfun(double a, double b) {…}
```

- But not just a different return type

```
int myfun(int a, int b) {…}
float myfun(int a, int b) {…}
```

X

Function Prototypes

- Functions are made up of a prototype and a body
  - Prototype specifies the function name, arguments and possibly return type
  - Body is the actual function code

```
fun myfun(a,b) = …;

int myfun(int a, int b) {…}
```

Objects and Classes

Objectives:

- Write a class containing some state and behaviour
- Create a new instance of a class

Custom Types

```
type 'a seq =
   | Nil
   |  Cons of 'a * (unit -> 'a seq);
```

```
public class Vector3D {
   float x;
   float y;
   float z;
}
```

State and Behaviour

```
type 'a seq =
 | Nil
 |  Cons of 'a * (unit -> 'a seq);

fun hd (Cons(x,_)) = x;
```

State and Behaviour

```
type 'a seq =
  | Nil
  |  Cons of 'a * (unit -> 'a seq);

fun hd (Cons(x,_)) = x;



public class Vector3D {
  float x;
  float y;
  float z;

  void add(float vx, float vy, float vz) {
    x=x+vx;
    y=y+vy;
    z=z+vz;
  }
}
```

STATE

BEHAVIOUR

Loose Terminology (again!)

State

Fields

Instance Variables

Properties

Variables

Members

Behaviour

Functions

Methods

Procedures

Classes, Instances and Objects

- Classes can be seen as templates for representing various ***concepts***
- We create ***instances*** of classes in a similar way. e.g.

```
MyCoolClass m = new  MyCoolClass();
MyCoolClass n = new  MyCoolClass();
```

  makes two instances of class MyCoolClass.
- An instance of a class is called an **object**

Defining a Class

```
public class Vector3D {
  float x;
  float y;
  float z;

  void add(float vx, float vy, float vz) {
    x=x+vx;
    y=y+vy;
    z=z+vz;
  }
}
```

Constructors

Objectives:

- Write a class with overloaded constructors
- Explain how a default constructor initialises fields

Constructors

```
MyObject m = new MyObject();
```

- You will have noticed that the RHS looks rather like a function call, and that's exactly what it is.

- It's a method that gets called when the object is constructed, and it goes by the name of a **constructor** (it's not rocket science). It maps to the datatype constructors you saw in ML.

- We use constructors to initialise the state of the class in a convenient way
  - A constructor has the same name as the class
  - A constructor has no return type

Constructors with Arguments

```
public class Vector3D {
  float x;
  float y;
  float z;

  Vector3D(float xi, float yi, float zi) {
    x=xi;
    y=yi;
    z=zi;
  }

  // ...
}
```

You can use 'this' to disambiguate names if needed: e.g. this.x = xi;

```
Vector3D v = new Vector3D(1.f,0.f,2.f);
```

Overloaded Constructors

```
public class Vector3D {
  float x;
  float y;
  float z;

  Vector3D(float xi, float yi, float zi) {
    x=xi;
    y=yi;
    z=zi;
  }

   Vector3D() {
    x=0.f;
    y=0.f;
    z=0.f;
  }

  // ...
}
```

```
Vector3D v = new Vector3D(1.f,0.f,2.f);
Vector3D v2 = new Vector3D();
```

Default Constructor

```
public class Vector3D {
   float x;
   float y;
   float z;
}

Vector3D v = new Vector3D();
```

If you don’t initialise a field it gets set to the ‘zero’ value for that type (don’t do this)

If you provide any constructor then the default will not be generated

- No constructor provided
- So blank one generated with no arguments

Is Even?

Objectives:

- Choose a good name for a unit test
- Write a unit test with Arrange, Act, Assert structure
- Pause a program using a breakpoint in IntelliJ
- Use Step-Over and Step-Into controls to walk through a paused program

Static and instance

Objectives:

- Write a class which counts how many instances have been created of it
- Give an example of a good use of a static method
- Give an example of a good use of an instance method
- Give an example of a good use of a static field and an instance field

Class-Level Data and Functionality I

- A **static** field is created only once in the program's execution, despite being declared as part of a class

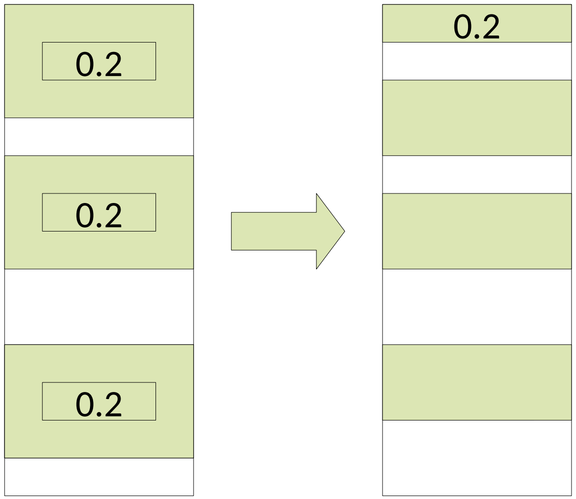
```
public class ShopItem {
  float mVATRate;
  static float sVATRate;
  ....
}
```

One of these created every time a new ShopItem is instantiated. Nothing keeps them all in sync.

Only one of these created ever. Every ShopItem object references it.

static => associated with the class
instance => associated with the object

Class-Level Data and Functionality II



instance field
(one per object)

static field
(one per class)

- Shared between instances
- Space efficient

static fields are good for constants. otherwise use with care.

- Also static methods:

```
public class Whatever {
  public static void main(String[] args) {
    ...
  }
}
```

Why use Static Methods?

- Easier to debug (only depends on static state)
- Self documenting
- Groups related methods in a Class without requiring an object

```
public class Math {
  public float sqrt(float x) {…}
  public double sin(float x) {…}
  public double cos(float x) {…}
}
```

vs

```
public class Math {
  public static float sqrt(float x) {…}
  public static float sin(float x) {…}
  public static float cos(float x) {…}
}
```

```
…
Math mathobject = new Math();
mathobject.sqrt(9.0);
…
```

```
…
Math.sqrt(9.0);
…
```

Identifying classes

Objectives:

- Identify potential classes and methods in a problem statement

What Not to Do

- Your ML has doubtless been one big file where you threw together all the functions and value declarations
- Lots of C programs look like this :-(
- We *could* emulate this in OOP by having one class and throwing everything into it
- We can do (much) better

Identifying Classes

- We want our class to be a grouping of conceptually-related state and behaviour
- One popular way to group is using grammar
  - Noun → Object
  - Verb → Method

"A quiz program that asks questions

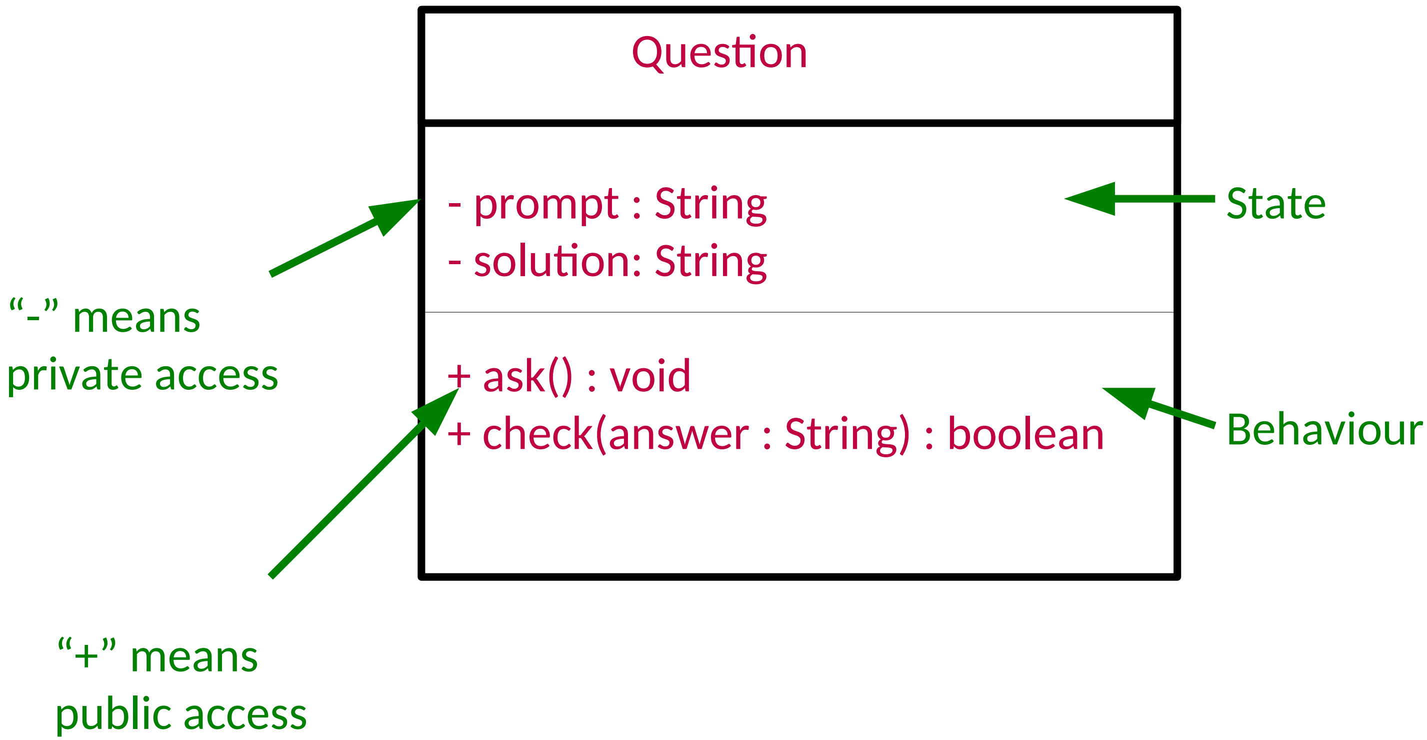
and checks the answers are correct"

UML

Objectives:

- Identify state and behaviour in a class in a UML class diagram
- Identify 'has-a' relationships between classes in a UML class diagram
- Explain a UML class diagram in words and vice-versa

UML: Representing a Class Graphically



The has-a Association

- Arrow going left to right says "a Quiz has zero or more questions"
- Arrow going right to left says "a Question has exactly 1 Quiz"
- What it means in real terms is that the Quiz class will contain a variable that somehow links to a set of Question objects, and a Question will have a variable that references a Quiz object.
- Note that we are only linking *classes*: we don't start drawing arrows to primitive types.

Demo: implement quiz

Implementing quiz

Objectives:

- Use simple classes with constructors, static and final fields to solve a problem

Encapsulation

Objectives:

- Define encapsulation
- Give an example of encapsulation in Java

Anatomy of an OOP Program (Java)

```java
public class MyFancyClass {

        public int someNumber;
        public String someText;

        public void someMethod() {

        }

        public static void main(String[] args) {
                MyFancyClass c = new
                        MyFancyClass();
        }

}
```

- Class name
- Access modifier
- Class state (properties that an object has such as colour or size)
- Class behaviour (actions an object can do)
- 'Magic' start point for the program (named main by convention)
- Create a reference to a MyFancyClass object and call it c
- Create an object of type MyFancyClass in memory

OOP Concepts

- OOP provides the programmer with a number of important concepts:
  - Modularity
  - Code Re-Use
  - Encapsulation
  - Inheritance (lecture 5)
  - Polymorphism (lecture 6)
- Let's look at these more closely...

Modularity and Code Re-Use

- You've long been taught to break down complex problems into more tractable sub-problems.
- Each class represents a sub-unit of code that (if written well) can be developed, tested and updated independently from the rest of the code.
- Indeed, two classes that achieve the same thing (but perhaps do it in different ways) can be swapped in the code
- Properly developed classes can be used in other programs without modification.

Encapsulation I

```
class Student {
   int age;
};

void main() {
   Student s = new Student();
   s.age = 21;

   Student s2 = new Student();
   s2.age=-1;

   Student s3 = new Student();
   s3.age=10055;
}
```

Encapsulation II

```
class Student {
  private int age;

  boolean setAge(int a) {
    if (a>=0 && a<130) {
          age=a;
          return true;
    }
    return false;
  }

  int getAge() {return age;}
}

void main() {
  Student s = new Student();
  s.setAge(21);
}
```

Encapsulation III

```
class Location {
  private float x;
  private float y;

  float getX() {return x;}
  float getY() {return y;}

  void setX(float nx) {x=nx;}
  void setY(float ny) {y=ny;}
}
```

```
class Location {

  private Vector2D v;

  float getX() {return v.getX();}
  float getY() {return v.getY();}

  void setX(float nx) {v.setX(nx);}
  void setY(float ny) {v.setY(ny);}
}
```

Encapsulation =

1) hiding internal state
2) bundling methods with state

Access modifiers

Objectives:

- Define the access modifiers: public, package, protected, private
- Give an example of how private refers to the class not the instance

Access Modifiers

	Everyone	Subclass	Same package (Java)	Same Class
private				X
package (Java)			X	X
protected		X	X	X
public	X	X	X	X

Surprising!

Immutability

Objectives:

- Explain why immutability is a useful property
- Build an immutable class using private fields and copying parameters when required
- Determine whether an object is immutable or not

Immutability

- Everything in ML was immutable (ignoring the reference stuff). Immutability has a number of advantages:
  - Easier to construct, test and use
  - Can be used in concurrent contexts
  - Allows lazy instantiation
- We can use our access modifiers to create immutable classes
- If you mark a variable or field as ‘final’ then it can’t be changed after initalisation

Demo: NotImmutable

Parameterised classes

Objectives:

- Contrast Java generics with ML parametric polymorphism
- Create instances of generic classes
- Implement your own generic class
- Demonstrate the impact of type-erasure on a generic class

Parameterised Classes

- ML's polymorphism allowed us to specify functions that could be applied to multiple types

```
> fun self(x)=x;
val self = fn : 'a -> 'a
```

Fun fact: identity is the only function in ML with type ‘a → ‘a

- In Java, we can achieve something similar through *Generics*; C++ through *templates*
  - Classes are defined with placeholders (see later lectures)
  - We fill them in when we create objects using them

```
LinkedList<Integer> = new LinkedList<Integer>()

LinkedList<Double> = new LinkedList<Double>()
```

Creating Parameterised Types

- These just require a placeholder type

```
class Vector3D<T> {
   private T x;
   private T y;

   T getX() {return x;}
   T getY() {return y;}

   void setX(T nx) {x=nx;}
   void setY(T ny) {y=ny;}
}
```

Generics use type-erasure

```
class Vector3D<T> {
  private T x;
  private T y;

  T getX() {return x;}
  T getY() {return y;}

  void setX(T nx) {x=nx;}
  void setY(T ny) {y=ny;}
}

Vector3D<Integer> v =
      new Vector3D<>();
Integer x = v.getX();
v.setX(4);
```

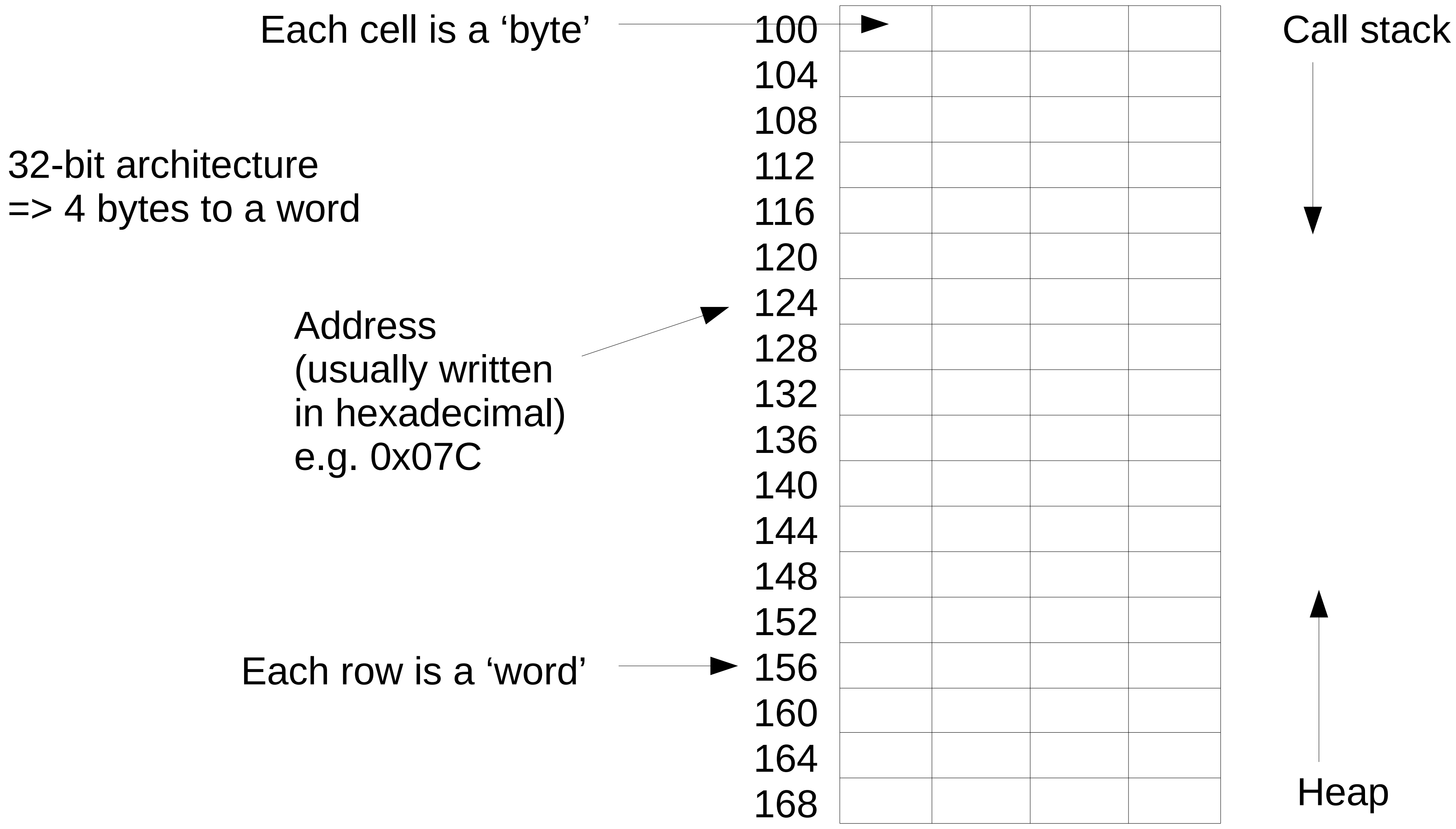
after type checking this compiles to ------>

```
class Vector3D {
  private Object x;
  private Object y;

  Object getX() {return x;}
  Object getY() {return y;}

  void setX(Object nx) {x=nx;}
  void setY(Object ny) {y=ny;}
}

Vector3D v = new Vector3D();
Integer x = (Integer)v.getX();
v.setX((Object)4);
```

The call stack and the heap

Objectives:

- Draw a memory diagram of stack allocation for chars, ints, longs and pointers
- Contrast the stack and the heap
- Demonstrate the evaluation of a recursive function on a memory diagram


Each cell is a 'byte'
32-bit architecture
=> 4 bytes to a word
Address
(usually written
in hexadecimal)
e.g. 0x07C
Each row is a 'word'
100
104
108
112
116
120
124
128
132
136
140
144
148
152
156
160
164
168
Call stack
Heap

```
    void f(int x) {
        char c = 'a';
        long l = 1234;
        int i = 10;
    }

>>  f(4);
```

100				
104				
108				
112				
116				
120				
124				
128				
132				
136				
140				
144				
148				
152				
156				
160				
164				
168				

3 This example is in C/C++

```
>> void f(int x) {
       char c = 'a';
       long l = 1234;
       int i = 10;
   }

   f(4);
```

100	4	0	0	0	x
104					c
108					l
112					
116					i
120					
124					
128					
132					
136					
140					
144					
148					
152					
156					
160					
164					
168					

```c
void f(int x) {
    char c = 'a';    // >>
    long l = 1234;
    int i = 10;
}

f(4);
```

100	4	0	0	0	x
104	97	.	.	.	c
108					l
112					
116					i
120					
124					
128					
132					
136					
140					
144					
148					
152					
156					
160					
164					
168					

```
   void f(int x) {
       char c = 'a';
>>     long l = 1234;
       int i = 10;
   }

   f(4);
```

1234 is bigger than one byte

1234 & 0xFF = 210
1234 >> 8 = 4

100	4	0	0	0	x
104	97	.	.	.	c
108	210	4	0	0	l
112	0	0	0	0	
116					i
120					
124					
128					
132					
136					
140					
144					
148					
152					
156					
160					
164					
168					

```
    void f(int x) {
        char c = 'a';
        long l = 1234;
>>      int i = 10;
    }

    f(4);
```

100	4	0	0	0	x
104	97	.	.	.	c
108	210	4	0	0	l
112	0	0	0	0	
116	10	0	0	0	i
120					
124					
128					
132					
136					
140					
144					
148					
152					
156					
160					
164					
168					

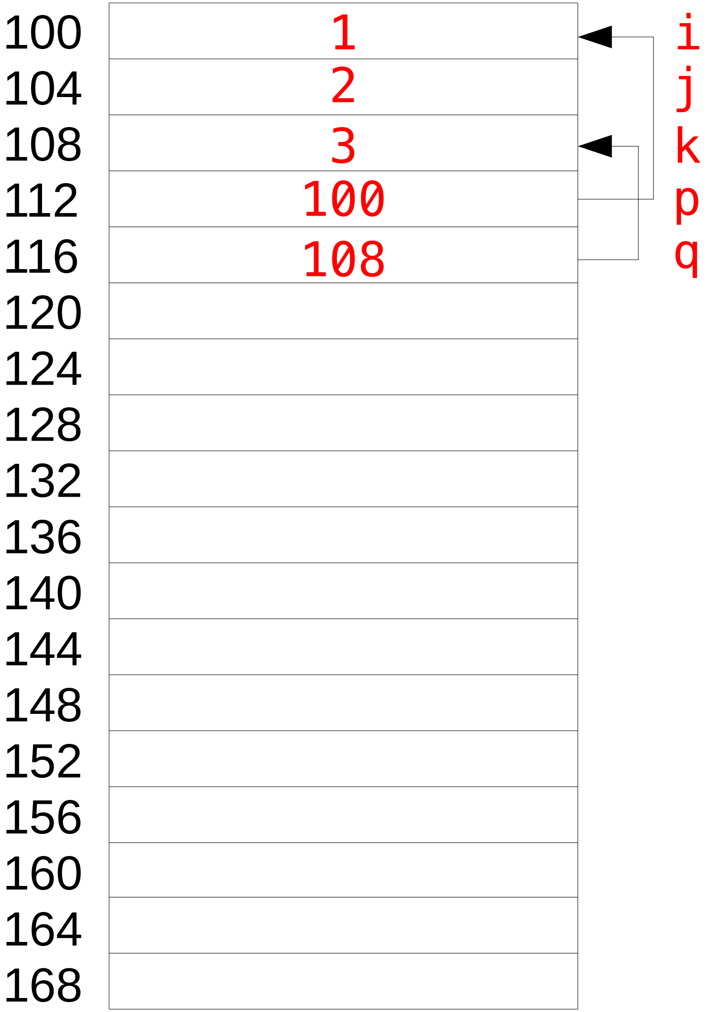
```c
void f(int x) {
    char c = 'a';
    long l = 1234;
>>  int i = 10;
}

f(4);
```

100	4	x
104	‘a’	c
108	1234	l
112		
116	10	i
120		
124		
128		
132		
136		
140		
144		
148		
152		
156		
160		
164		
168		

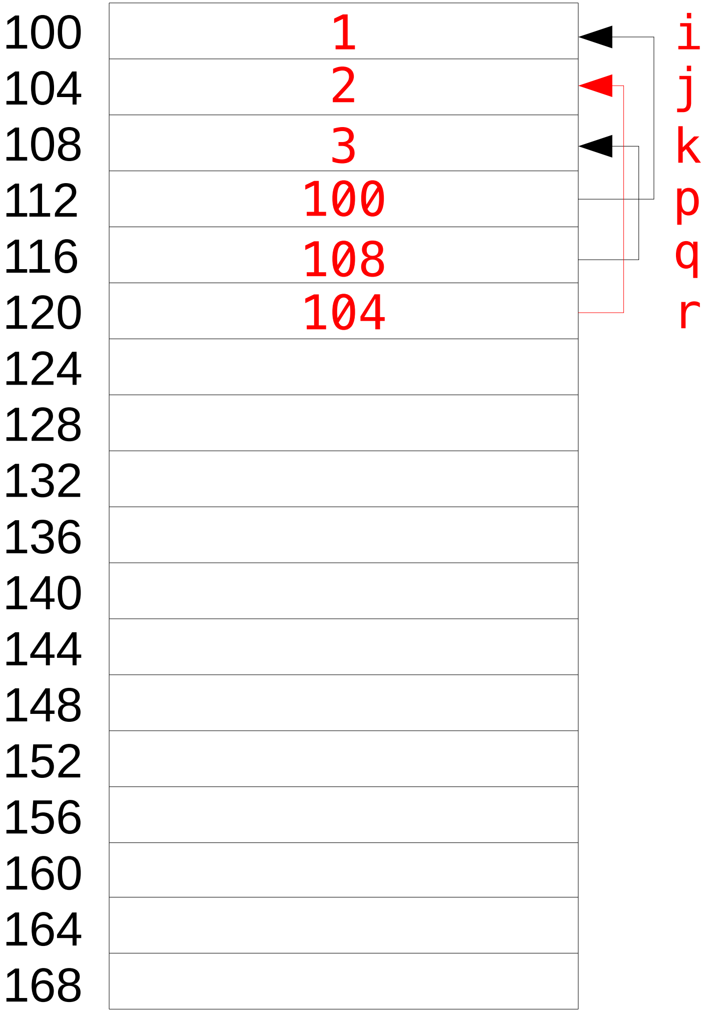
```c
void f() {
        int i = 1;
        int j = 2;
        int k = 3;
        int* p = &i;
        int* q = &k;
}
```

* on a LHS means
‘its a pointer’

& on a RHS means
‘take the address of’



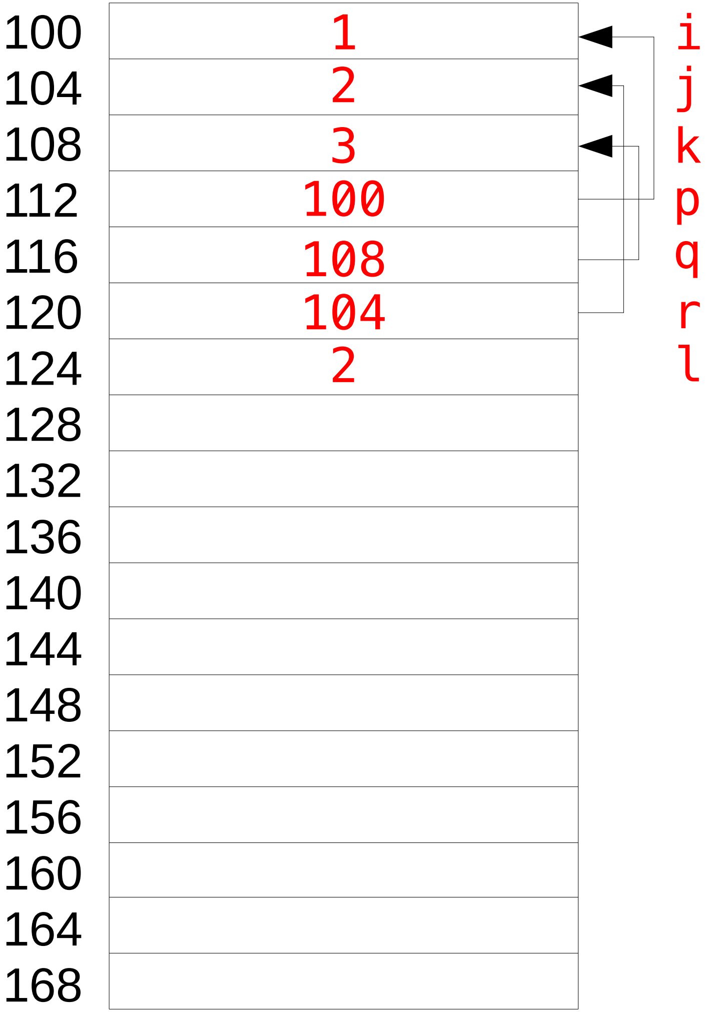
```c
void f() {
        int i = 1;
        int j = 2;
        int k = 3;
        int* p = &i;
        int* q = &k;
        int* r = p + 1;
}
```



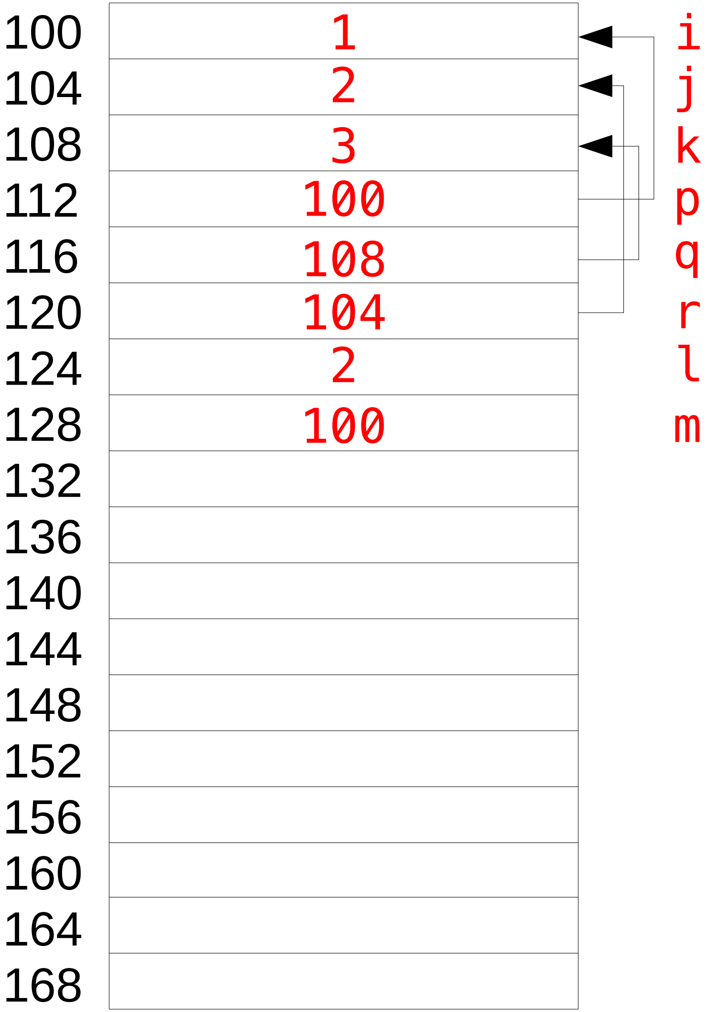
We can do arithmetic on pointers (based on the datatype size)

```
void f() {
    int i = 1;
    int j = 2;
    int k = 3;
    int* p = &i;
    int* q = &k;
    int* r = p + 1;
    int l = *r;
}
```

* on the RHS means ‘dereference’ i.e. follow the pointer.



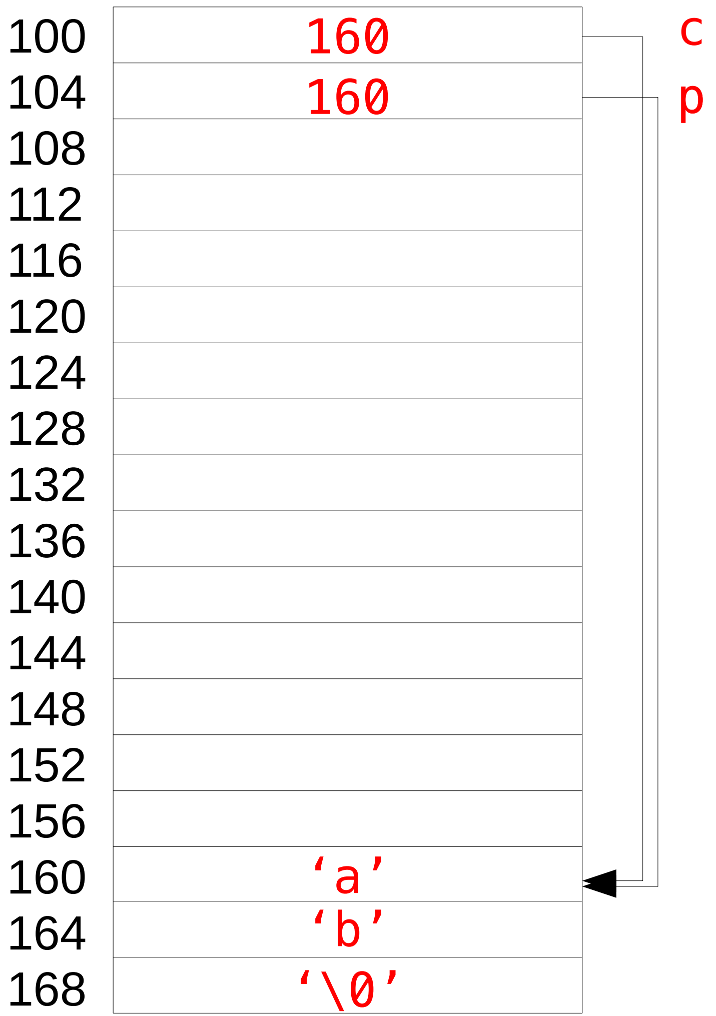
```
void f() {
        int i = 1;
        int j = 2;
        int k = 3;
        int* p = &i;
        int* q = &k;
        int* r = p + 1;
        int l = *r;
        int m = *(q + 1);
}
```



Nothing will stop you
making mistakes!

```
int len() {
    char[] c = new[]
        {'a','b','\0'};
    char* p = c;
}
```

In C++ you can choose whether you want to allocate on the stack or the heap

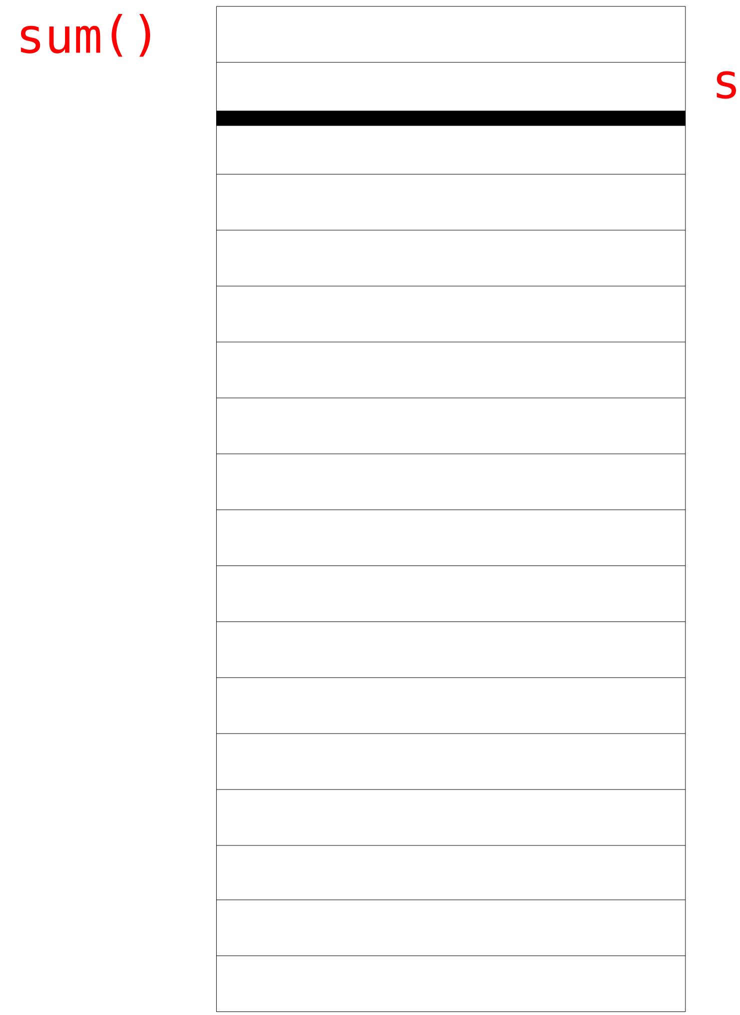


Items on the stack exist only for the duration of your function call

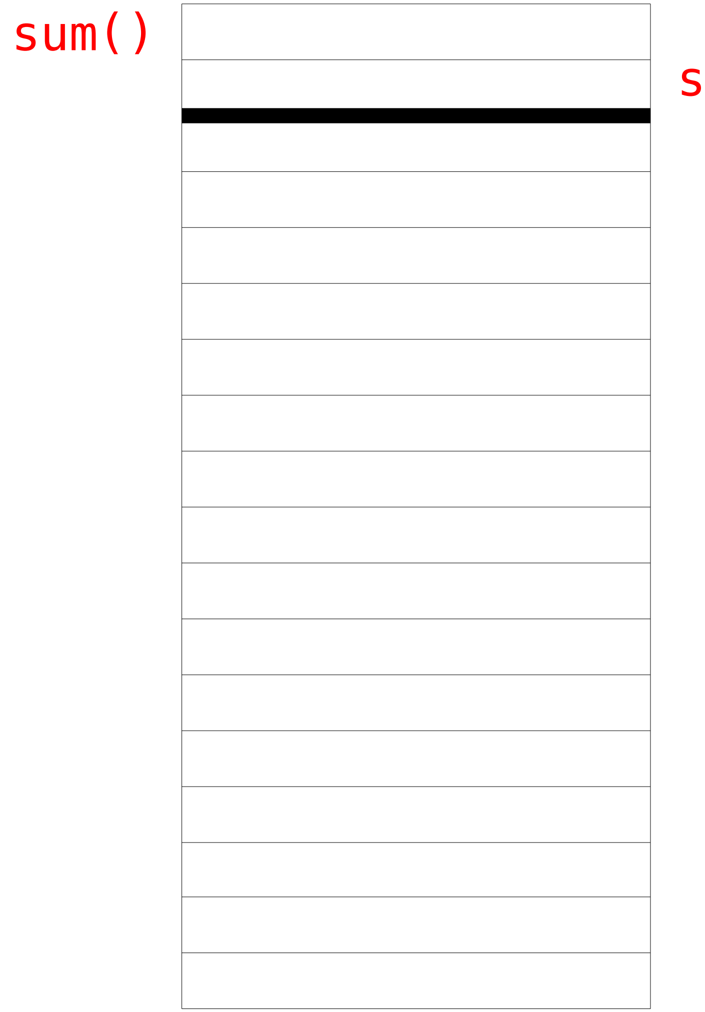
Items on the heap exist until they are deleted

```
>> static int sum() {
     int s = sum(3);
     return s;
   }

   static int sum(int n) {
     if (n == 0) {
       return 0;
     }
     int m = sum(n - 1);
     int r = m + n;
     return r;
   }
```

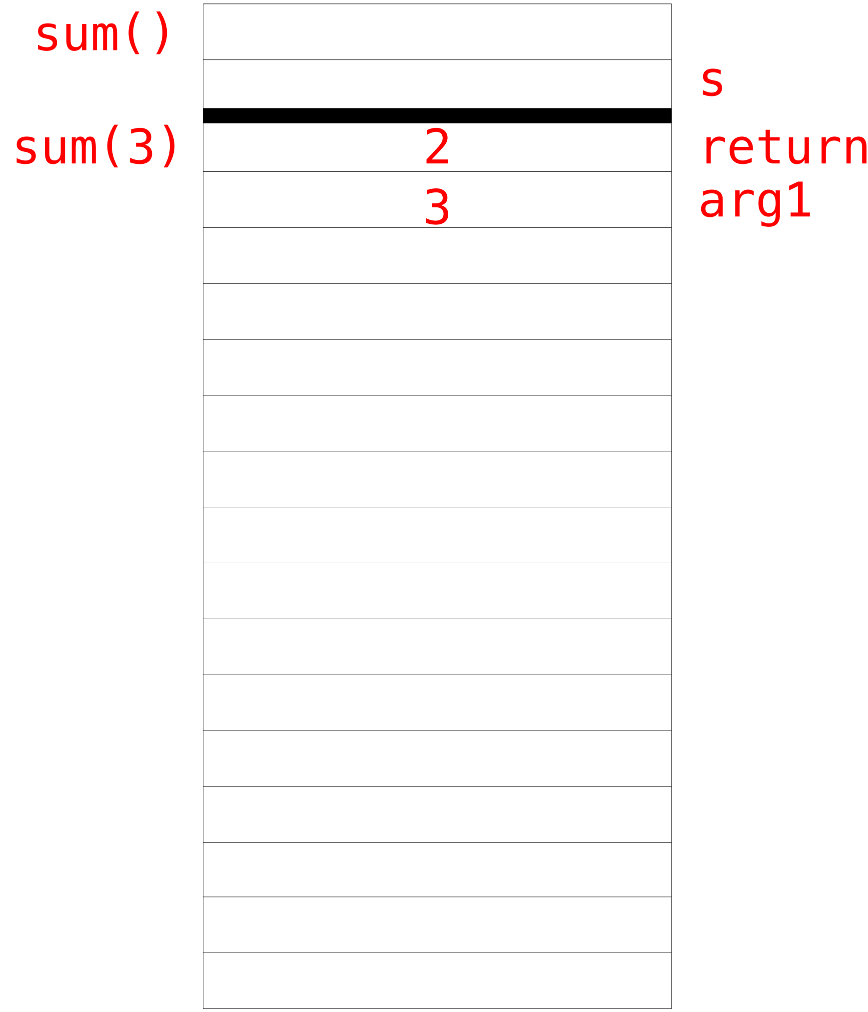
```java
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```



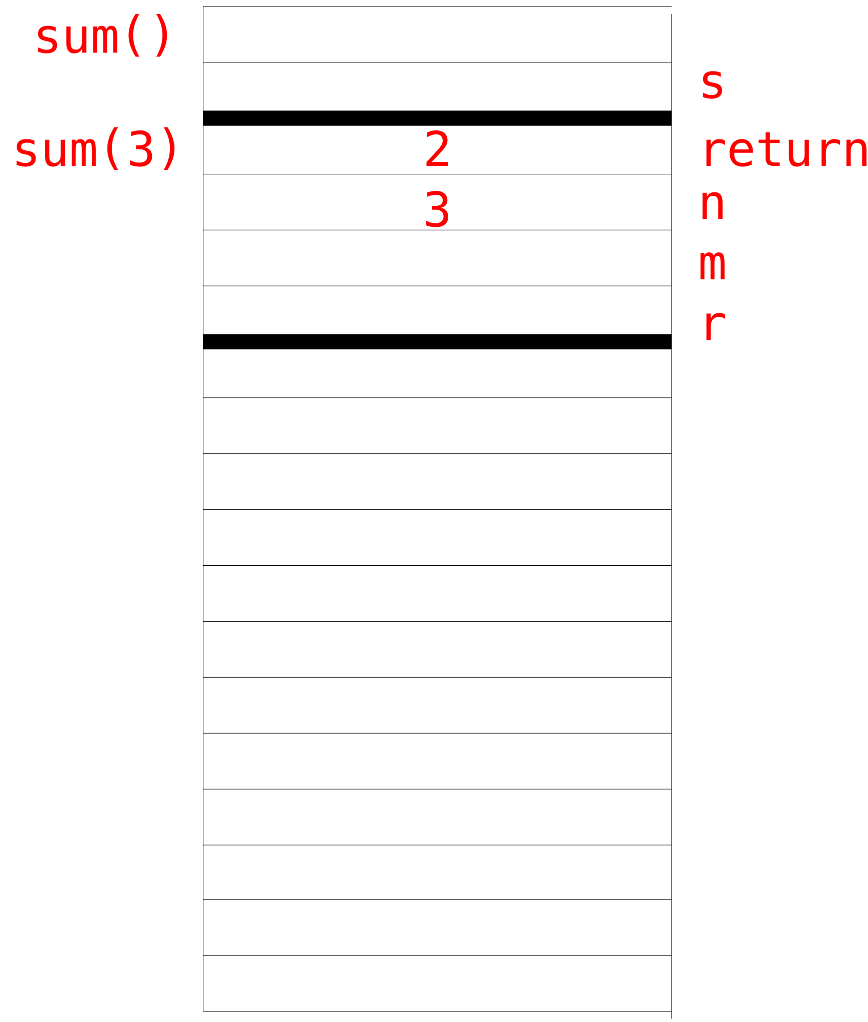
```
   static int sum() {
>>   int s = sum(3);
     return s;
   }

   static int sum(int n) {
     if (n == 0) {
       return 0;
     }
     int m = sum(n - 1);
     int r = m + n;
     return r;
   }
```



```
   static int sum() {
>>   int s = sum(3);
     return s;
   }

   static int sum(int n) {
     if (n == 0) {
       return 0;
     }
     int m = sum(n - 1);
     int r = m + n;
     return r;
   }
```



```java
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```



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  int s = sum(3);
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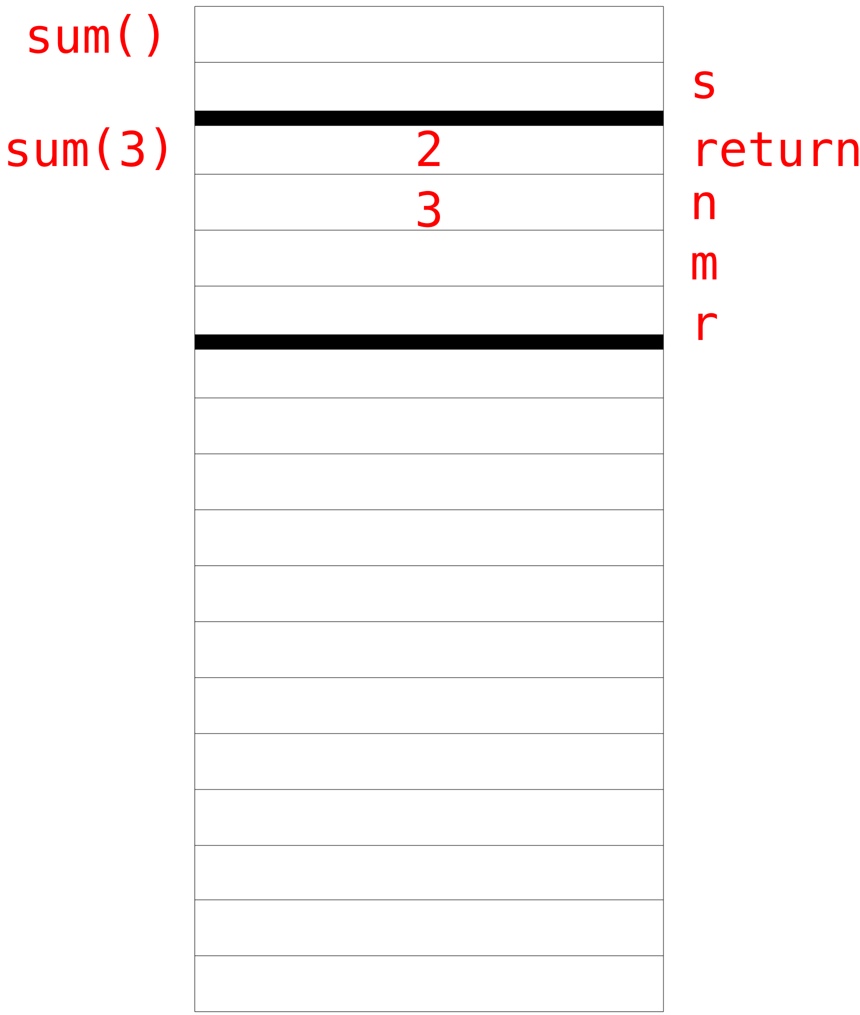
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```



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  int s = sum(3);
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static int sum(int n) {
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  }
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  int r = m + n;
  return r;
}
```

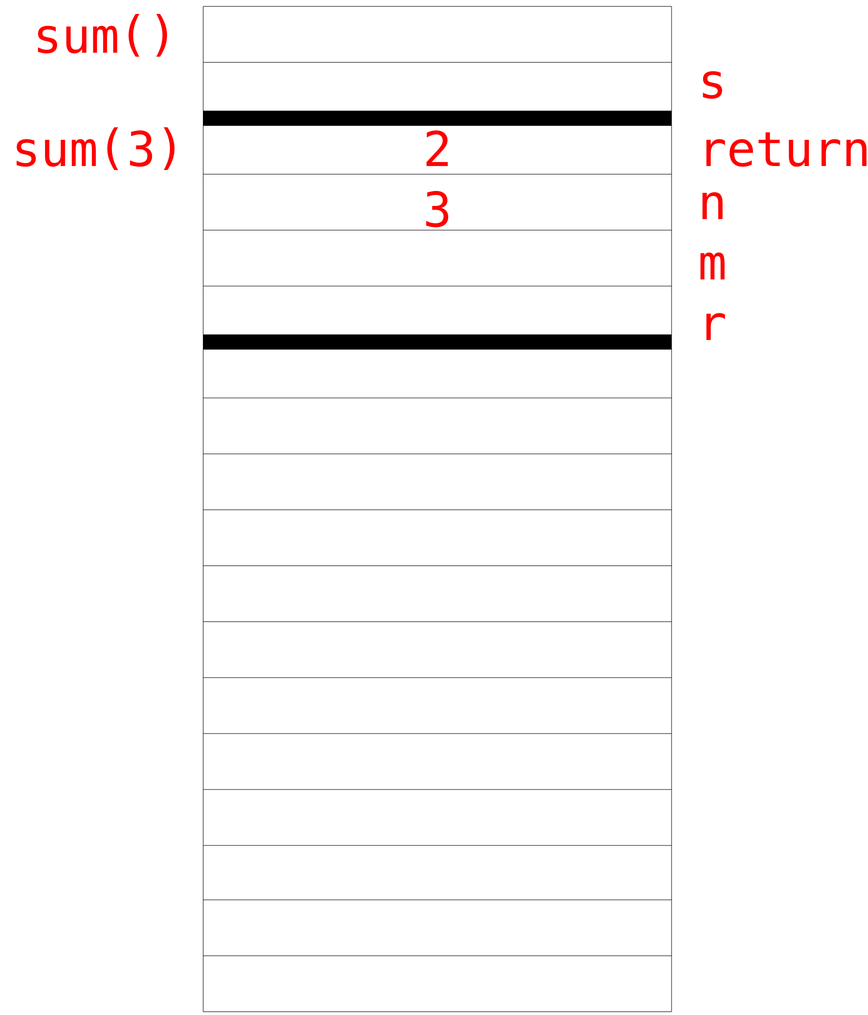

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  int s = sum(3);
  return s;
}

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  if (n == 0) {
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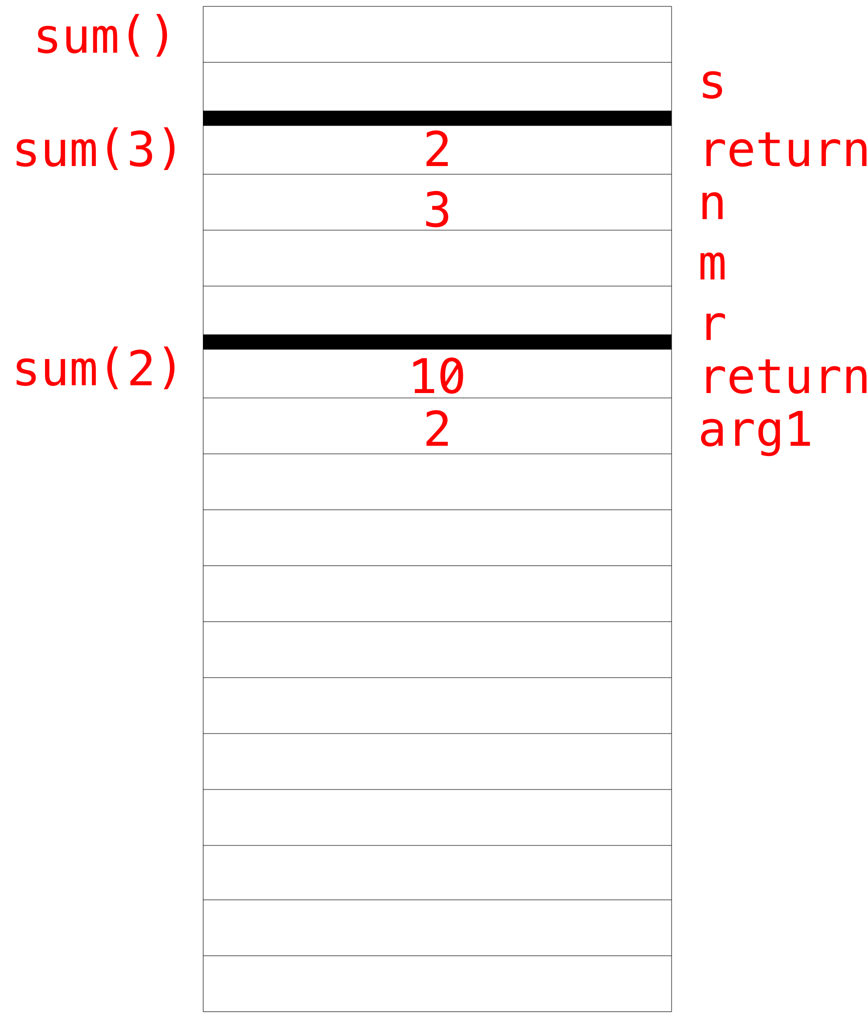
  int r = m + n;
  return r;
}
```



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  int r = m + n;
  return r;
}
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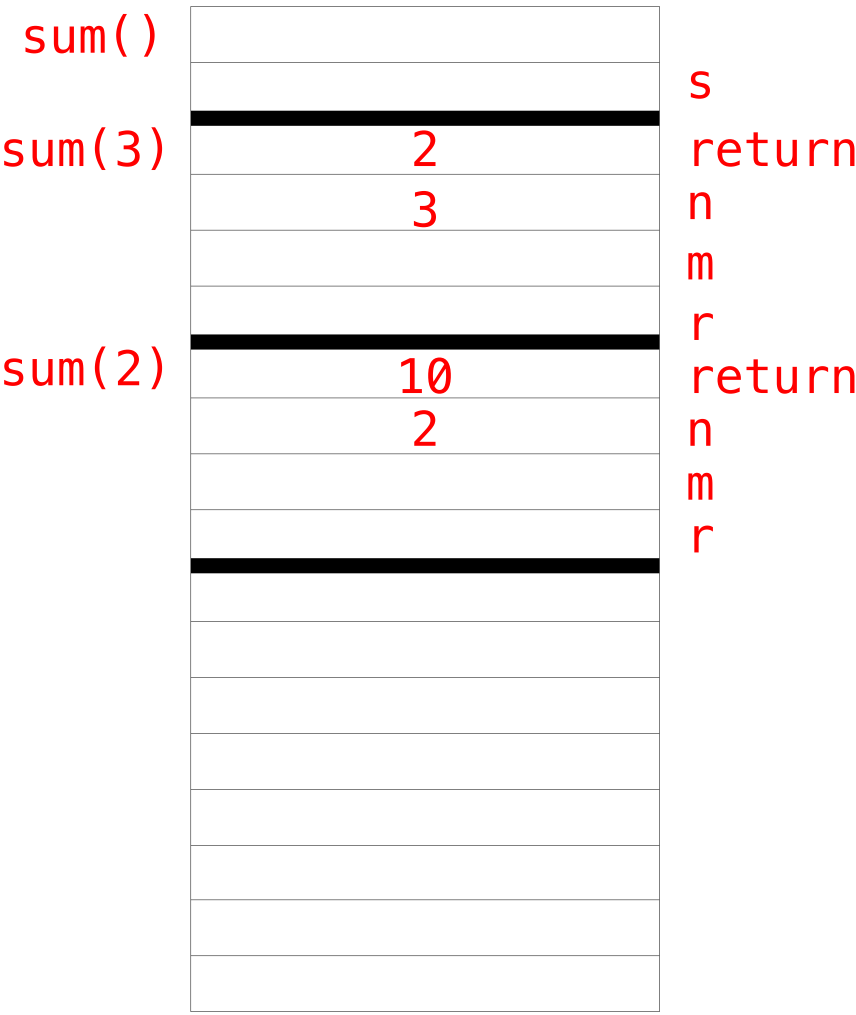

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     int s = sum(3);
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     int m = sum(n - 1);
     int r = m + n;
     return r;
   }
```

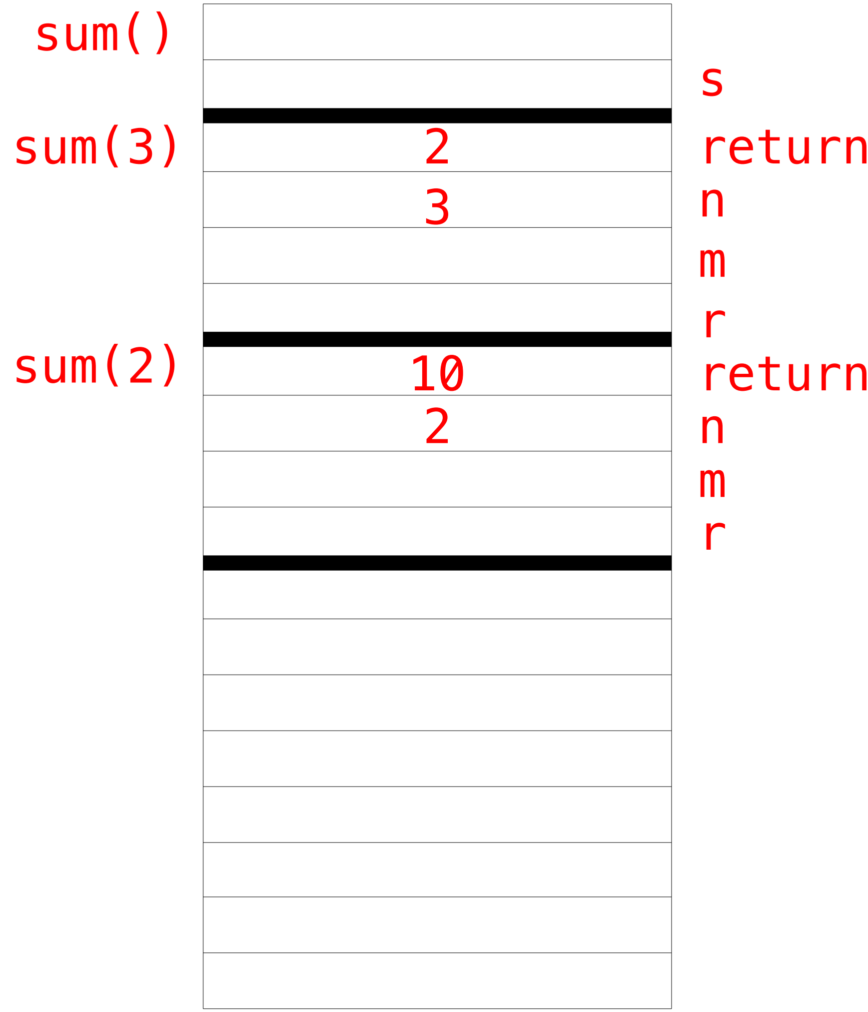

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  if (n == 0) {
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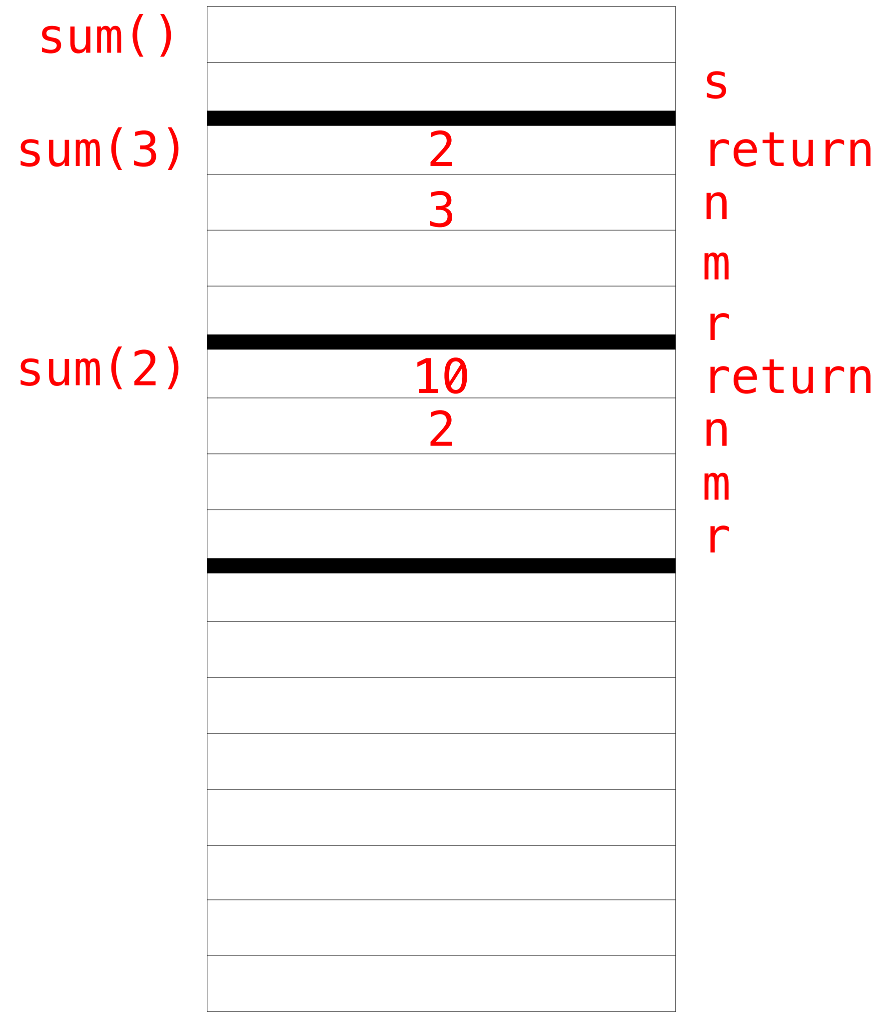
  int r = m + n;
  return r;
}
```



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     int r = m + n;
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   }
```

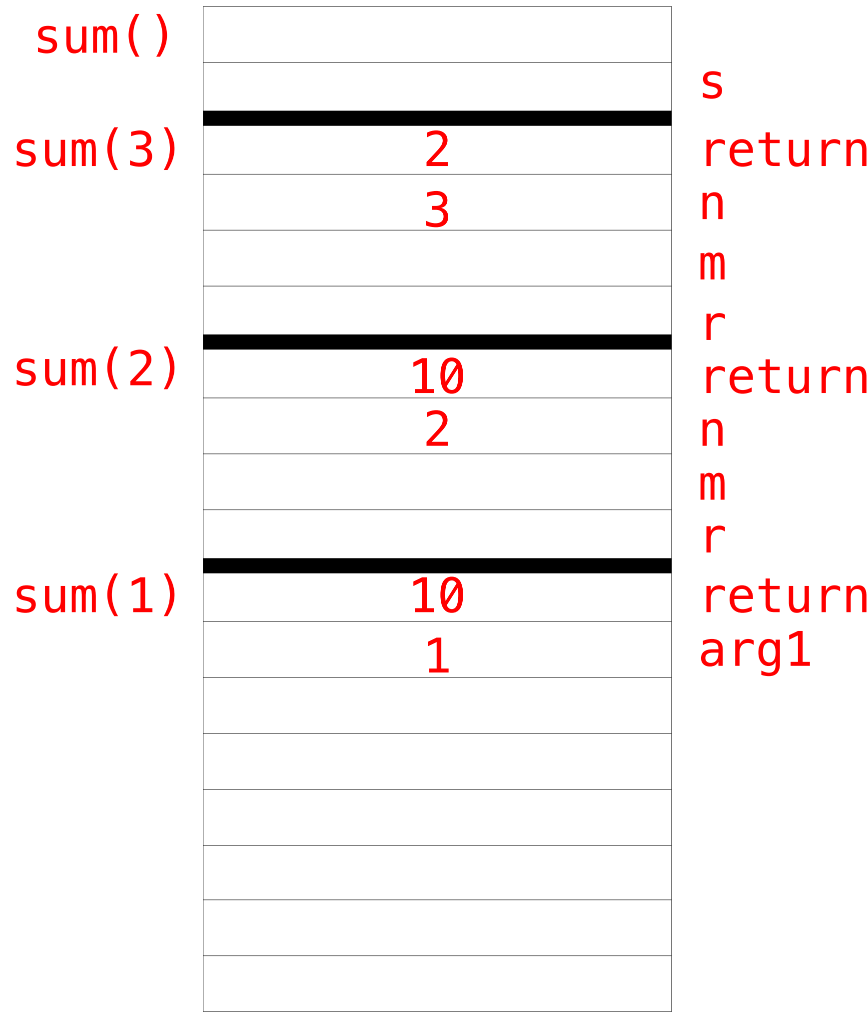

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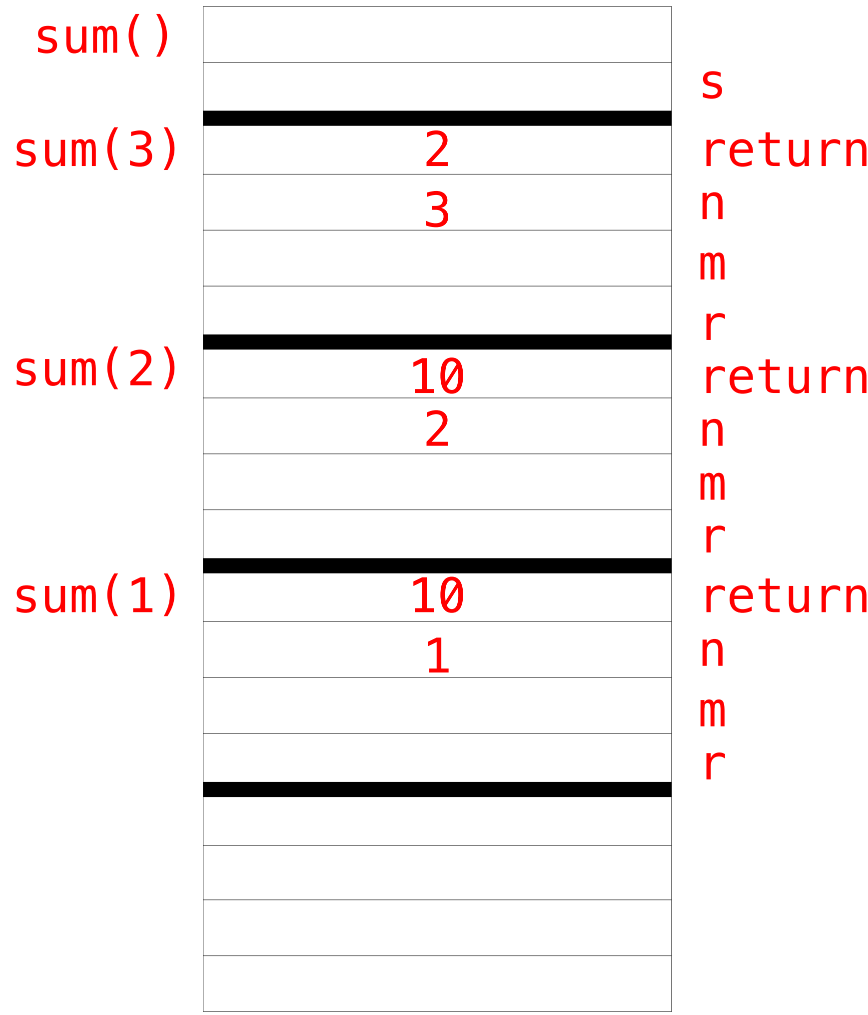
      }
      int m = sum(n - 1);
      int r = m + n;
      return r;
    }
```



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}

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  }
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  int r = m + n;
  return r;
}
```

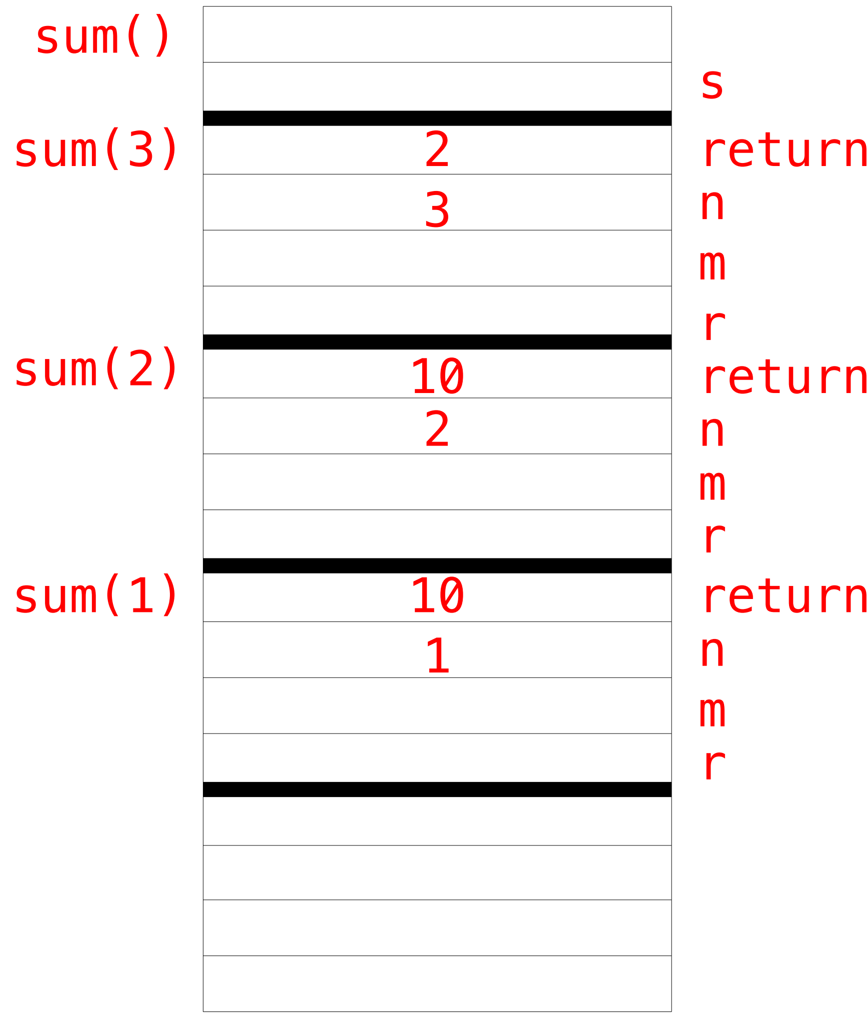

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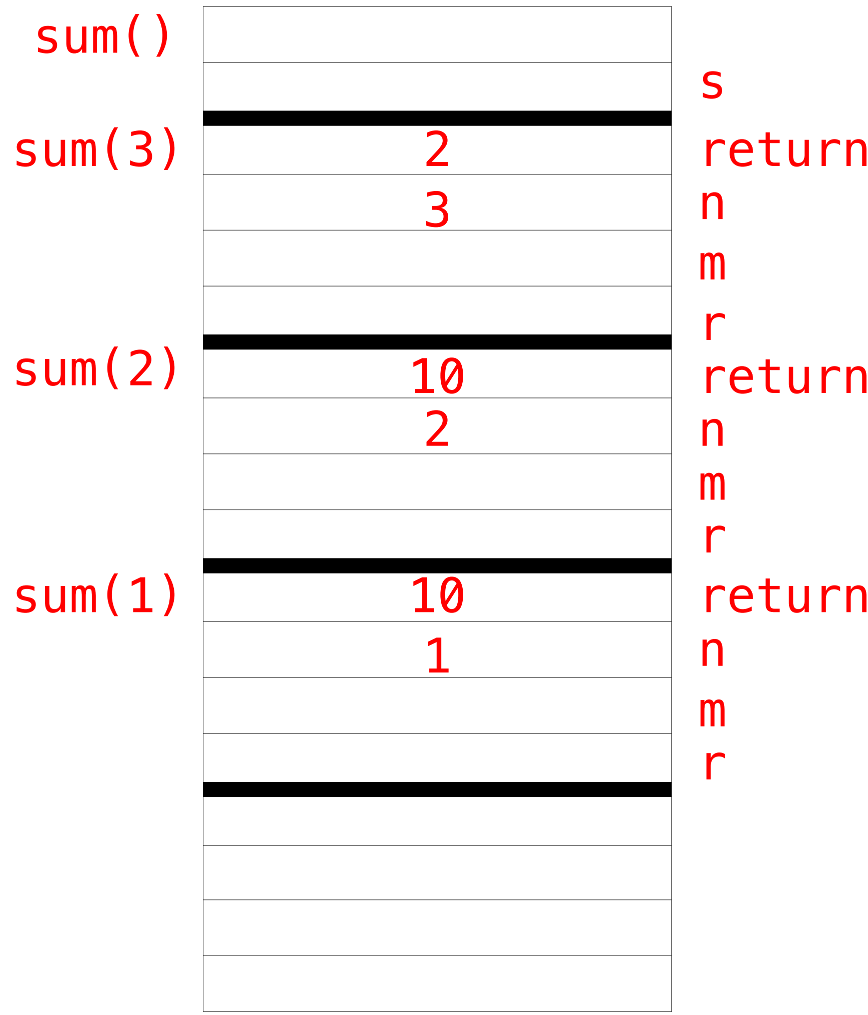
     int r = m + n;
     return r;
   }
```



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  int m = sum(n - 1);
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}
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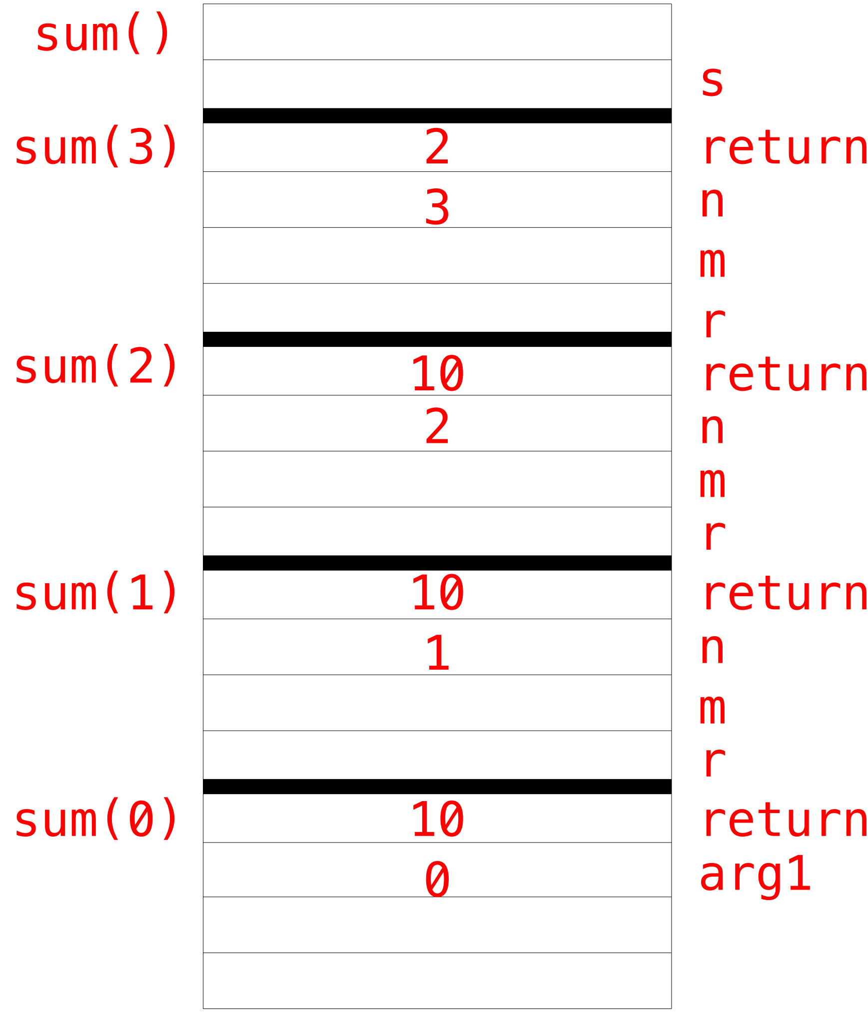

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>>
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  if (n == 0) {
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  int r = m + n;
  return r;
}
```
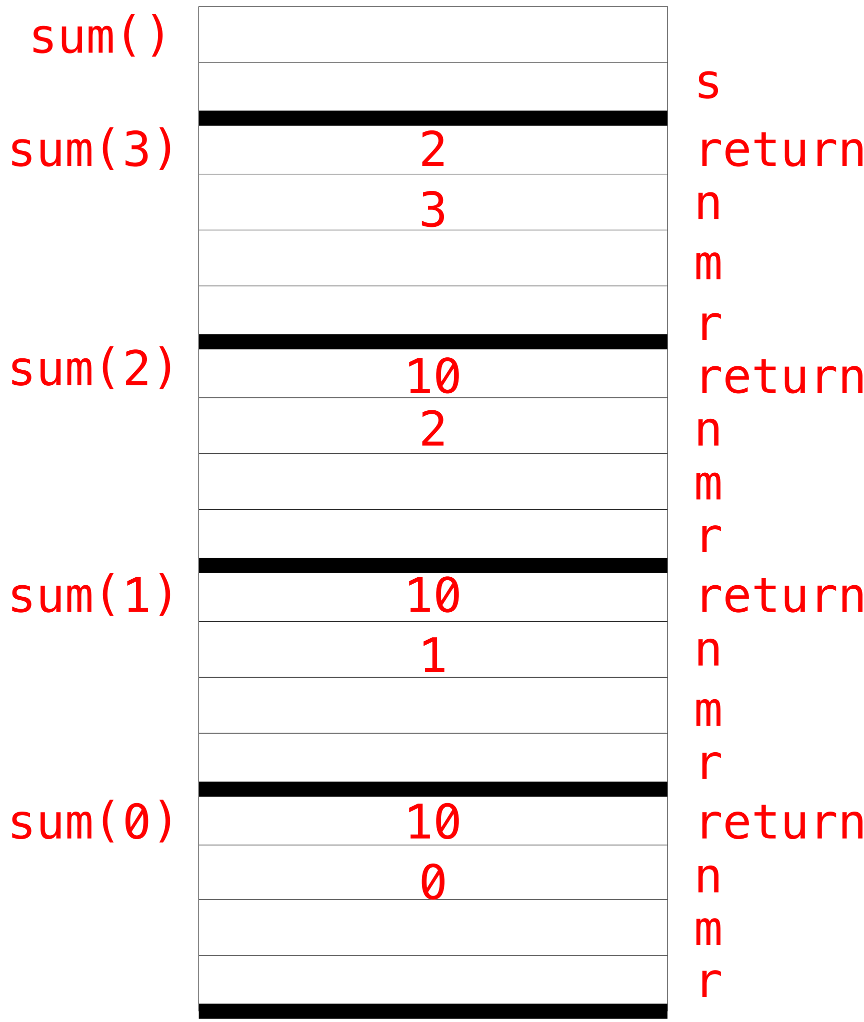
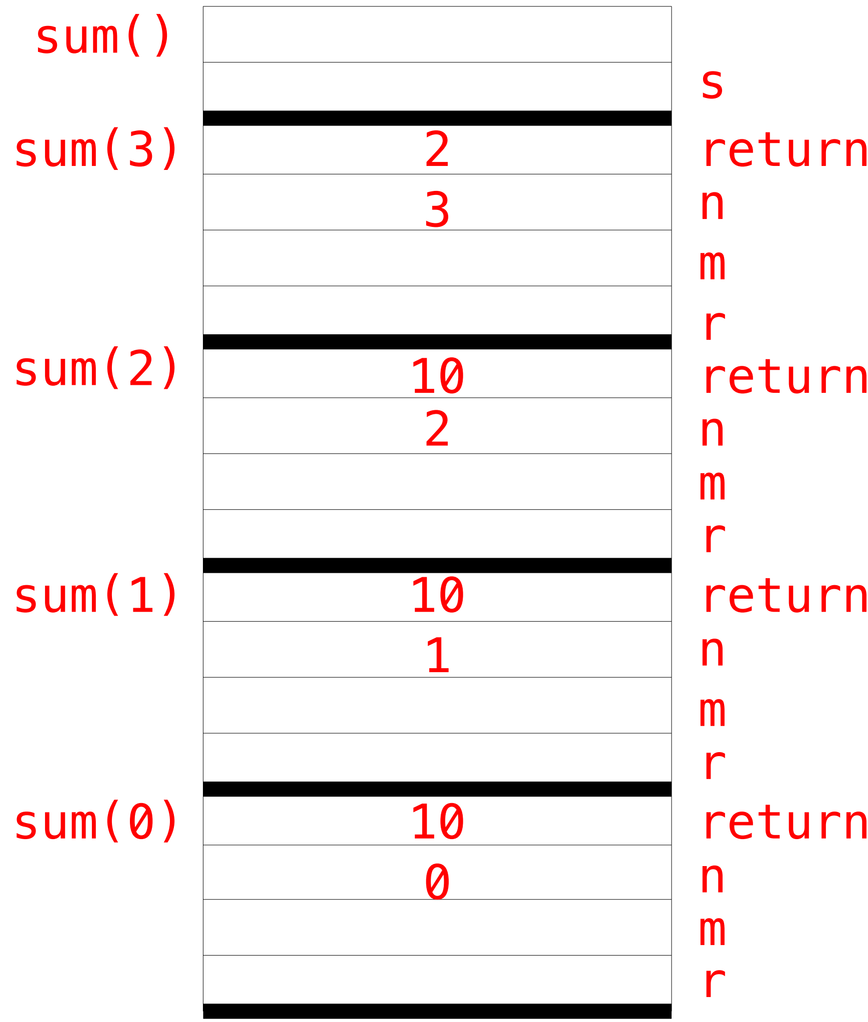
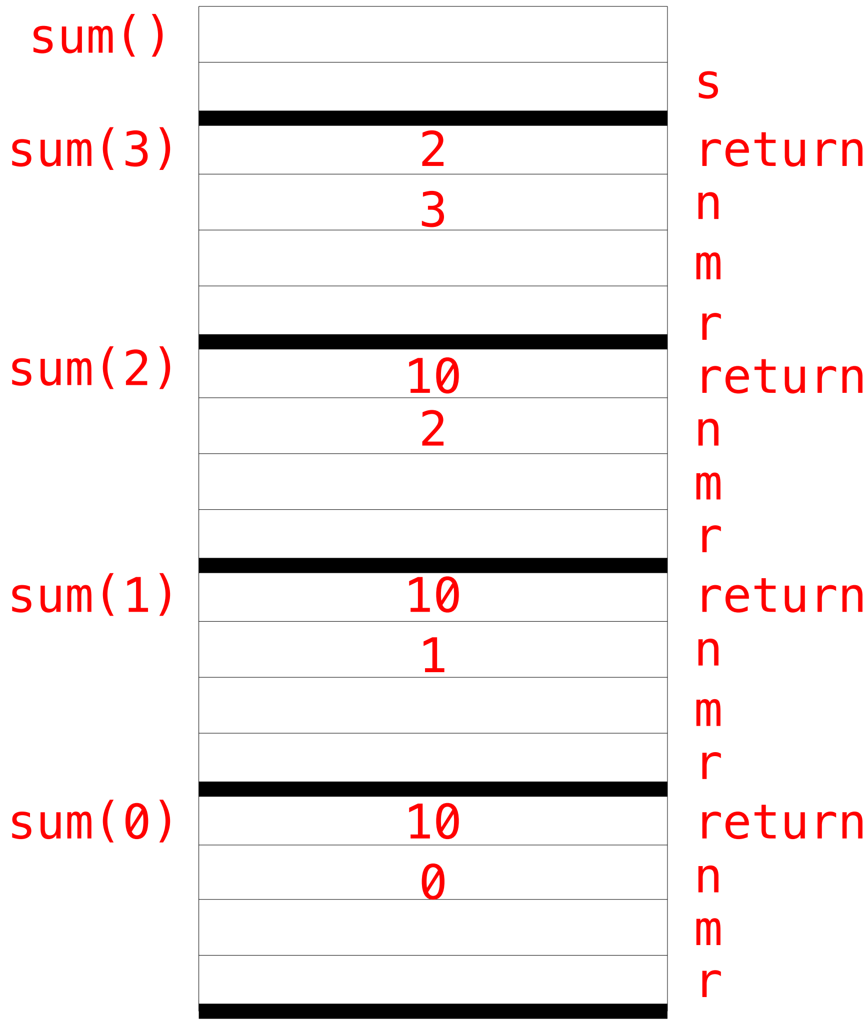



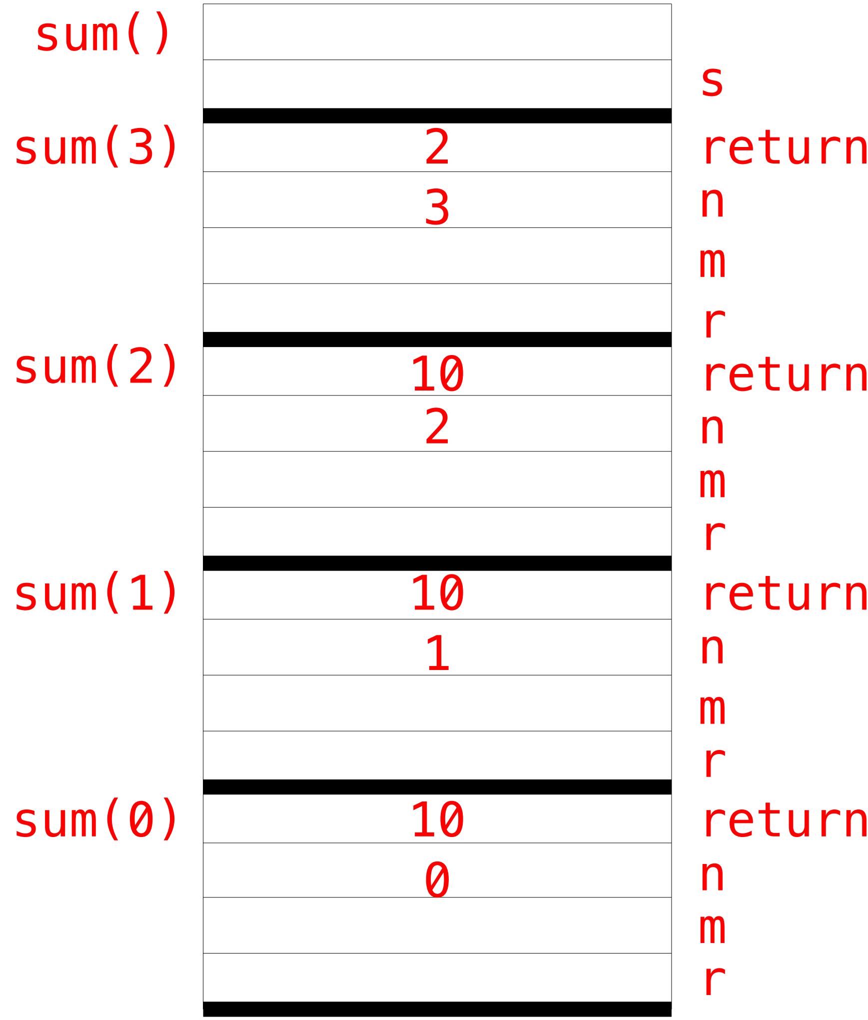
```
    static int sum() {
      int s = sum(3);
      return s;
    }

    static int sum(int n) {
>>    if (n == 0) {
        return 0;
      }
      int m = sum(n - 1);
      int r = m + n;
      return r;
    }
```



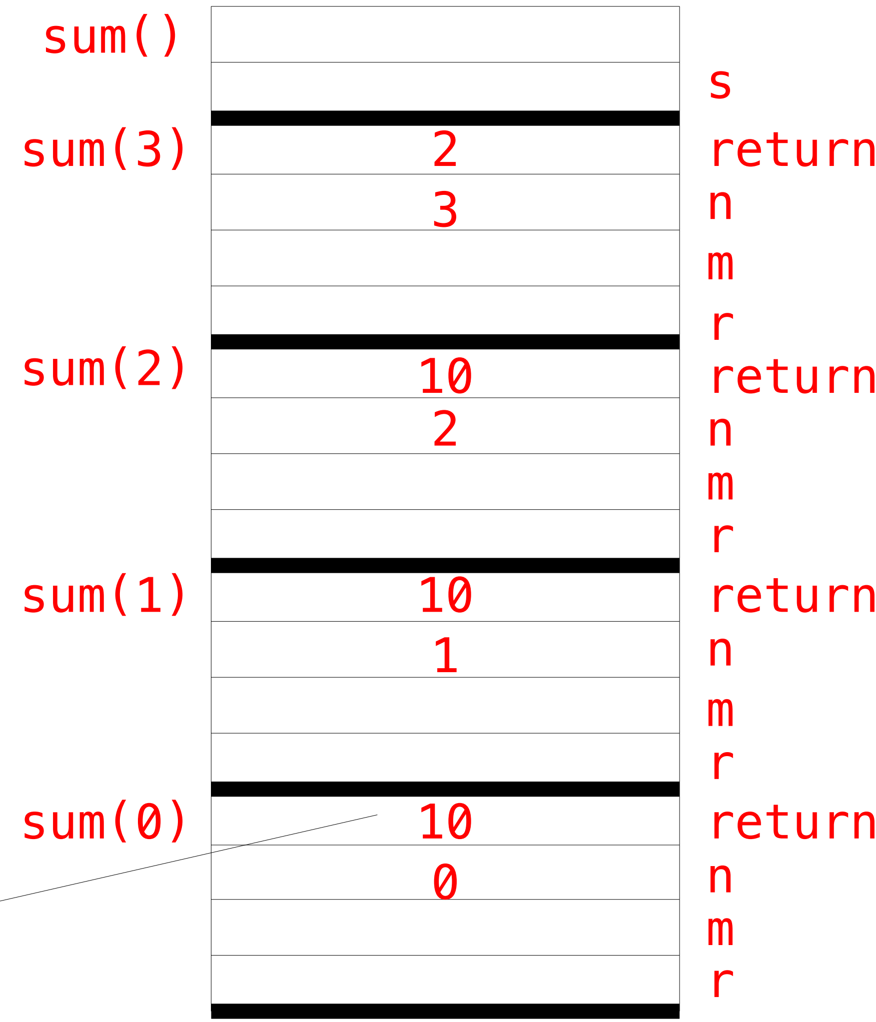
```
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
>>  return 0;
  }
  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```



```
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;      // >>
  }
  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```

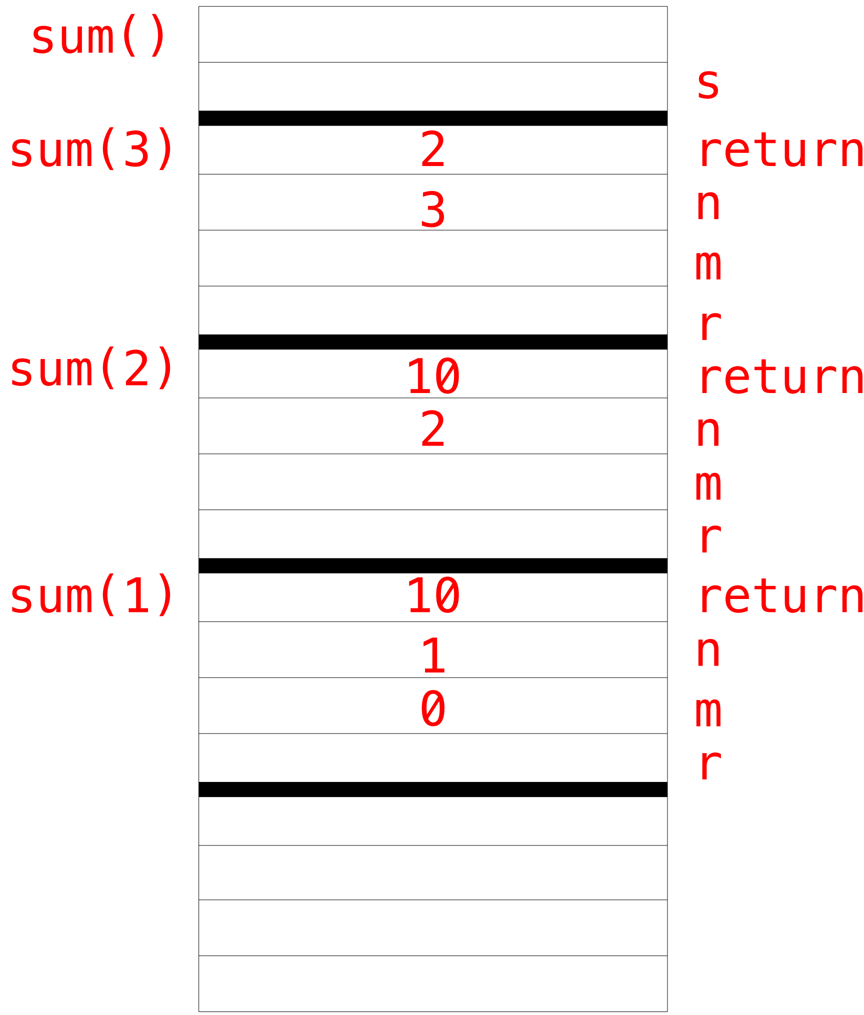


```
>>
 1 static int sum() {
 2   int s = sum(3);
 3   return s;
 4 }
 5
 6 static int sum(int n) {
 7   if (n == 0) {
 8     return 0;      <<
 9   }
10   int m = sum(n - 1);
11   int r = m + n;
12   return r;
13 }
```

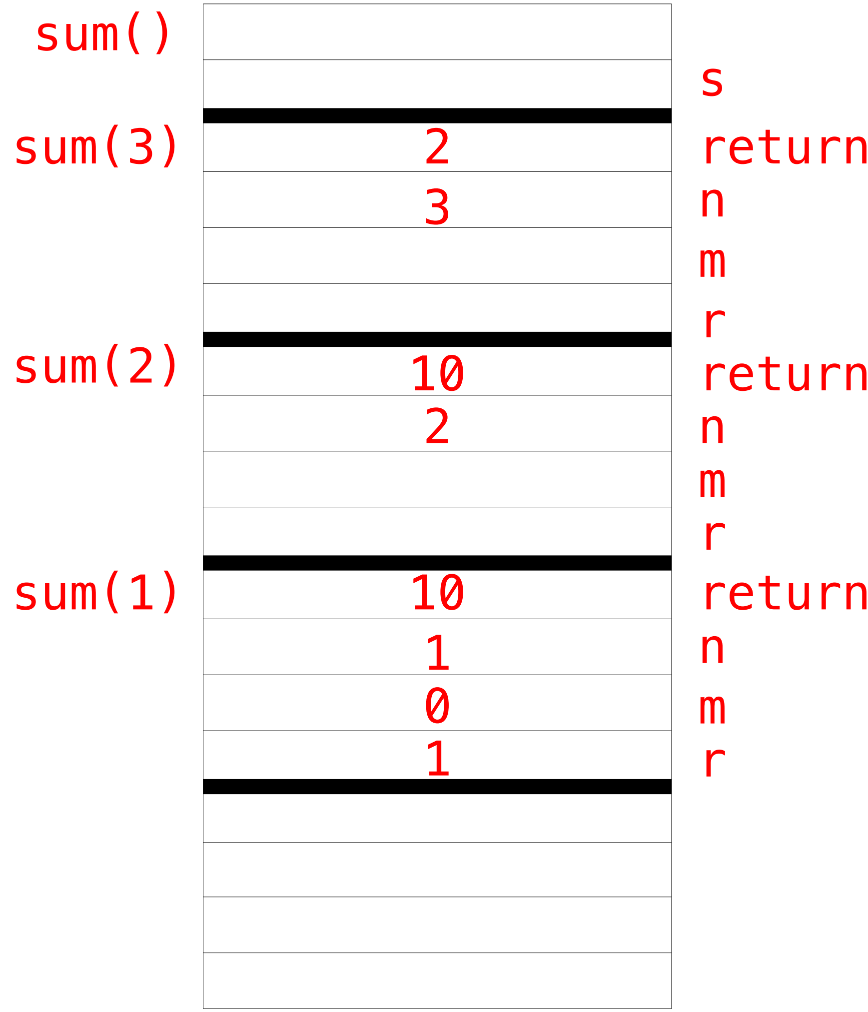


Return the value 0 and then
execute instruction 10

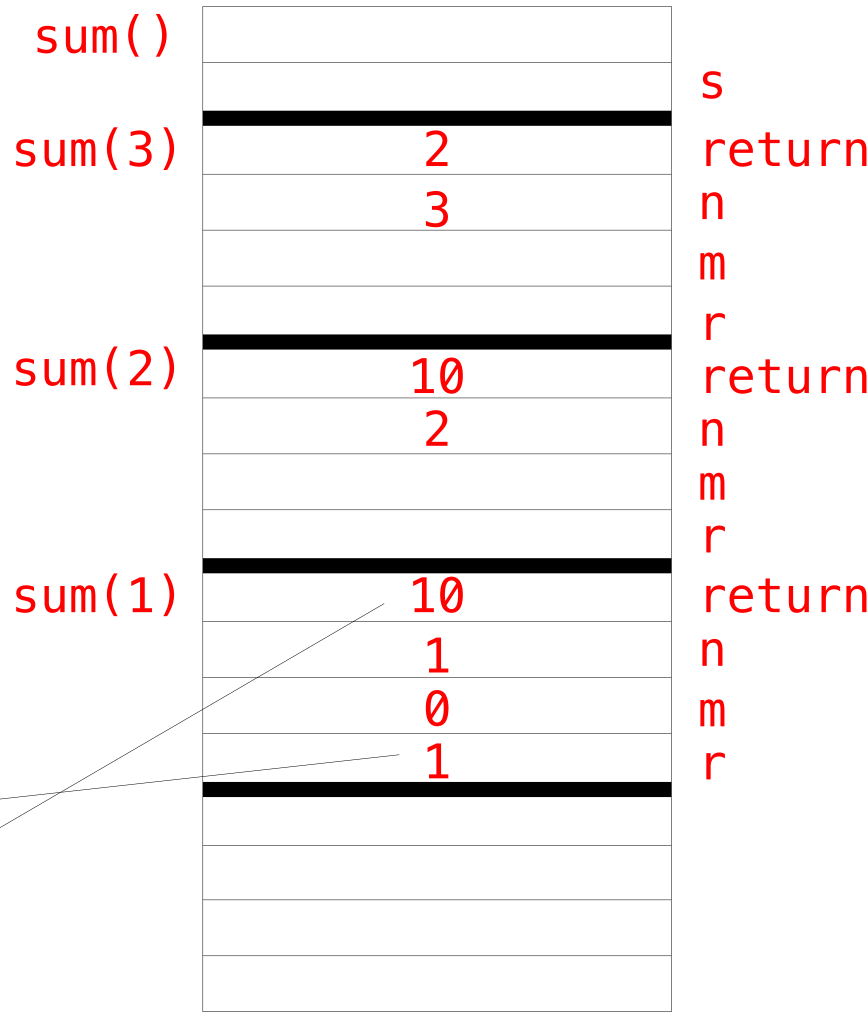
```java
   static int sum() {
     int s = sum(3);
     return s;
   }

   static int sum(int n) {
     if (n == 0) {
       return 0;
     }
>>   int m = sum(n - 1);
     int r = m + n;
     return r;
   }
```



```
   static int sum() {
     int s = sum(3);
     return s;
   }

   static int sum(int n) {
     if (n == 0) {
       return 0;
     }
     int m = sum(n - 1);
>>   int r = m + n;
     return r;
   }
```

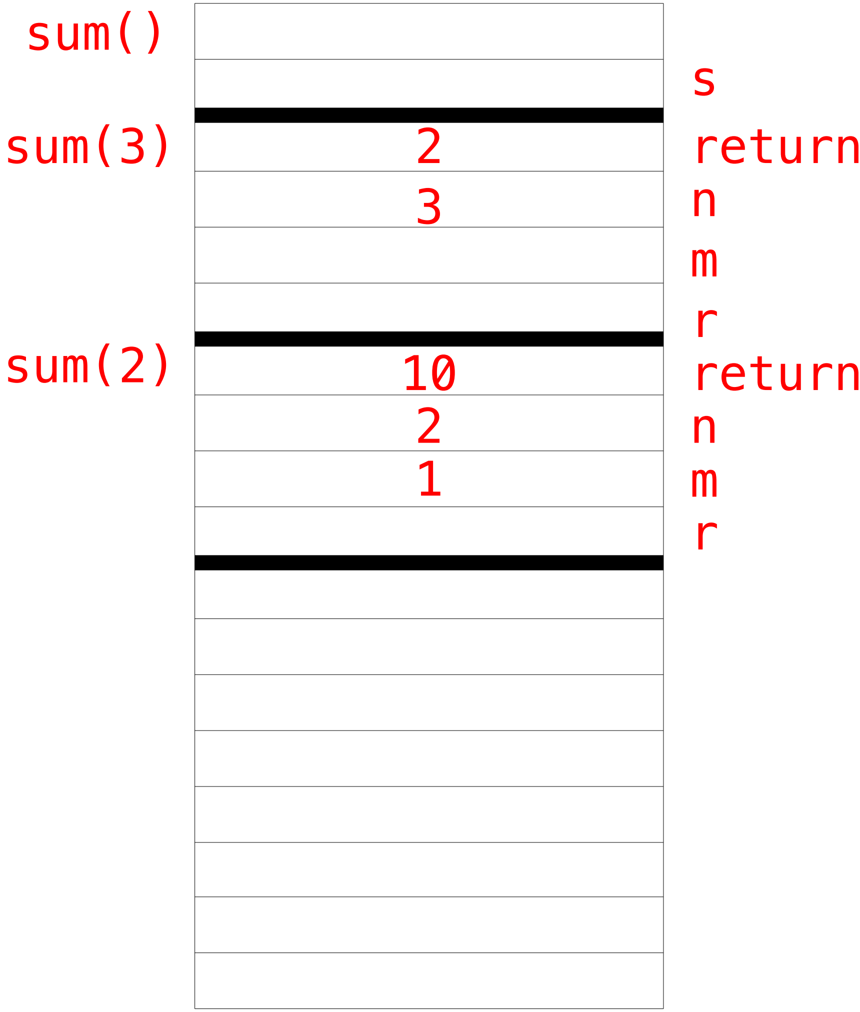


```
   1  static int sum() {
   2    int s = sum(3);
   3    return s;
   4  }
   5
   6  static int sum(int n) {
   7    if (n == 0) {
   8      return 0;
   9    }
  10    int m = sum(n - 1);
  11    int r = m + n;
>> 12   return r;
  13  }
```

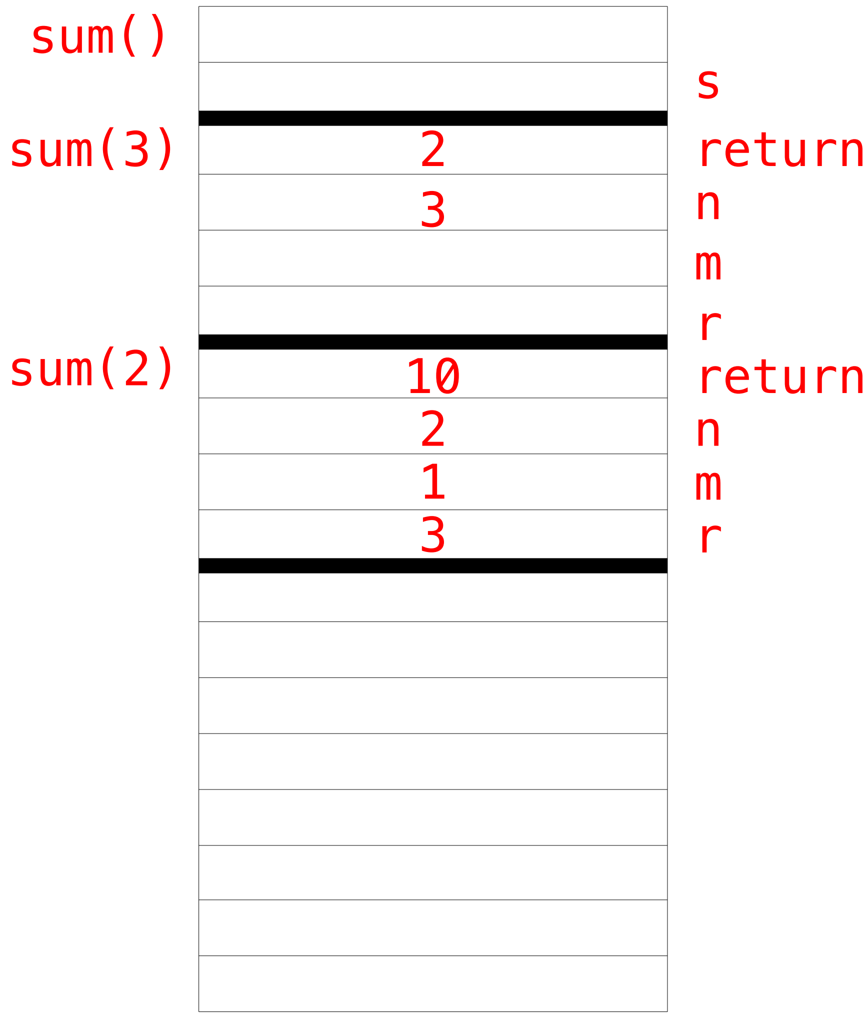


Return the value 1 and then
execute instruction 10

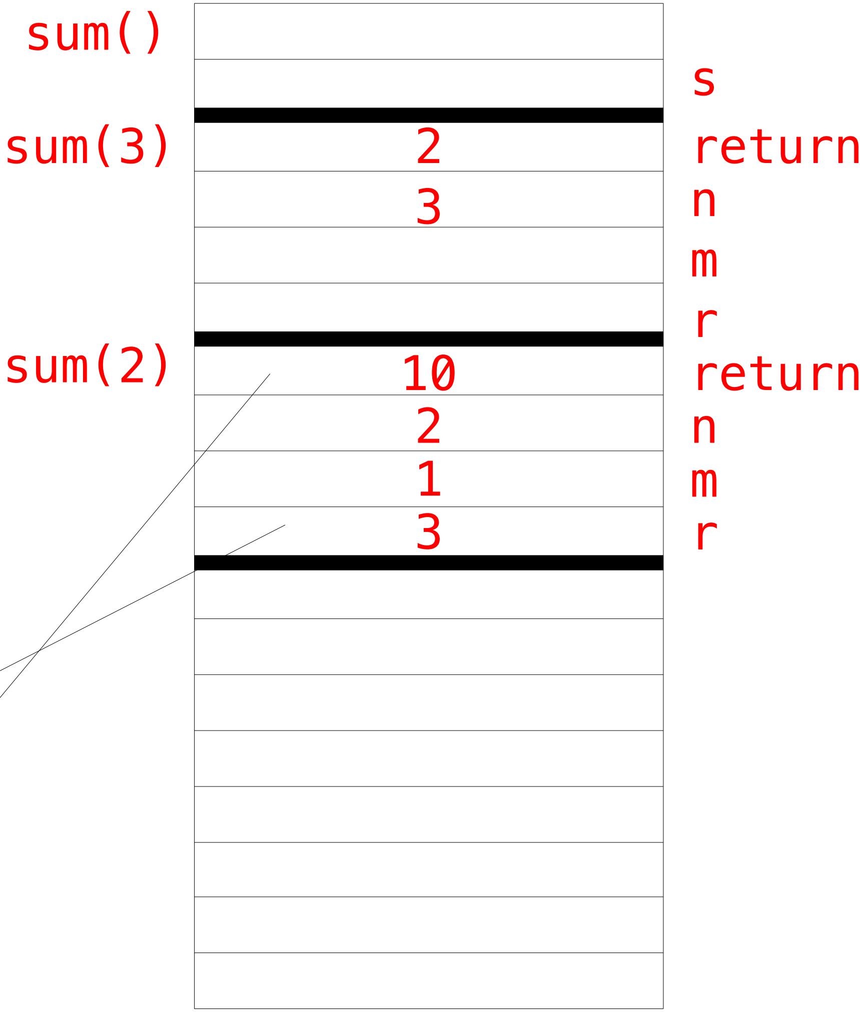
```
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```



```java
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
  int m = sum(n - 1);
  int r = m + n;   // >>
  return r;
}
```

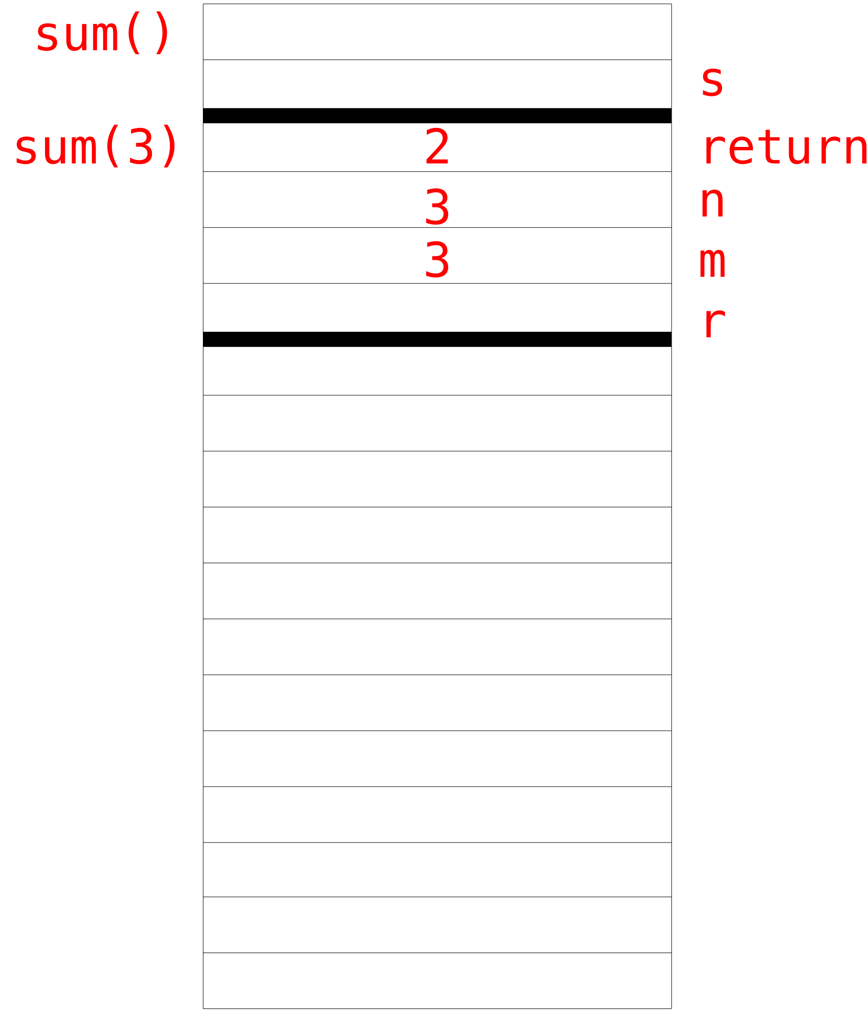


```java
   1 static int sum() {
   2   int s = sum(3);
   3   return s;
   4 }
   5
   6 static int sum(int n) {
   7   if (n == 0) {
   8     return 0;
   9   }
  10   int m = sum(n - 1);
  11   int r = m + n;
>> 12   return r;
  13 }
```

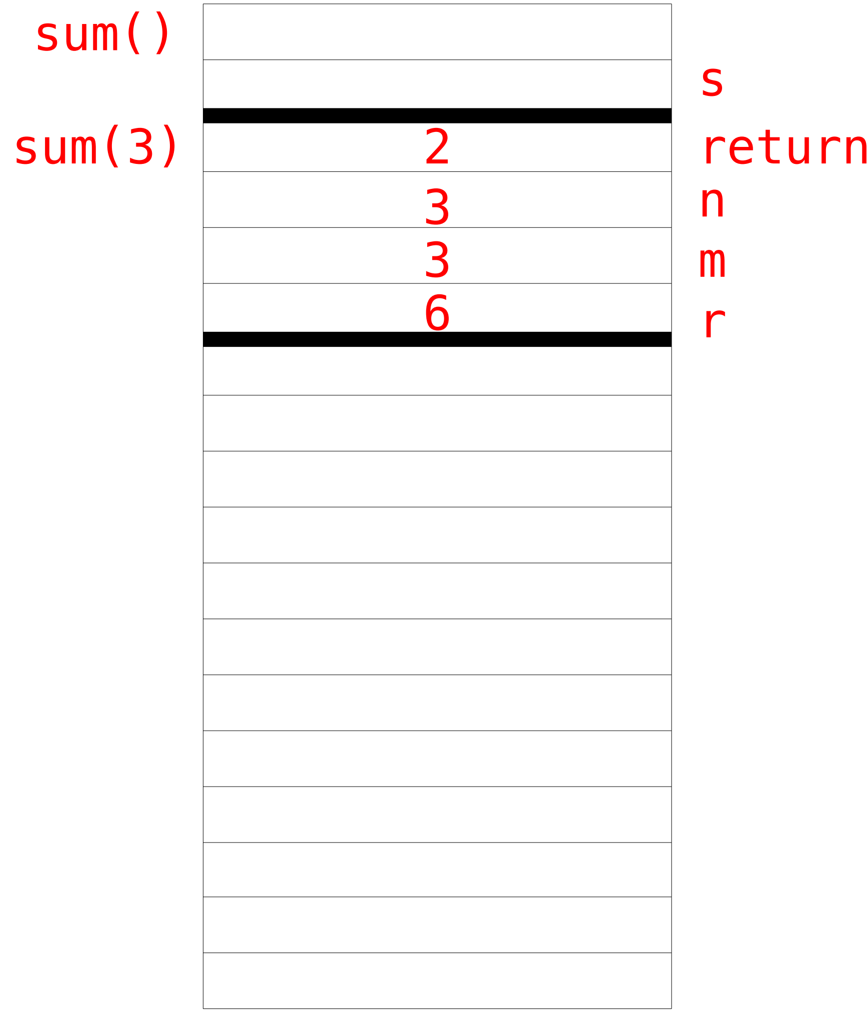


Return the value 3 and then
execute instruction 10

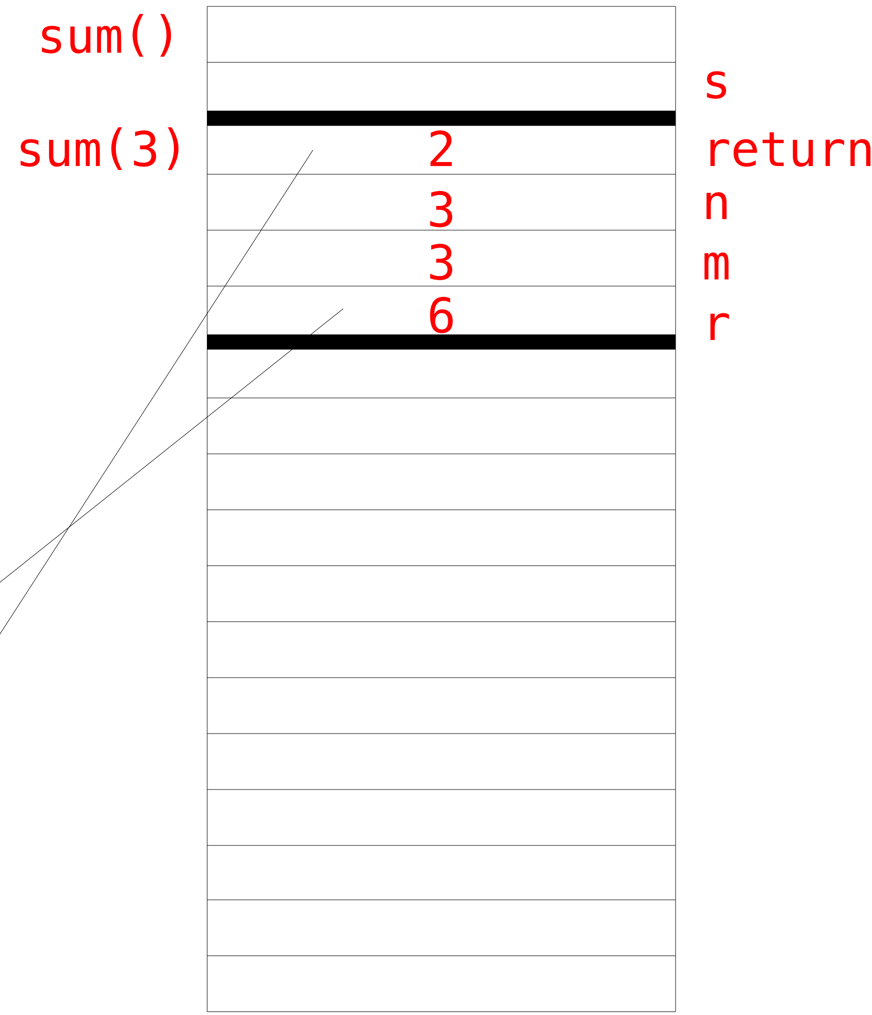
```
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
>>  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```



```
static int sum() {
  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
  int m = sum(n - 1);
>>  int r = m + n;
  return r;
}
```

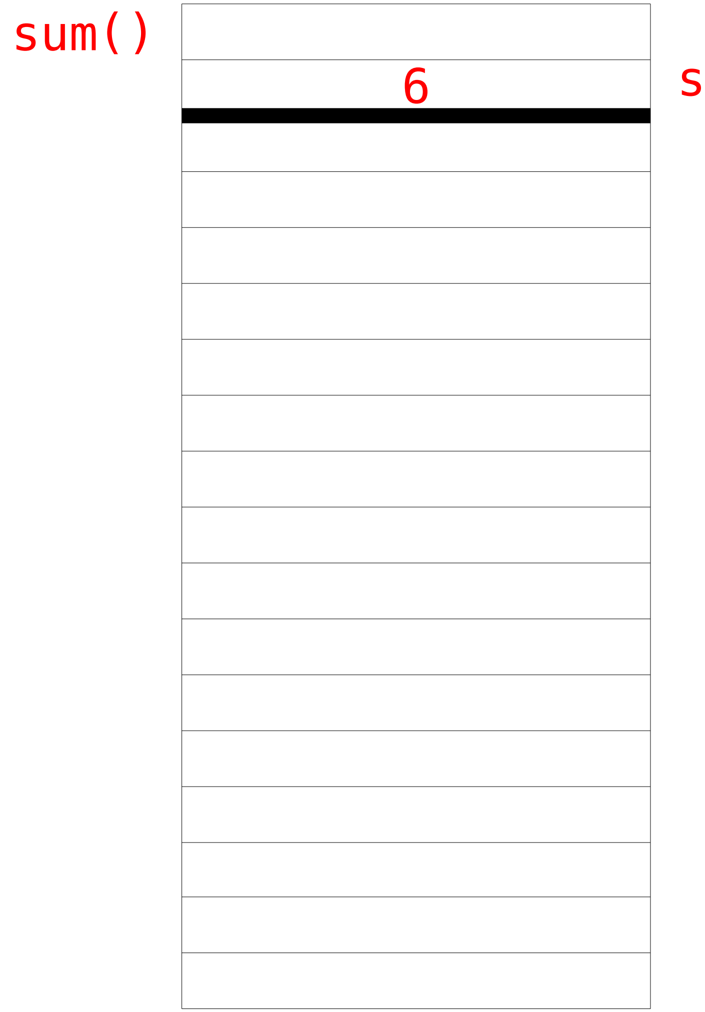


```
    1  static int sum() {
    2    int s = sum(3);
    3    return s;
    4  }
    5
    6  static int sum(int n) {
    7    if (n == 0) {
    8      return 0;
    9    }
   10    int m = sum(n - 1);
   11    int r = m + n;
>> 12    return r;
   13  }
```

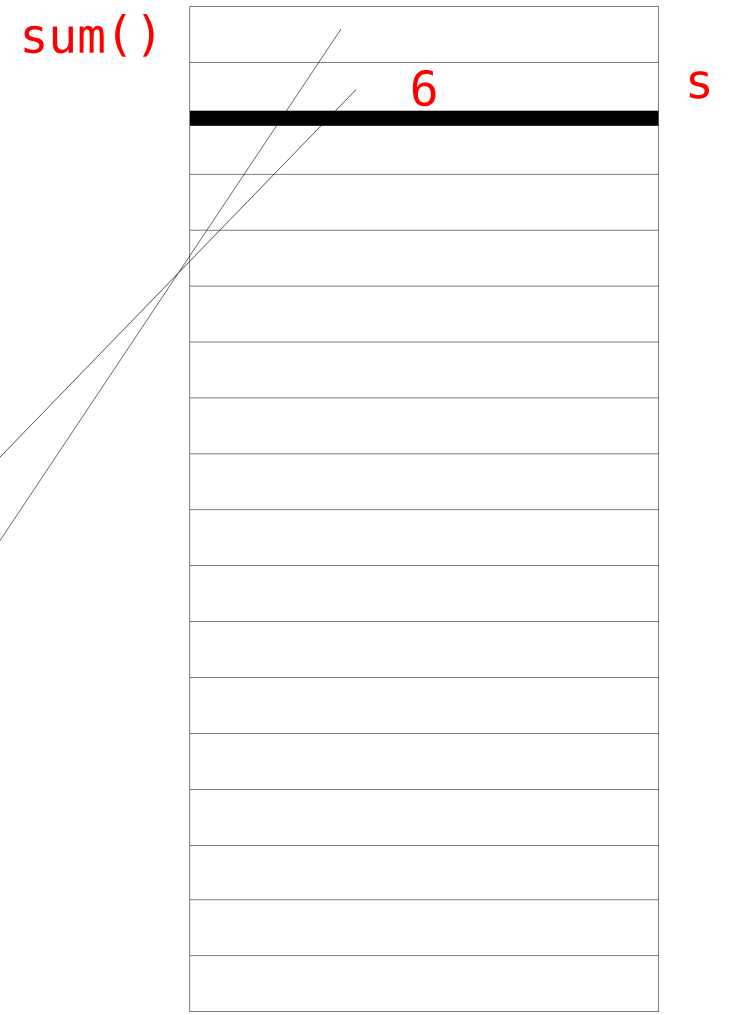


Return the value 6 and then
execute instruction 2

```
static int sum() {
>>  int s = sum(3);
  return s;
}

static int sum(int n) {
  if (n == 0) {
    return 0;
  }
  int m = sum(n - 1);
  int r = m + n;
  return r;
}
```



```
    static int sum() {
      int s = sum(3);
>>    return s;
    }

    static int sum(int n) {
      if (n == 0) {
        return 0;
      }
      int m = sum(n - 1);
      int r = m + n;
      return r;
    }
```



Return the value 6 and then execute whatever called us

References and pointers

Objectives:

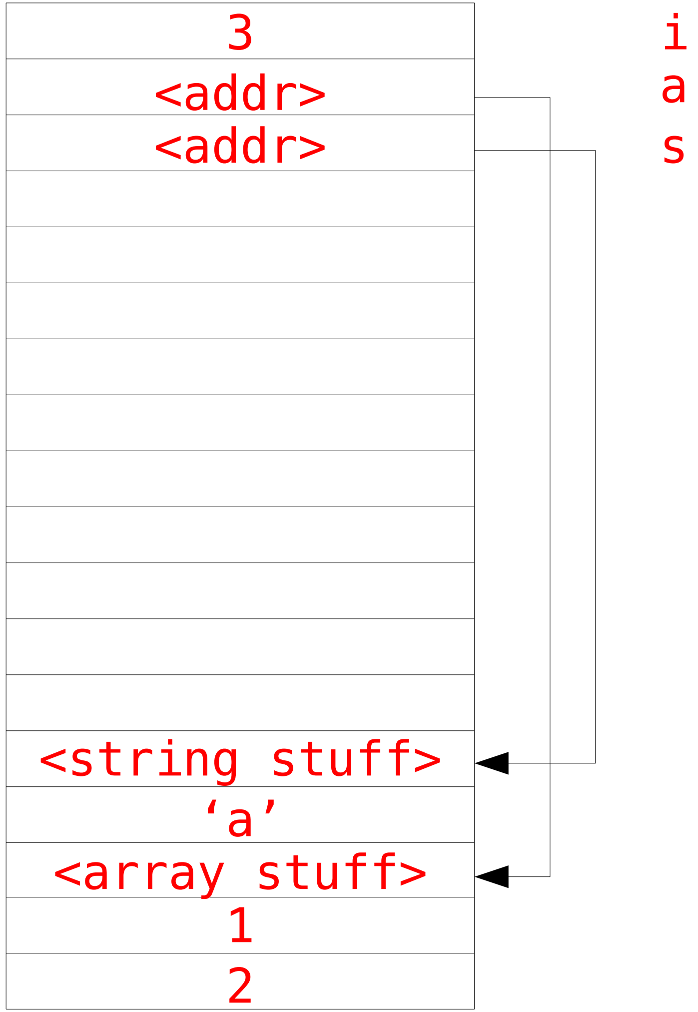
- Compare pointers and references in Java
- Declare an unassigned reference
- Describe what happens when you call 'new' in Java

In Java primitive types go on the stack

Everything else goes on the heap

```java
static void test() {
    int i = 3;
    int[] a = new int[] {1,2};
    String s = "a";
}
```

Java delete’s for us automatically. This is called Garbage Collection



This example is in Java

```java
static void test() {
    int i = 3;
    int[] a = new int[] {1,2};
    String s = "a";
}
```

‘a’ and ‘s’ are references. These are like pointers but you can’t do arithmetic on them.

When you say s.toUpperCase() you are ‘dereferencing’ s and calling the method toUpperCase on it.

References in C++ are a completely different concept!

```
   static void test() {
>>     int i = 3;
       int* k = &i;
       int& j = i;
   }
```

This example is in C++

```
static void test() {
    int i = 3;
    int* k = &i;
    int& j = i;
}
```

```
static void test() {
    int i = 3;
    int* k = &i;
    int& j = i;
}
```

& on the LHS means ‘reference’

Recap for Java

- Primitive types on the stack
- Everything else on the heap
- References are values on the stack that ‘point’ to somewhere on the heap
- References are like pointers but you can’t do artithmetic on them
- Java references are not much like C++ references

Distinguishing References and Pointers

	Pointers	References in Java
Can be unassigned (null)	Yes	Yes
Can be assigned to established object	Yes	Yes
Can be assigned to an arbitrary chunk of memory	Yes	**No**
Can be tested for validity	**No**	Yes
Can perform arithmetic	Yes	**No**

References in Java

- Declaring unassigned

```
SomeClass ref = null;  // explicit

SomeClass ref2;  // implicit
```

- Defining/assigning

```
// Assign
SomeClass ref = new ClassRef();

// Reassign to alias something else
ref = new ClassRef();

// Reference the same thing as another reference
SomeClass ref2 = ref;
```

Argument passing

Objectives:

- Define pass-by-value
- Demonstrate the difference in side-effects for passing primitive types and references as values

Argument Passing

- **Pass-by-value**. Copy the value into a new one in the stack

```
void test(int x) {...}
int y=3;
test(y);

void test(Object o) {...}
Object p = new Object();
test(p);
```

The value passed here is the reference to the object.

When run the test method's argument o is copy of the reference p that points to the same object

Inheritance

Objectives:

- Define specialisation, generalisation, sub-class, super-class, code-inheritance, type-inheritance
- State the Liskov Substitution Principle
- Give an example of the Liskov Substitution Principle
- Draw inheritance relationships on a UML class diagram

Inheritance I

```
class Student {
  private int age;
  private String name;
  private int grade;
  ...
}

class Lecturer {
  private int age;
  private String name;
  private int salary;
  ...
}
```

- There is a lot of duplication here
- Conceptually there is a hierarchy that we're not really representing
- Both Lecturers and Students are people (no, really).
- We can view each as a kind of specialisation of a general person
  - They have all the properties of a person
  - But they also have some extra stuff specific to them

Demo: expression evaluator

Inheritance II

```
class Person {
  protected int age;
  protected String name;
  ...
}

class Student extends Person {
  private int grade;
  ...
}

class Lecturer extends Person {
  private int salary;
  ...
}
```

- We create a *base class* (Person) and add a new notion: classes can *inherit* properties from it
  - Both state, functionality and type
- We say:
  - Person is the *superclass* of Lecturer and Student
  - Lecturer and Student *subclass* Person

'extends' in Java gives you both code- and type-inheritance

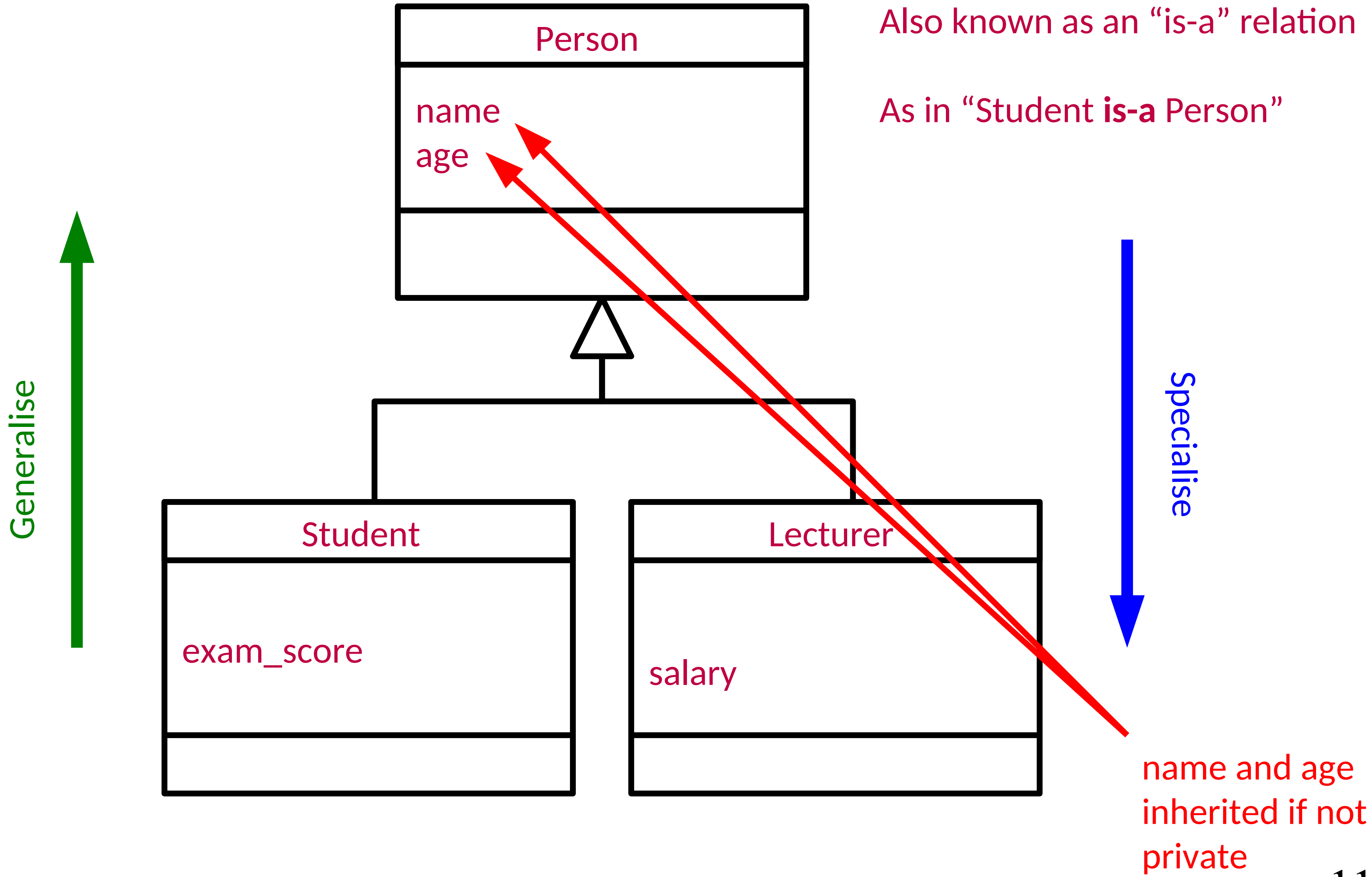
Note: Java is a **nominative** type language (rather than a **structurally** typed one)

If you mark a class 'final' then it can't be extended and 'final' methods can't be overridden

Liskov Substitution Principle

- If S is a subtype of T then objects of type T may be replaced with objects of type S
- Student is a subtype of Person so anywhere I can have a Person I can have a Student instead

Representing Inheritance Graphically



Also known as an “is-a” relation

As in “Student **is-a** Person”

Casting

Objectives:

- Apply widening and narrowing to objects with a sub-typing relationship
- Give an example of how narrowing might fail and succeed at run-time

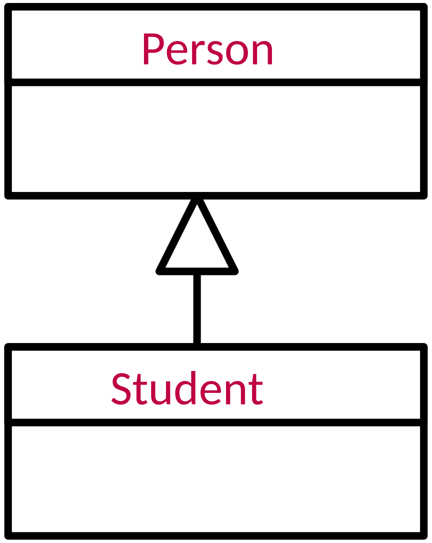
Casting

- Many languages support *type casting* between numeric types

```
int i = 7;
float f = (float) i;   // f==7.0
double d = 3.2;
int i2 = (int) d;     // i2==3
```

- With inheritance it is reasonable to type cast an object to any of the types above it in the inheritance tree...

Widening



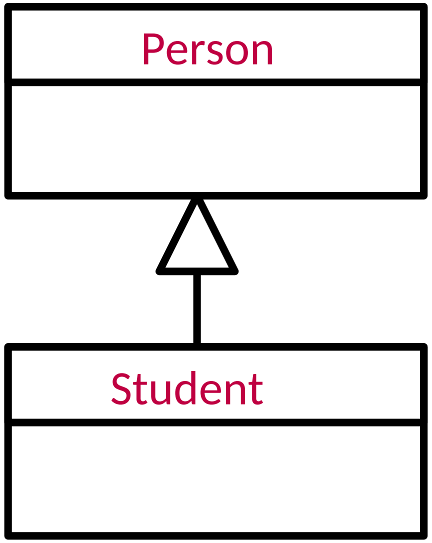
- Student is-a Person
- Hence we can use a Student object anywhere we want a Person object
- Can perform *widening* conversions (up the tree)

```
Student s = new Student()

Person p = s;
```

```
public void print(Person p) {...}

Student s = new Student();
print(s);
```

Implicit widening

Narrowing



- Narrowing conversions move down the tree (more specific)
- Need to take care...

OK because underlying object really is a Student

```
Person p = new Person();

Student s = (Student) p;
```

FAILS at runtime. Not enough info
In the real object to represent
a Student

```
public void print(Person p) {
   Student s = (Student) p;
}

Student s = new Student();
print(s);
```

Inheriting fields and methods

Objectives:

- Give an example of how public, package, protected and private modifiers affect inheritance
- Give an example of field shadowing
- Give an example distinguishing between overriding and overloading a method

Fields and Inheritance

```
class Person {
   public String name;
   protected int age;
   private double height;
}

class Student extends Person {

  public void do_something() {
    name="Bob";
    age=70;
    height=1.70;
  }

}
```

Student inherits this as a public variable and so can access it

Student inherits this as a protected variable and so can access it

Student inherits this but as a **private** variable and so cannot access it directly

This line doesn't compile

Fields and Inheritance: Shadowing

```
class A {   public int x; }

class B extends A {
   public int x;
}

class C extends B {
  public int x;

  public void action() {
    // Ways to set the x in C
    x = 10;
    this.x = 10;

    // Ways to set the x in B
    super.x = 10;
    ((B)this).x = 10;

    // Ways to set the x in A
    ((A)this.x = 10;
  }
}
```

‘this’ is a reference to the current object

‘super’ is a reference to the parent object

all classes extend Object (capital O)

if you write ‘class A {}’ you actually get ‘class extends Object {}’

Object a = new A();   // substitution principle

Don’t write code like this. No-one will understand you!

Methods and Inheritance: Overriding

- We might want to require that every Person can dance. But the way a Lecturer dances is not likely to be the same as the way a Student dances...

Know the difference: overriding vs overloading

```
class Person {
   public void dance() {
      jiggle_a_bit();
   }
}
```

← Person defines an original implementation of dance()

```
class Student extends Person {
   public void dance() {
      body_pop();
   }
}
```

← Student overrides the original

Lecturer overloads the inherited dance() method →

```
class Lecturer extends Person {
   public void dance(int duration) {...}
}
```

← Lecturer inherits the original implementation and jiggles

Expression evaluator

Objectives:

- State the purpose and effect of the @Override annotation
- Give an example of customising how an object is printed by overriding toString

Abstract classes and abstract methods

Objectives:

- Define an abstract method
- State the rules pertaining to abstract classes
- Draw a abstract class and method on a UML class diagram

Abstract Methods

- Sometimes we want to force a class to implement a method but there isn't a convenient default behaviour
- An **abstract** method is used in a base class to do this
- It has no implementation whatsoever

```
class abstract Person {
  public abstract void dance();
}

class Student extends Person {
  public void dance() {
    body_pop();
  }
}

class Lecturer extends Person {
  public void dance() {
    jiggle_a_bit();
  }
}
```

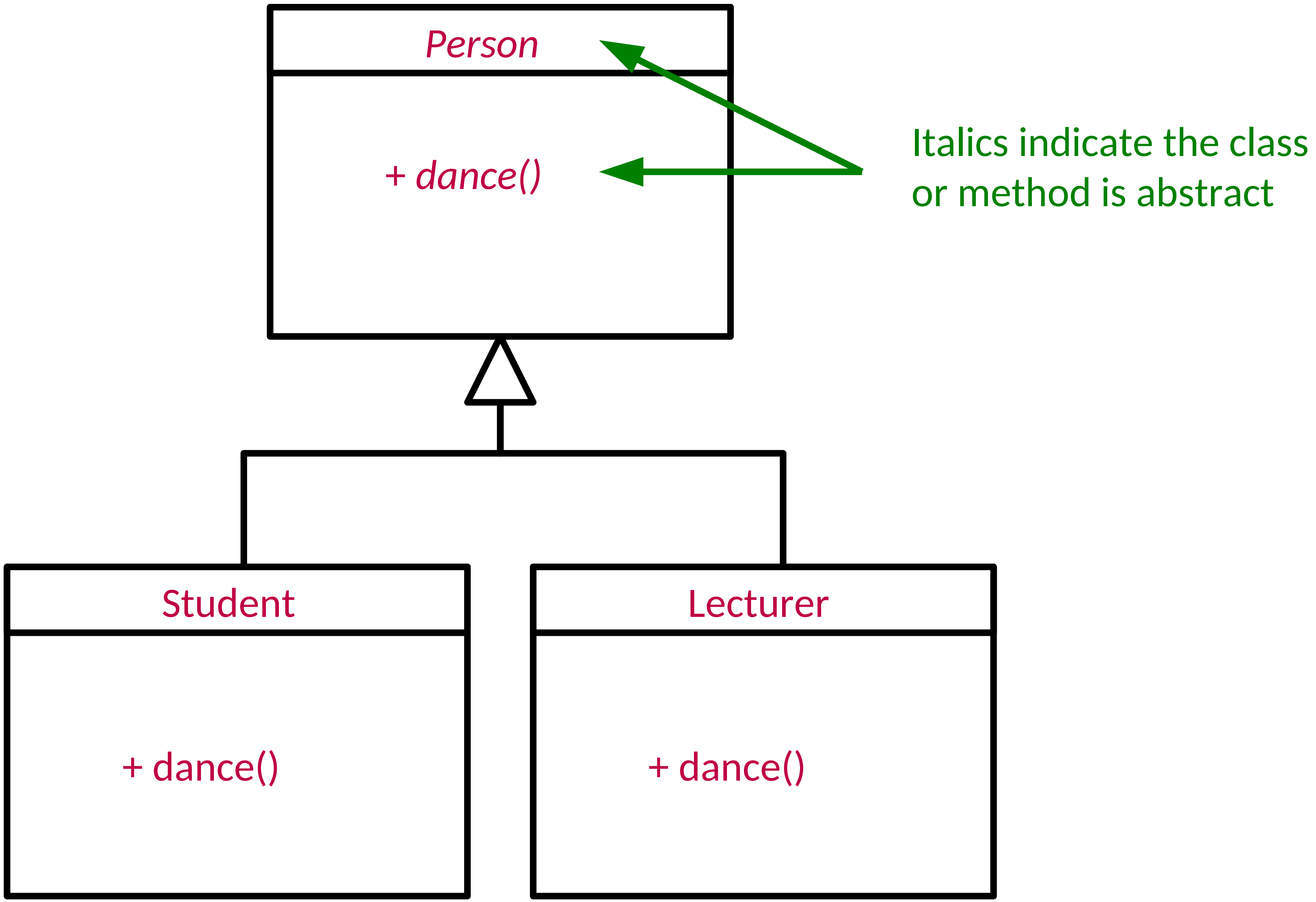
Abstract Classes

- Note that I had to declare the class abstract too. This is because it has a method without an implementation so we can't directly instantiate a Person.

```
public abstract class Person {
   public abstract void dance();
}
```

- All state and non-abstract methods are inherited as normal by children of our abstract class
- Interestingly, Java allows a class to be declared abstract even if it contains no abstract methods!

Representing Abstract Classes



Subtype polymorphism

Objectives:

- Give an example which has different behaviour under static or dynamic polymorphism
- Give an example showing how instanceof avoids a runtime error when casting an object.

Polymorphic Methods

```
Student s = new Student();
Person p = (Person)s;
p.dance();
```

- Assuming Person has a dance() method, what should happen here?

Demo: revisit expressions from last time

- General problem: when we refer to an object via a parent type and both types implement a particular method: which method should it run?

Polymorphism: values and variables can have more than one type

```
int eval(Expression e) {

}
```

← can be Literal, Mult or Plus

Polymorphic Concepts I

- **Static** polymorphism
  - Decide at <u>compile-time</u>
  - Since we don't know what the true type of the object will be, we just run the method based on its static type

```
Student s = new Student();
Person p = (Person)s;
p.dance();
```

- Compiler says “p is of type Person”
- So p.dance() should do the default dance() action in Person

C++ can do this. Java cannot

Polymorphic Concepts II

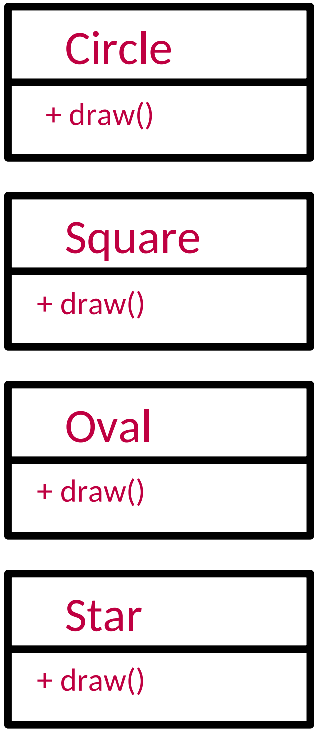
- **Dynamic** polymorphism
  - Run the method in the child
  - Must be done at run-time since that's when we know the child's type
  - Also known as ‘dynamic dispatch’

```
Student s = new Student();
Person p = (Person)s;
p.dance();
```

- Compiler looks in memory and finds that the object is really a Student
- So p.dance() runs the dance() action in Student

C++ can do this when you choose, Java does it always

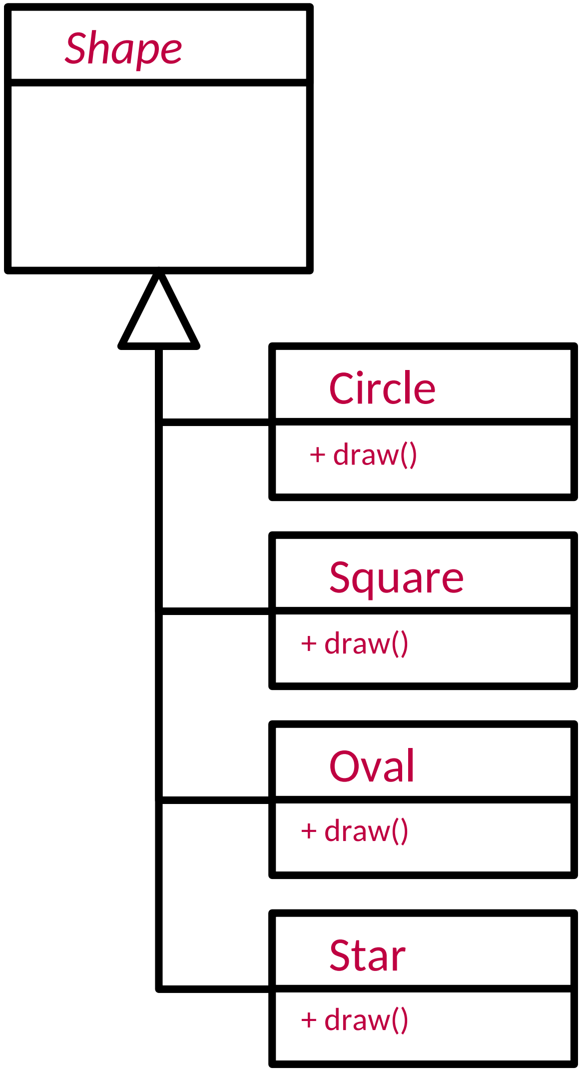
The Canonical Example I



- A drawing program that can draw circles, squares, ovals and stars
- It would presumably keep a list of all the drawing objects
- **Option 1**
  - Keep a list of Circle objects, a list of Square objects,...
  - Iterate over each list drawing each object in turn
  - What has to change if we want to add a new shape?

Demo

The Canonical Example II



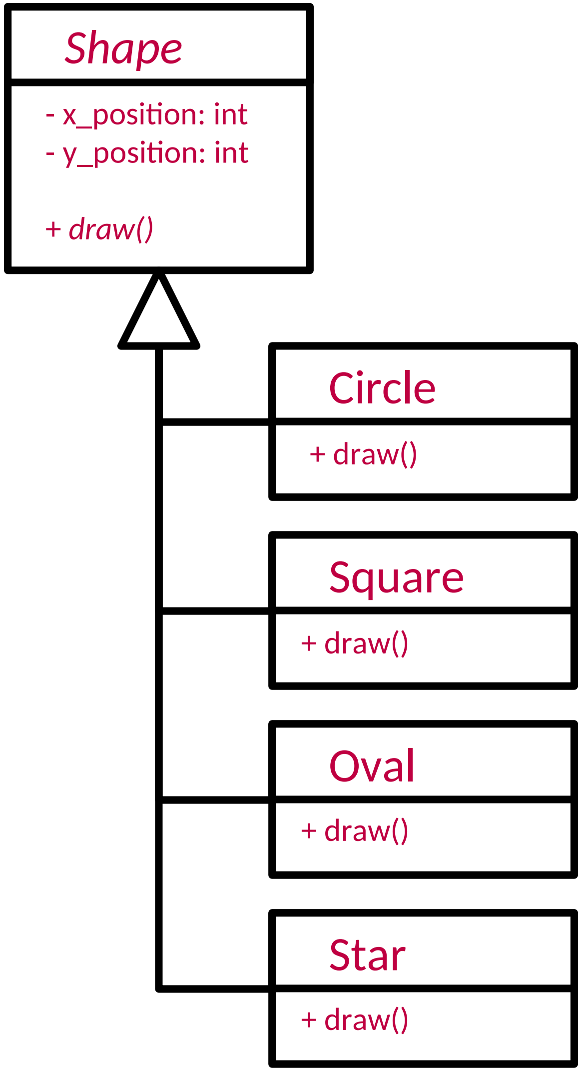
- **Option 2**
  - Keep a single list of Shape references
  - Figure out what each object really is, narrow the reference and then draw()

```
for every Shape s in myShapeList
  if (s is really a Circle)
    Circle c = (Circle)s;
    c.draw();
  else if (s is really a Square)
    Square sq = (Square)s;
    sq.draw();
  else if...
```

  - What if we want to add a new shape?

Demo

The Canonical Example III



- **Option 3 (Polymorphic)**
  - Keep a single list of Shape references
  - Let the compiler figure out what to do with each Shape reference

```
For every Shape s in myShapeList
  s.draw();
```

  - What if we want to add a new shape?

Demo

Implementations

- Java
  - All methods are dynamic polymorphic.
- Python
  - All methods are dynamic polymorphic.
- C++
  - Only functions marked *virtual* are dynamic polymorphic

- Polymorphism in OOP is an extremely important concept that you need to make <u>sure</u> you understand...

Subtype polymorphism and fields

Objectives:

- Give an example that demonstrates that fields are static polymorphic

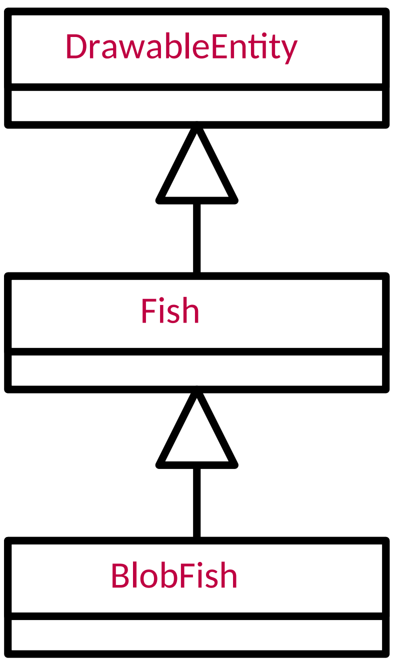
Multiple inheritance

Objectives:

- Give an example where multiple inheritance might be useful
- Explain the issue of inheriting two versions of the same method and its resolution
- Give an example of the diamond inheritance problem

Harder Problems

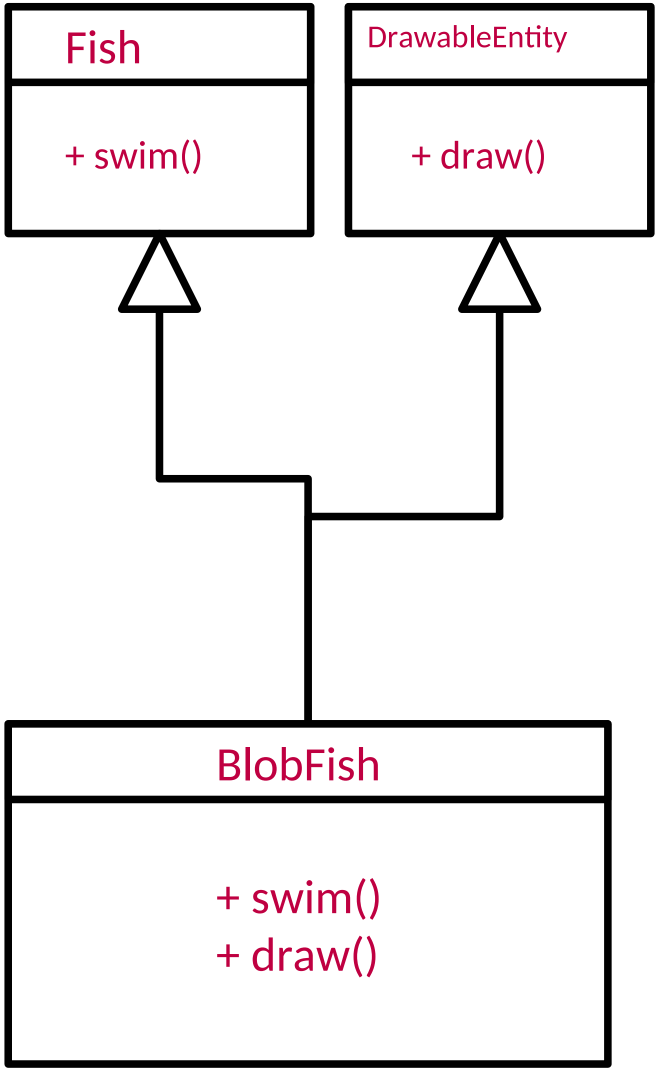
- Given a class Fish and a class DrawableEntity, how do we make a BlobFish class that is a drawable fish?



X Dependency between two independent concepts

X Conceptually wrong

Multiple Inheritance

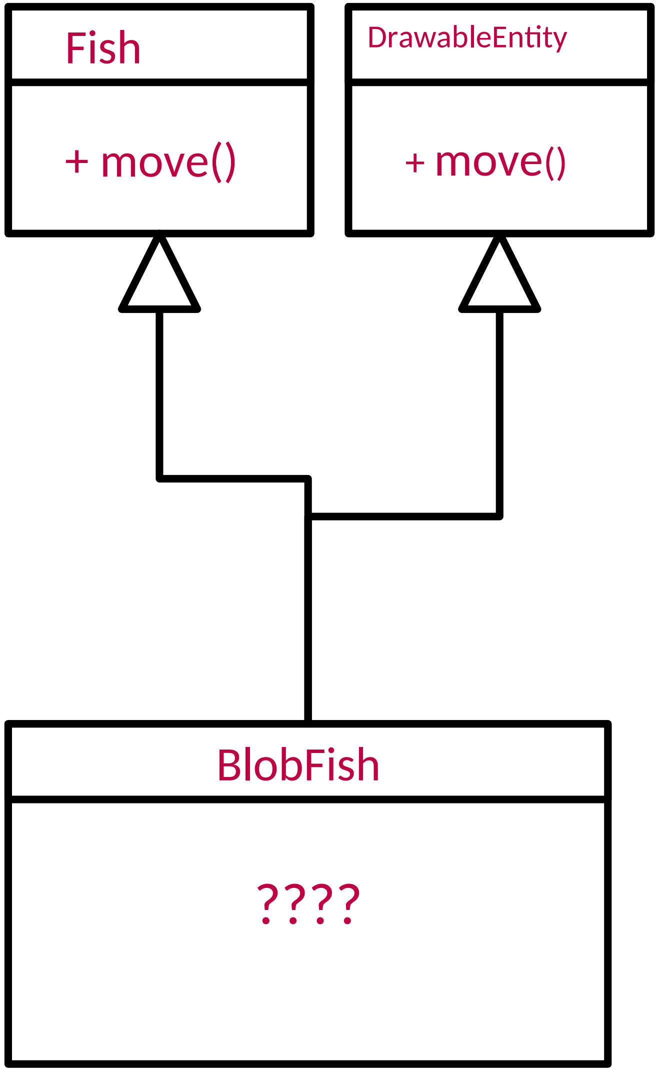


- If we multiple inherit, we capture the concept we want
- BlobFish inherits from both and is-a Fish and is-a DrawableEntity
- C++:

```
class Fish {…}
class DrawableEntity {…}

class BlobFish : public Fish,
                 public DrawableEntity {…}
```

- But...

Multiple Inheritance Problems



- What happens here? Which of the move() methods is inherited?
- Have to add some grammar to make it explicit
- C++:

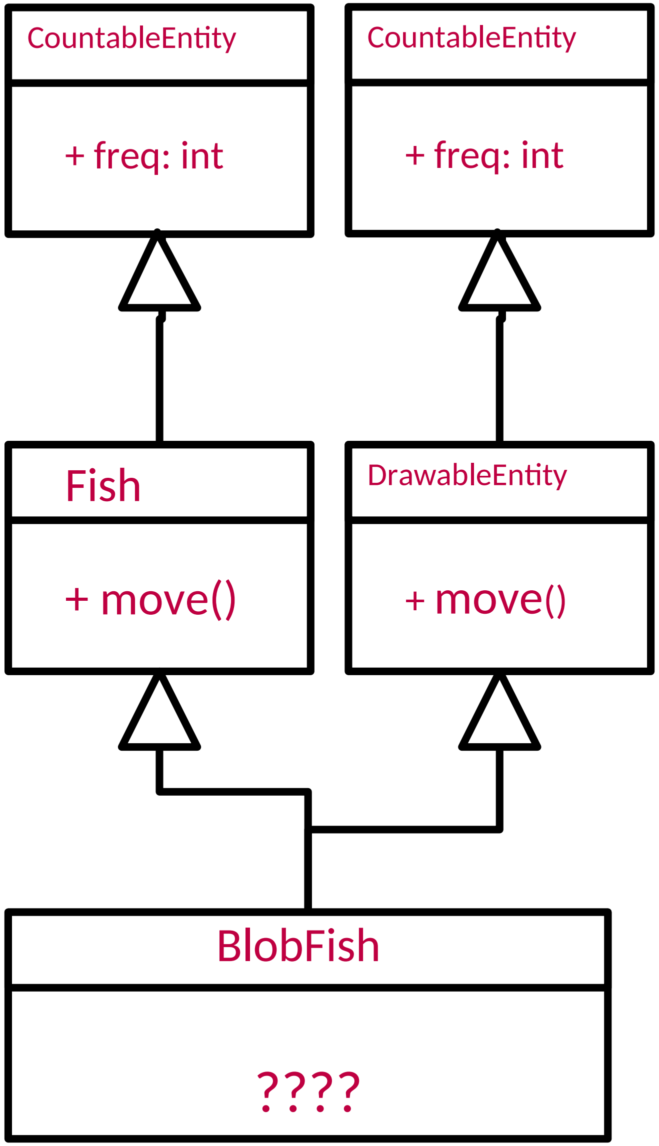
```
BlobFish *bf = new BlobFish();
bf->Fish::move();
bf->DrawableEntity::move();
```

- Yuk.

This is like field shadowing e.g.

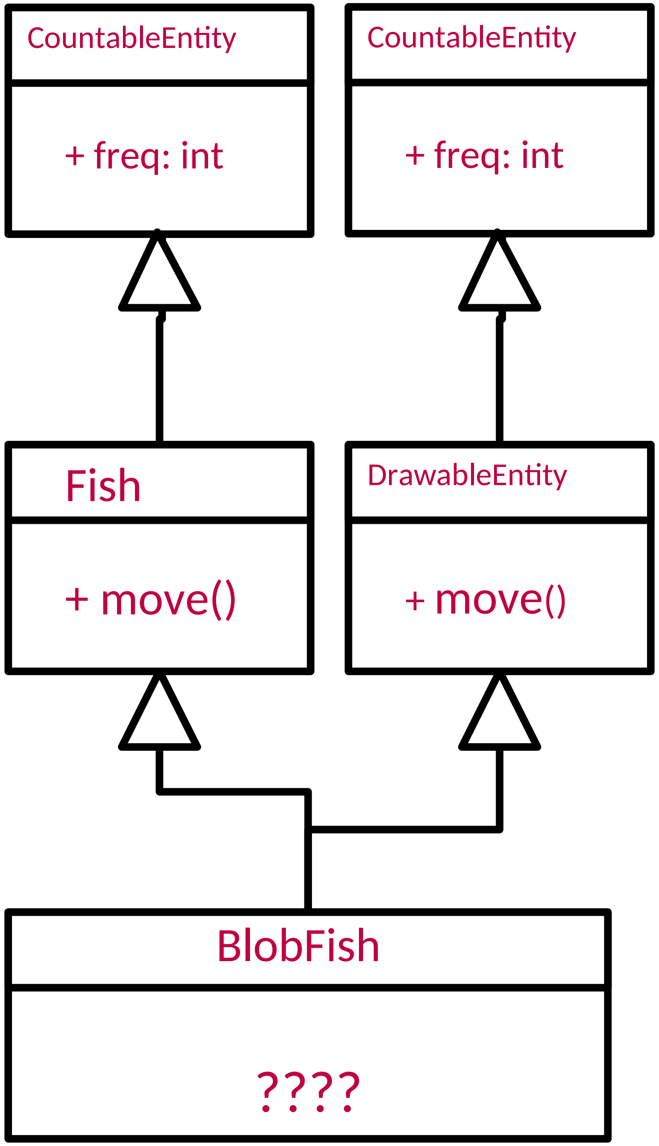
```
class A {              class B extends A {
  int x;                 int x;
}                      }
```

Multiple Inheritance Problems

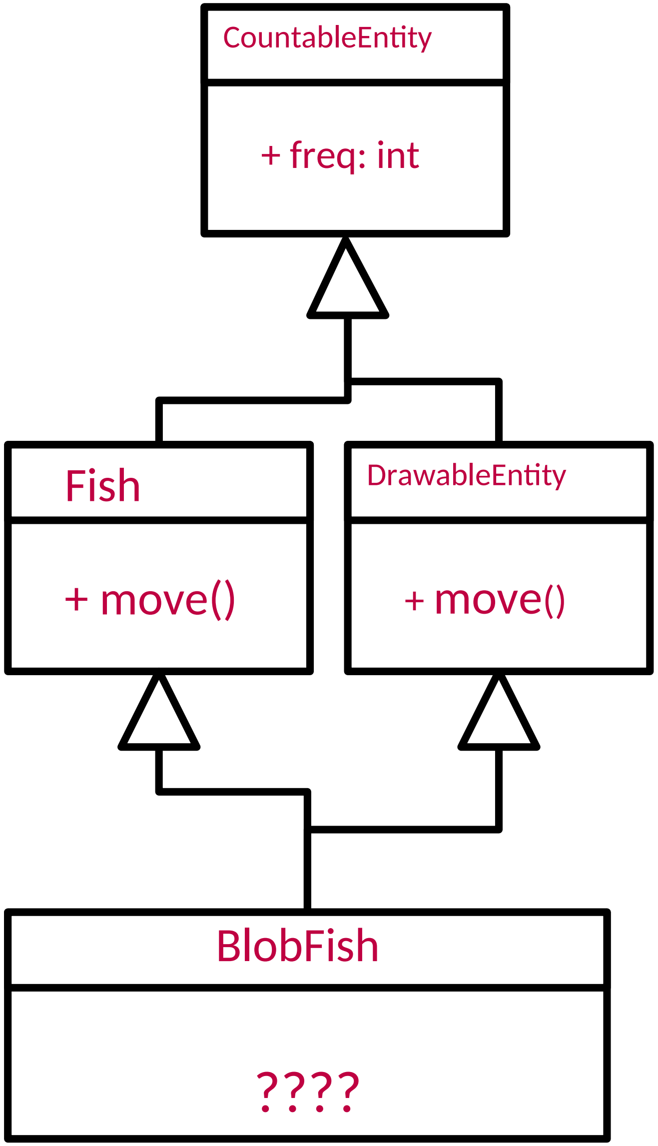


- What happens if Fish and DrawableEntity extend the same class?
- Do I get two copies?

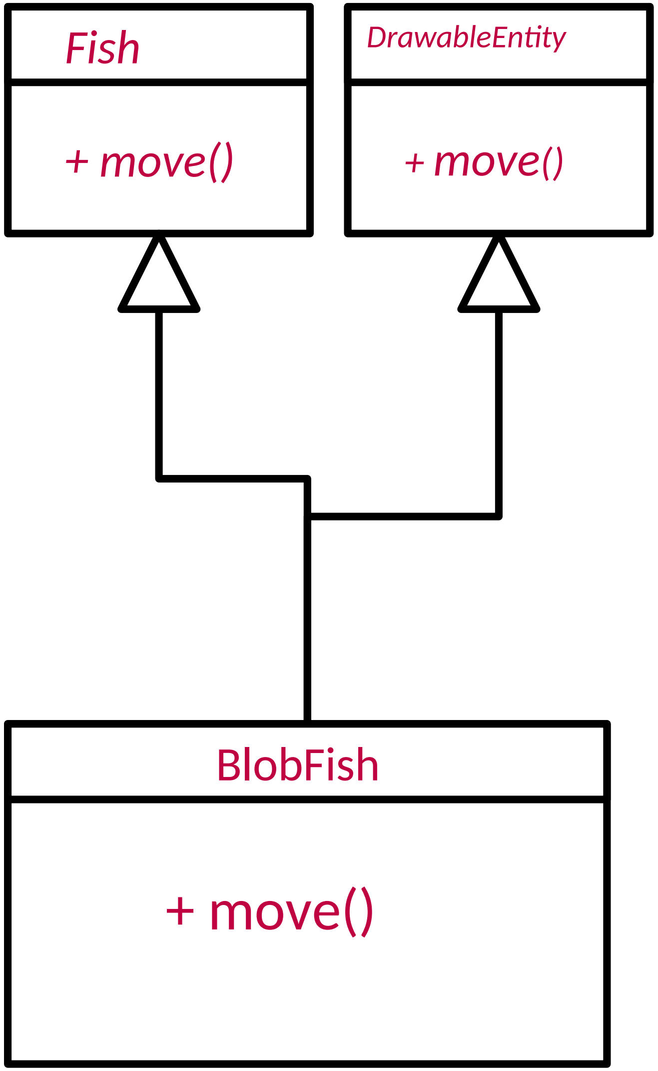
The diamond problem



or



Fixing with Abstraction



- Actually, this problem goes away if one or more of the conflicting methods is abstract

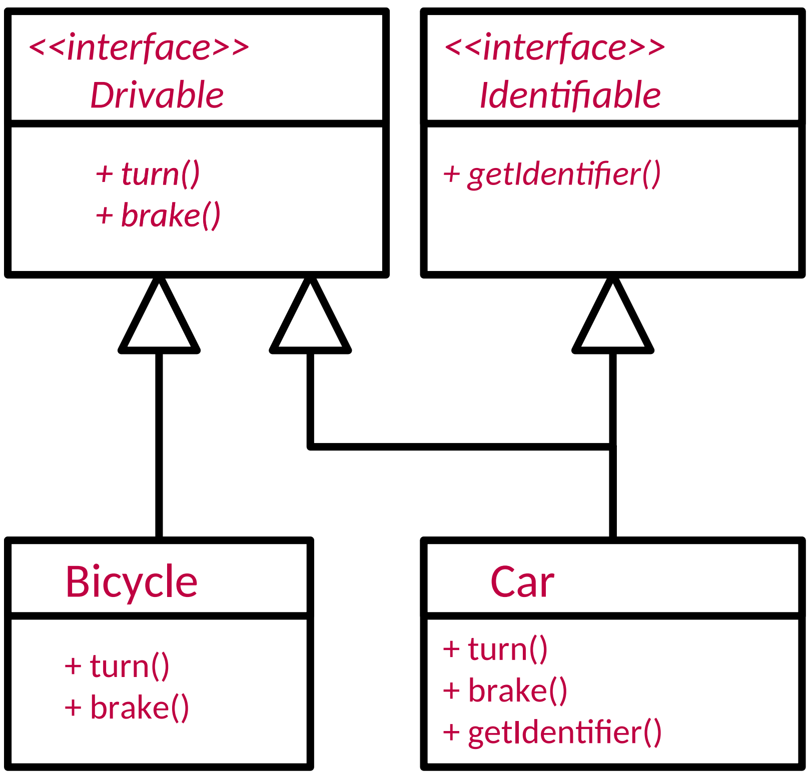
Interfaces

Objectives:

- Explain why fully-abstract classes do not incur the complexities of multiple inheritance
- Give an example of the difference between code-inheritance and type-inheritance
- Give an example of doing multiple type-inheritance in Java
- Give an example of resolving ambiguous default methods

Java's Take on it: Interfaces

- Classes can have at most **one** parent. Period.
- But special 'classes' that are totally abstract can do multiple inheritance – call these **interfaces**




```
interface Drivable {
  public void turn();
  public void brake();
}

interface Identifiable {
  public void getIdentifier();
}

class Bicycle implements Drivable {
  public void turn() {...}
  public void brake() {... }
}

class Car implements Drivable, Identifiable {
  public void turn() {...}
  public void brake() {... }
  public void getIdentifier() {...}
}
```

adjective (pointing to "Drivable")

This is type inheritance (not code inheritance)

Interfaces have a load of implicit modifiers

```
interface Foo {
   int x = 1;
   int y();
}
```

means

```
interface Foo {
    public static final int x = 1;
    public int y();
}
```

Interfaces can have default methods

```
interface Foo {
    int x = 1;
    int y();
    default int yPlusOne() {
        return y() + 1;
    }
}
```

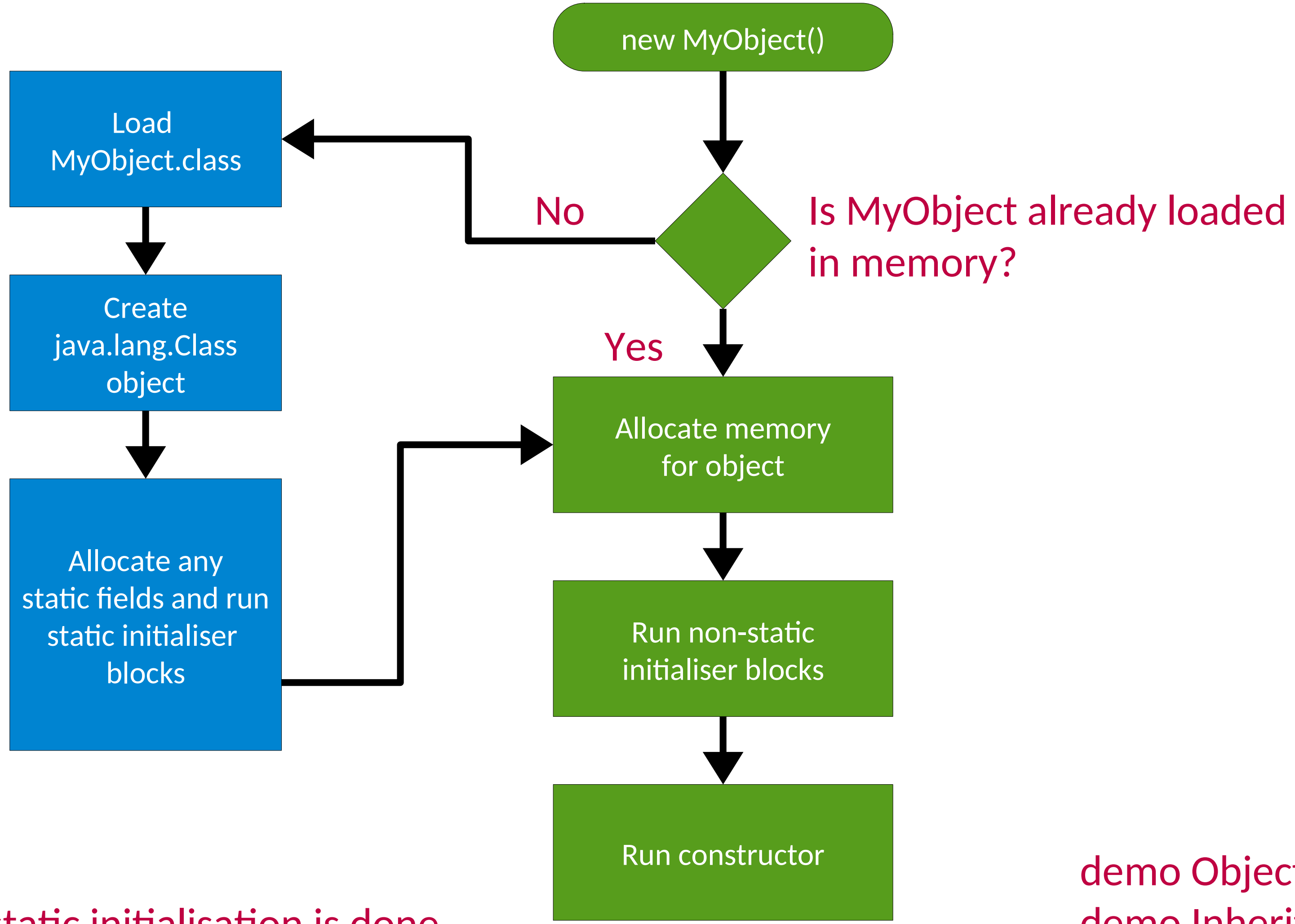
- Allows you to add new functionality without breaking old code
- If you implement conflicting default methods you have to provide your own

Object initialisation

Objectives:

- Know the order of initialization for objects
- Implement an example to show the order in which static fields, static initialisers, instance fields, constructors and the superclass are initialised
- Define the term 'constructor chaining'
- Give an example of explicitly calling the super constructor of your class

Creating Objects in Java



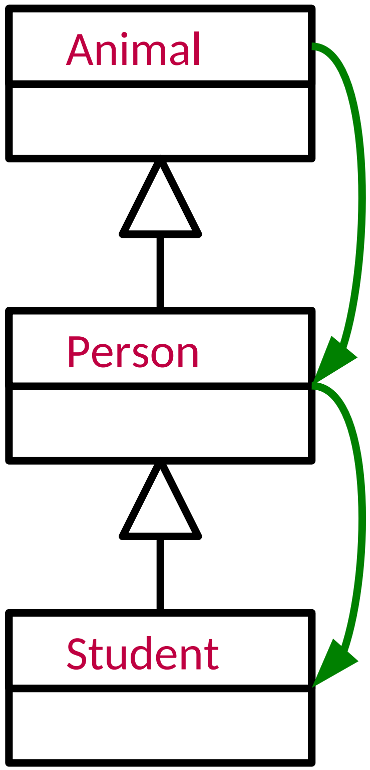
static initialisation is done in textual order

demo ObjectConstruction
demo InheritedConstruction

Constructor Chaining

- When you construct an object of a type with parent classes, we call the constructors of all of the parents in sequence

Student s = new Student();



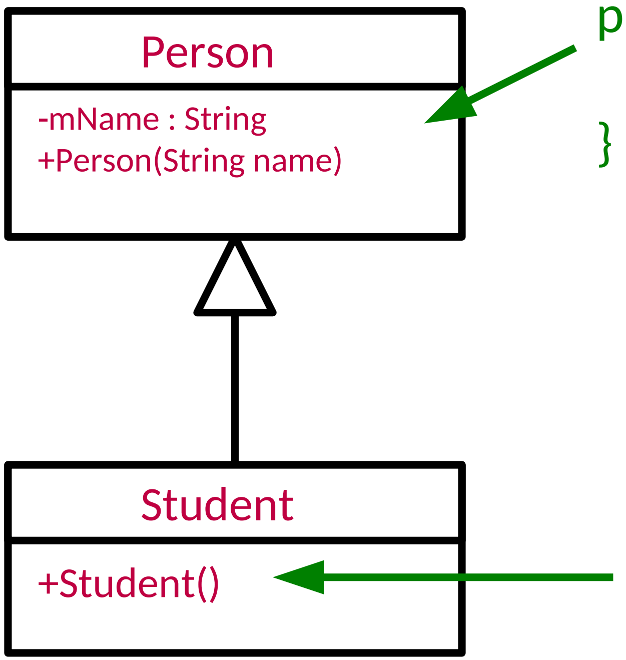
1. Call Animal()

2. Call Person()

3. Call Student()

Chaining without Default Constructors

- What if your classes have explicit constructors that take arguments? You need to explicitly chain
- Use **super** in Java:




```
public Person (String name) {
    mName=name;
}
```

```
public Student () {
    super("Bob");
}
```

Demo: NoDefaultConstructor

Object destruction and garbage collection

Objectives:

- Describe deterministic destruction and how it permits Resource Acquisition Is Initialisation (RAII)
- Give an example of how try-with-resources can be used to guarantee the release of resources
- Explain why finalizers cannot be used for releasing resources reliably
- Describe the mark-and-sweep algorithm
- Show how we can still 'leak' memory even with a garbage collector

Deterministic Destruction

- Objects are created, used and (eventually) destroyed. Destruction is very language-specific
- Deterministic destuction is what you would expect
  - Objects are deleted at predictable times
  - Perhaps manually deleted (C++):

```
void UseRawPointer()
{
   MyClass *mc = new MyClass();
   // ...use mc...
   delete mc;
}
```

  - Or auto-deleted when out of scope (C++):

```
void UseSmartPointer()
{
   MyClass mc;
  // ...use mc...
}  // mc deleted here
```

In C++ this means create a new instance of MyClass on the stack using the default constructor

Destructors

- Most OO languages have a notion of a destructor too
  - Gets run when the object is destroyed
  - Allows us to release any resources (open files, etc) or memory that we might have created especially for the object

C++

```
class FileReader {
  public:

    // Constructor
    FileReader() {
      f = fopen("myfile","r");
    }

    // Destructor
    ~FileReader() {
      fclose(f);
    }

  private :
    FILE *file;
}
```

```
int main(int argc, char ** argv) {

  FileReader f;

  // Use object here
  ...

}  // object destructor called here
```

This is called RAII = Resource Acquisition Is Initialisation

Non-Deterministic Destruction

- Deterministic destruction is easy to understand and seems simple enough. But it turns out we humans are rubbish of keeping track of what needs deleting when
- We either forget to delete (→ memory leak) or we delete multiple times (→ crash)
- **We can instead leave it to the system to figure out when to delete**
  - **“Garbage Collection”**
  - The system somehow figures out when to delete and does it for us
  - In reality it needs to be cautious and sure it can delete. This leads to us not being able to predict exactly when something will be deleted!!
- **This is the Java approach!!**

Demo: Finalizer

What about Destructors?

- Conventional destructors don’t make sense in non-deterministic systems
  - When will they run?
  - Will they run at all??
- Instead we have finalisers: same concept but they only run when the system deletes the object (which may be never!)
- Java provides try-with-resources as an alternative to RAII

Demo: TryWithResources

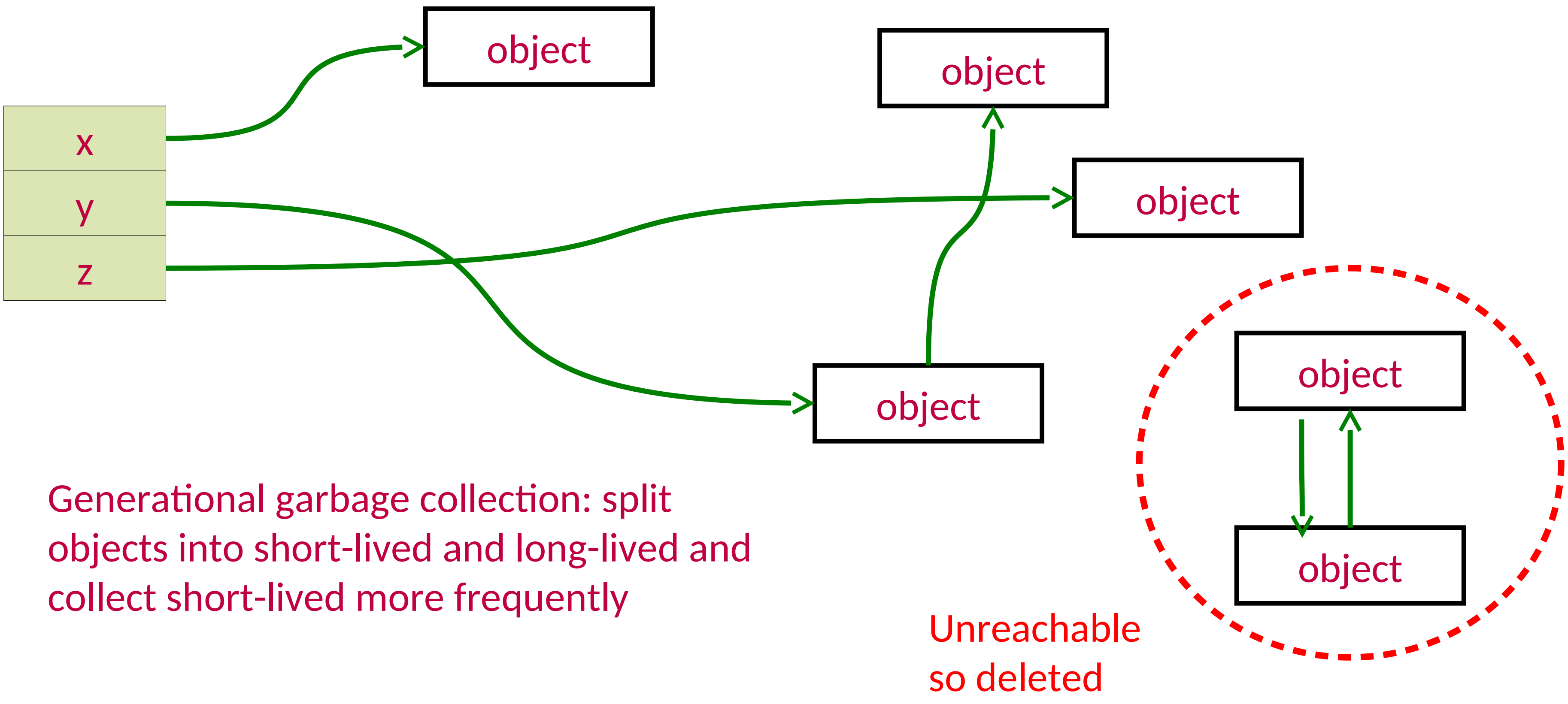
Garbage Collection

- So how exactly does garbage collection work? How can a system know that something can be deleted?
- The garbage collector is a separate process that is constantly monitoring your program, looking for things to delete
- Running the garbage collector is obviously not free. If your program creates a lot objects, you will soon notice the collector running
    - Can give noticeable pauses to your program!
    - But minimises memory leaks (it does not prevent them…)
- Keywords:
    - ‘Stop the world’ - pause the program when collecting garbage
    - ‘incremental’ - collect in multiple phases and let the program run in the gaps
    - ‘concurrent’ - no pauses in the program

Demo: Leak

Mark and sweep

- Start with a list of all references you can get to
- Follow all references recursively, marking each object
- Delete all objects that were not marked



Generational garbage collection: split objects into short-lived and long-lived and collect short-lived more frequently

Boxing and Unboxing

Objectives:

- Define the terms boxing and unboxing
- Give an example of how auto-unboxing can give rise to unexpected errors

Boxing and unboxing

- Boxing: turn an int into an Integer
- Unboxing: turn an Integer into an int
- Java will do auto-boxing and unboxing

```
public void something(Integer I) {
    ...
}

int i = 4;
something(i);
```

auto-boxing

```
public void other(int i) {
    …
}

Integer i = null;
other(i);
```

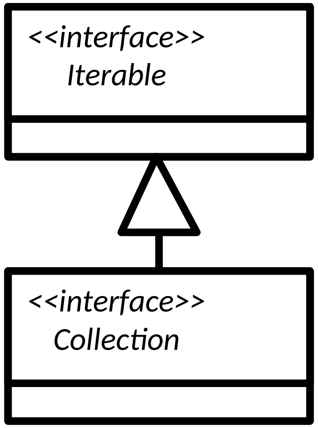
auto-unboxing
(and a NPE)

Collections

Objectives:

- Know the basic inheritance structure of collections including Iterable and Collection interfaces
- Be able to use Sets, Lists, Maps, Queues
- Have a general idea of the complexity of operations on different implementations of the collection types

Java's Collections Framework



- Important chunk of the class library
- A collection is some sort of grouping of things (objects)
- Usually when we have some grouping we want to go through it ("***iterate*** over it")

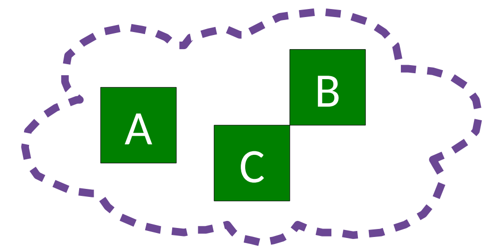
- The Collections framework has two main interfaces: Iterable and Collection. They define a set of operations that all classes in the Collections framework support
- add(Object o), clear(), isEmpty(), etc.

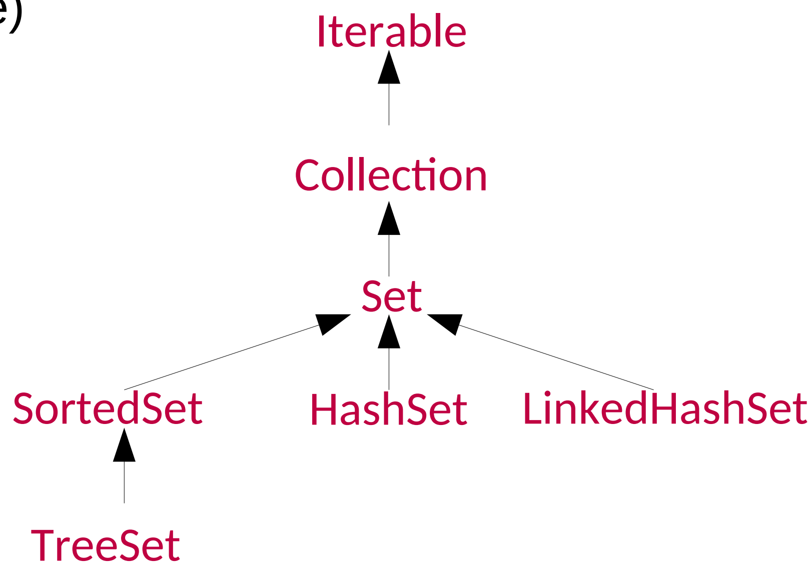
Sometimes an operation doesn't make sense – throw UnsupportedOperationError

Sets

<<interface>> Set

- A collection of elements with no duplicates that represents the mathematical notion of a set
- TreeSet: objects stored in order
- HashSet: objects in unpredictable order but fast to operate on (see Algorithms course)





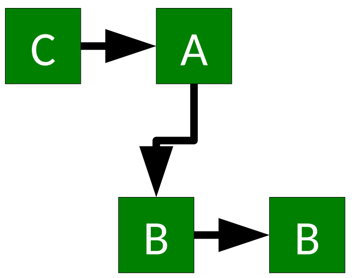

```
Set<Integer> ts = new TreeSet<>();
ts.add(15);
ts.add(12);
ts.contains(7);  // false
ts.contains(12); // true
ts.first(); // 12 (sorted)
```

A form of type inference

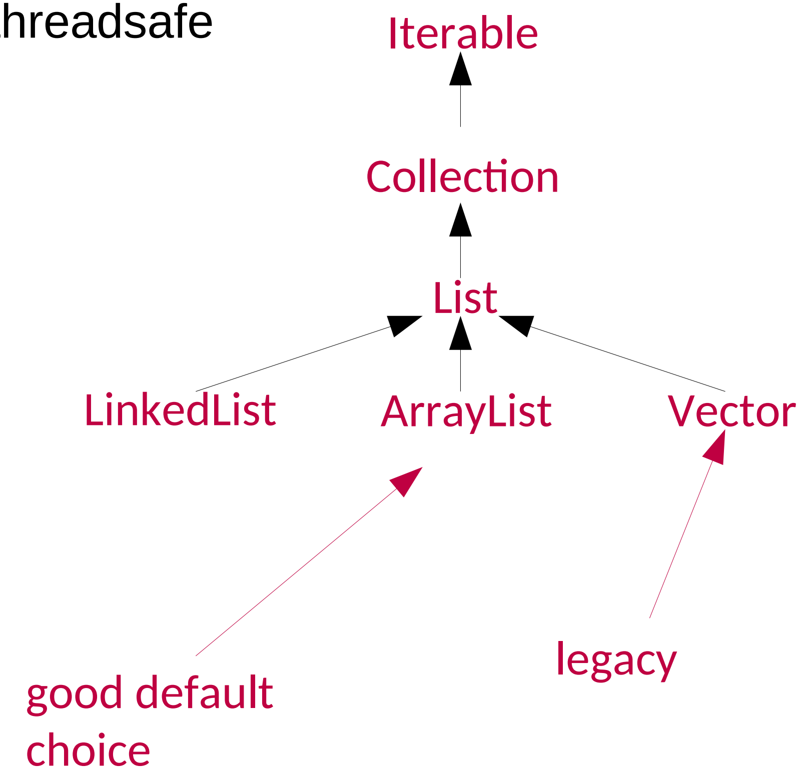
Lists

<<interface>> List

- An ordered collection of elements that may contain duplicates
- LinkedLIst: linked list of elements
- ArrayList: array of elements (efficient access)
- Vector: Legacy, as ArrayList but threadsafe



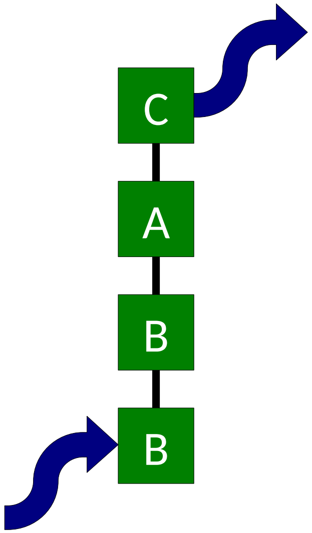

```
List<Double> ll = new ArrayList<>();
ll.add(1.0);
ll.add(0.5);
ll.add(3.7);
ll.add(0.5);
ll.get(1);  // get element 2 (==3.7)
```



Queues

<<interface>> Queue

- An ordered collection of elements that may contain duplicates and supports removal of elements from the head of the queue
- offer() to add to the back and poll() to take from the front
- LinkedList: supports the necessary functionality
- PriorityQueue: adds a notion of priority to the queue so more important stuff bubbles to the top

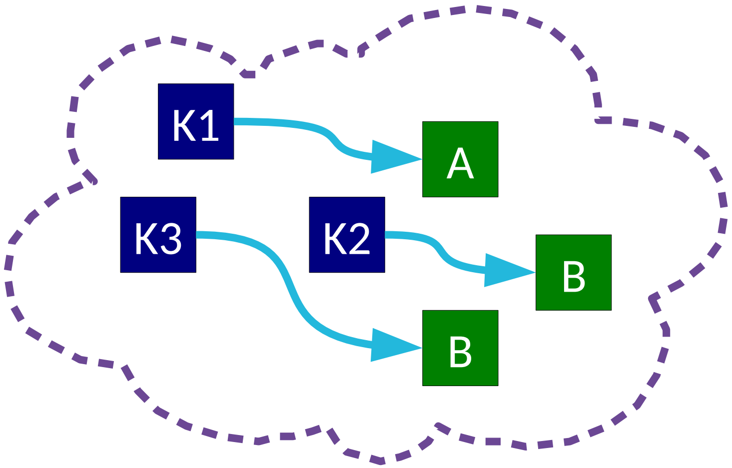



```
Queue<Double> ll = new LinkedList<>();
ll.offer(1.0);
ll.offer(0.5);
ll.poll(); // 1.0
ll.poll(); // 0.5
```

Maps

<<interface>> Map

- Like dictionaries in ML
- Maps key objects to value objects
- Keys must be unique
- Values can be duplicated and (sometimes) null.
- TreeMap: keys kept in order
- HashMap: Keys not in order, efficient (see Algorithms)




```
Map<String, Integer> tm =  new TreeMap<String,Integer>();
tm.put("A",1);
tm.put("B",2);
tm.get("A");   // returns 1
tm.get("C"); // returns null
tm.contains("G");  // false
```

	Hash Table	Resizable Array	Balanced Tree	Linked List	Hash Table + Linked List
Set	HashSet		TreeSet		LinkedHashSet
List		ArrayList		LinkedList	
Deque		ArrayDeque		LinkedList	
Map	HashMap		TreeMap		LinkedHashMap

	get	add	contains	next	remove(0)	iterator. remove
ArrayList	O(1)	O(1)	O(n)	O(1)	O(n)	O(n)
LinkedList	O(n)	O(1)	O(n)	O(1)	O(1)	O(1)

		add	contains	next
HashSet		O(1)	O(1)	O(h/n)
TreeSet		O(log n)	O(log n)	O(log n)
LinkedHashSet		O(1)	O(1)	O(1)

	get		containsKey	next
HashMap	O(1)		O(1)	O(h/n)
LinkedHashMap	O(1)		O(1)	O(1)
TreeMap	O(log n)		O(log n)	O(log n)

	peek	offer			poll	size
LinkedList	O(1)	O(log n)			O(log n)	O(1)
ArrayDeque	O(1)	O(1)			O(1)	O(1)
PriorityQueue	O(1)	O(log n)			O(log n)	O(1)

Source: https://docs.oracle.com/javase/8/docs/technotes/guides/collections/overview.html

Source: Java Generics and Collections (pages: 188, 211, 222, 240)

Don’t just memorise these – think about how the datastructure works

Specific return type and general argument

- Should your method take a Set, a SortedSet or a TreeSet?
- General rule of thumb:
  - use the most general type possible for parameters
  - use the most specific type possible for return values (without over committing your implementation)

Iterators

Objectives:

- Iterate over a collection using a for-loop, a for-each loop and an Iterator
- Define the concept of Fail-Fast behaviour
- Give an example of modifying collection structure using an Iterator

Iteration

- for loop

```
LinkedList<Integer> list = new LinkedList<Integer>();
...
for (int i=0; i<list.size(); i++) {
    Integer next = list.get(i);
}
```

- foreach loop (Java 5.0+)

```
LinkedList list = new LinkedList();
...
for (Integer i : list) {
   ...
}
```

Iterators

- What if our loop changes the structure?

```
for (int i=0; i<list.size(); i++) {
    If (i==3) list.remove(i);
}
```

- Java introduced the Iterator class

```
Iterator<Integer> it = list.iterator();

while(it.hasNext()) {Integer i = it.next();}

for (; it.hasNext(); ) {Integer i = it.next();}
```

- Safe to modify structure

```
while(it.hasNext()) {
    it.remove();
}
```

Demo: Fast fail behaviour

Comparing objects

Objectives:

- Understand the difference between reference equality and value equality
- Be aware of the 'equals contract' and give an example of overriding the equals method
- Give an example of implementing a natural ordering on a class using the Comparable interface
- Give an example of implementing a Comparator

Comparing Objects

- You often want to impose orderings on your data collections
- For TreeSet and TreeMap this is automatic

```
TreeMap<String, Person> tm = ...
```

- For other collections you may need to explicitly sort

```
LinkedList<Person> list = new LinkedList<Person>();
//...
Collections.sort(list);
```

- For numeric types, no problem, but how do you tell Java how to sort Person objects, or any other custom class?

Comparing Primitives

>	Greater Than
>=	Greater than or equal to
==	Equal to
!=	Not equal to
<	Less than
<=	Less than or equal to

- Clearly compare the value of a primitive
- But what does (ref1==ref2) do??
  - Test whether they point to the same object?
  - Test whether the objects they point to have the same state?

Reference Equality

- r1==r2, r1!=r2
- These test *reference equality*
- i.e. do the two references point ot the same chunk of memory?

```
Person p1 = new Person("Bob");
Person p2 = new Person("Bob");

(p1==p2);     <-- False (references differ)

(p1!=p2);     <-- True (references differ)

(p1==p1);     <-- True
```

Value Equality

- Use the equals() method in Object
- Default implementation just uses reference equality (==) so we have to override the method

```
public EqualsTest {
    public int x = 8;

    @Override
    public boolean equals(Object o) {
        EqualsTest e = (EqualsTest)o;
        return (this.x==e.x);
    }

    public static void main(String args[]) {
        EqualsTest t1 = new EqualsTest();
        EqualsTest t2 = new EqualsTest();
        System.out.println(t1==t2);
        System.out.println(t1.equals(t2));
    }
}
```

Learn the ‘equals’ contract

Demo: What’s wrong with equals

Java Quirk: hashCode()

- Object also gives classes hashCode()
- Code assumes that if equals(a,b) returns true, then a.hashCode() is the same as b.hashCode()
- So you should override hashCode() at the same time as equals()

Learn the ‘hashcode’ contract

Comparable<T> Interface I

int compareTo(T obj);

- Part of the Collections Framework
- Doesn't just tell us true or false, but smaller, same, or larger: useful for sorting.
- Returns an integer, r:
  - r<0 This object is less than obj
  - r==0 This object is equal to obj
  - r>0 This object is greater than obj

Comparable<T> Interface II

```
public class Point  implements Comparable<Point> {
    private final int mX;
    private final int mY;
    public Point (int, int y) { mX=x; mY=y; }

    // sort by y, then x
    public int compareTo(Point p) {
        if ( mY>p.mY) return 1;
        else if (mY<p.mY) return -1;
        else {
            if (mX>p.mX) return 1;
            else if (mX<p.mX) return -1;
            else return 0.
        }
    }
}
```

implementing Comparable defines a natural ordering for your class

ideally this should be consistent with equals i.e. x.compareTo(y) == 0 <=> x.equals(y)

must define a total order

```
// This will be sorted automatically by y, then x
Set<Point> list = new TreeSet<Point>();
```

Demo

Comparator<T> Interface I

int compare(T obj1, T obj2)

- Also part of the Collections framework and allows us to specify a specific ordering for a particular job
- E.g. a Person might have natural ordering that sorts by surname. A Comparator could be written to sort by age instead...

Comparator<T> Interface II

```
public class Person  implements Comparable<Person> {
    private String mSurname;
    private int mAge;
    public int compareTo(Person p) {
        return mSurname.compareTo(p.mSurname);
    }
}

public class AgeComparator implements Comparator<Person> {
  public int compare(Person p1, Person p2) {
     return (p1.mAge-p2.mAge);
  }
}

...
ArrayList<Person> plist = ...;
...
Collections.sort(plist);   // sorts by surname
Collections.sort(plist, new AgeComparator());   // sorts by age
```

delegate to the field's compareTo method

Operator Overloading

- Some languages have a neat feature that allows you to overload the comparison operators. e.g. in C++

```
class Person {
  public:
    Int mAge
    bool operator==(Person &p) {
        return (p.mAge==mAge);
    };
  }


Person a, b;
b == a;   // Test value equality
```

people argue about whether this is good or bad.

(Java won't let you do it)

Exception handling

Objectives:

- Contrast various approaches for error handling: return codes, deferred error handling and exceptions
- Give an example of a good use of a checked or unchecked exceptions
- Reason about the pros and cons of exceptions and their best practice

Return Codes

- The traditional imperative way to handle errors is to return a value that indicates success/failure/error

```
public int divide(double a, double b) {
   if (b==0.0) return -1; // error
   double result = a/b;
   return 0; // success
}

...

if ( divide(x,y)<0) System.out.println("Failure!!");
```

Go – returns a pair res, err
Haskell – Maybe type

- Problems:
  - Could ignore the return value
  - Have to keep checking what the return values are meant to signify, etc.
  - The actual result often can't be returned in the same way
  - Error handling code is mixed in with normal execution

Deferred Error Handling

- A similar idea (with the same issues) is to set some state in the system that needs to be checked for errors.
- C++ does this for streams:

```
ifstream file( "test.txt" );
if ( file.good() )
{
    cout << "An error occurred opening the file" << endl;
}
```

Exceptions

- An exception is an object that can be *thrown* or *raised* by a method when an error occurs and *caught* or *handled* by the calling code
- Example usage:

```
try {
  double z = divide(x,y);
}
catch(DivideByZeroException d) {
  // Handle error here
}
```

Flow Control During Exceptions

- When an exception is thrown, any code left to run in the try block is skipped

```
double z=0.0;
boolean failed=false;
try {
  z = divide(5,0);
  z = 1.0;
}
catch(DivideByZeroException d) {
  failed=true;
}
z=3.0;
System.out.println(z+" "+failed);
```

Throwing Exceptions

- An exception is an object that has Exception as an ancestor
- So you need to create it (with new) before throwing

```
double divide(double x, double y) throws DivideByZeroException {
  if (y==0.0) throw new DivideByZeroException();
  else return x/y;
}
```

Multiple Handlers

- A try block can result in a range of different exceptions. We test them in sequence

```
try {
   FileReader fr = new FileReader("somefile");
   Int r = fr.read();
}
catch(FileNoteFound fnf) {
   // handle file not found with FileReader
}
catch(IOException d) {
   // handle read() failed
}
```

finally

- With resources we often want to ensure that they are closed whatever happens

```
try {
  fr,read();
  fr.close();
}
catch(IOException ioe) {
  // read() failed but we must still close the FileReader
  fr.close();
}
```

finally II

- The finally block is added and will *always* run (after any handler)

```
try {
  fr.read();
}
catch(IOException ioe) {
  // read() failed
}
finally {
  fr.close();
}
```

Remember try-with-resources

Creating Exceptions

- Just extend Exception (or RuntimeException if you need it to be unchecked). Good form to add a detail message in the constructor but not required.

```
public class DivideByZero extends Exception {}

public class ComputationFailed extends Exception {
    public ComputationFailed(String msg) {
        super(msg);
    }
}
```

If your exception is caused by another then chain them - demo

- You can also add more data to the exception class to provide more info on what happened (e.g. store the numerator and denominator of a failed division)

Keyword: exception chaining

Exception Hierarchies

- You can use inheritance hierarchies

```
public class MathException extends Exception {...}
public class InfiniteResult extends MathException {...}
public class DivByZero extends MathException {...}
```

- And catch parent classes

```
try {
   ...
}
catch(InfiniteResult ir) {
   // handle an infinite result
}
catch(MathException me) {
  // handle any MathException or DivByZero
}
```

Checked vs Unchecked Exceptions

- Checked: must be handled or passed up.
  - Used for recoverable errors
  - Java requires you to declare checked exceptions that your method throws
  - Java requires you to catch the exception when you call the function

```
double somefunc() throws SomeException {}
```

- Unchecked: not expected to be handled. Used for programming errors
  - Extends RuntimeException
  - Good example is NullPointerException

Evil I: Exceptions for Flow Control

- At some level, throwing an exception is like a GOTO
- Tempting to exploit this

```
try {
  for (int i=0; ; i++) {
    System.out.println(myarray[i]);
  }
}
catch (ArrayOutOfBoundsException ae) {
  // This is expected
}
```

- This is not good. Exceptions are for exceptional circumstances only
  - Harder to read
  - May prevent optimisations

Evil II: Blank Handlers

- Checked exceptions must be handled
- Constantly having to use try...catch blocks to do this can be annoying and the temptation is to just gaffer-tape it for now

```
try {
  FileReader fr = new FileReader(filename);
}
catch (FileNotFound fnf) {
}
```

If it can't happen then throw a chained RuntimeException

- ...but we never remember to fix it and we could easily be missing serious errors that manifest as bugs later on that are extremely hard to track down

Advantages of Exceptions

- Advantages:
  - Class name can be descriptive (no need to look up error codes)
  - Doesn't interrupt the natural flow of the code by requiring constant tests
  - The exception object itself can contain state that gives lots of detail on the error that caused the exception
  - Can't be ignored, only handled
- Disadvantages:
  - Surprising control flow – exceptions can be thrown from anywhere
  - Lends itself to single threads of execution
  - Unrolls control flow, doesn’t unroll state changes

Covariance and Contravariance

Objectives:

- Define covariance and contravariance
- Give an example arguing for the correctness of covariant return types
- Give an example arguing for the correctness of contravariant parameter types
- Show what problems arise with covariant arrays in Java
- Show how wildcard types in generics allow us to capture covariance

Remember the substitution principle?

- If A extends B then I should be able to use B everywhere I expect an A

```
class A {

   Polygon getShape() {
     return new Polygon(…);
   }

}
```

```
class B extends A {

   Polygon getShape() {
     return …
   }

}
```

```
void process(A o) {
   drawShape(o.getShape());
}
process(new B());
```

Covariant return types are substitutable

- Overriding methods are covariant in their return types

```
class A {

  Polygon getShape() {
    return new Polygon(…);
  }

}
```

```
class B extends A {

  Triangle getShape() {
    return …
  }

}
```

```
void process(A o) {
   drawShape(o.getShape());
}
process(new B());
```

o.getShape() returns a Triangle but Triangle is a subtype of Polygon and so by substitutability we can pass it to drawShape

Contravariant parameters also substitute

- Overriding methods can be contravariant in their parameters

```
class A {

   void setShape(Triangle o) {
     …
   }

}
```

```
class B extends A {

   void setShape(Polygon o) {
     …
   }

}
```

o.setShape() wants a Polygon and by substitutability its ok to pass it a Triangle

You can't actually do this in Java! The two setShapes are overloads not overrides

```
void process(A o) {
   o.setShape(new Triangle());
}
process(new B());
```

Java arrays are covariant

- If B is a subtype of A then B[] is a subtype of A[]

```
String[] s = new String[] { “v1”, “v2” };

Object[] t = s;

Object v = t[0];

t[1] = new Integer(4);
```

- `Object[] t = s;` ← Compiles – arrays are covariant
- `Object v = t[0];` ← Works – t[0] is actually a String but we can assign that to Object
- `t[1] = new Integer(4);` ← Fails (at runtime) – t[] is actually an array of Strings, you can’t put an Integer in it

Imagine if Arrays were a generic class

```
class Array<Object> {

  // Object x = array[i]
  Object get(int index) {
    …
  }

  // array[i] = value
  void set(int index,
           Object value) {
    …
  }
}
```

```
class Array<String> {

  // String x = array[i]
  String get(int index) {
    …
  }

  // array[i] = value
  void set(int index,
           String value) {
    …
  }
}
```

Covariant return type – all is good!

Covariant parameter type – bad news

Generics in Java are not covariant

- if B is a subtype of A then T<B> is not a subtype of T<A>

```
List<String> s = List.of(“v1”, “v2”);

List<Object> t = s;            ◄──── Does not compile

Object v = t.get(0);           ◄──── Would be safe – we can assign String to Object

t.set(1,new Integer(4));       ◄──── Is not safe
```

Wildcards let us capture this

- if B is a subtype of A then T<B> is a subtype of T<? extends A>

```
List<String> s = List.of("v1", "v2");

List<? extends Object> t = s;

Object v = t.get(0);

t.set(1,new Integer(4));
```

Compiles

Works: '? extends Object' is assignable to Object

Does not compile – the compiler knows it needs something that extends object but it doesn't know what it is!

Inner classes and lambda

Objectives:

- Give examples showing the capabilities of: static inner classes, instance inner classes, method-local classes, anonymous inner classes.
- Define the concept of a functional interface
- Give an example of how to use a lambda in Java and how to enable others to pass a lambda to your methods.
- Recognise the terms: statement lambda, expression lambda and method reference

Inner classes

```
class Outer {

  private static void f();
  private int x = 4;

  static class StaticInner {

     void g() {
        f();
        new Outer().x = 3;
     }
  }

  class InstanceInner {
     int g() {
        return x + 1;
     }
  }

}
```

Inner classes may not have static members

Static inner classes are a member of the outer class and so can access private members

Instance inner classes are a member of the outer object and so can access outer instance variables:

Outer o = new Outer();
InstanceInner i = o.new InstanceInner()

Method-local classes

```
class Outer {

  int y = 6;

  void f() {
     int x = 5;
     class Foo {
        int g() {
          return x + y + 1;
        }
     }
     Foo foo = new Foo();

  }

}
```

Method-local classes in instance methods can access instance variables of the class

Method-local classes can access local variables (and so are never static classes).

Anonymous inner classes

```
class Outer {

  int y = 6;

  Object f() {
     int x = 5;
     Object o = new Object() {
       public String toString() {
         return String.valueOf(x+y+1);
       }
     };
     return o;
  }
}
```

x here is ‘effectively final’ - compile error if you try to change it

o is a new class. It extends Object but it has no name. It can access all local and instance variables.

Note: here we return o to the caller and it can be used anywhere in the program even though it refers to y and x.

Lambda

```
Consumer<String> c1 = s -> System.out.println(s);
c1.accept(“hello”);


BiFunction<Integer,Integer,Boolean> c2 = (i,j) -> i+j > 5;
boolean a = c2.apply(3,1);

Predicate<Integer> b4 = v -> {
   if (v > 0) {
     return isPrime(v);
   }
   else {
     return isPrime(v*v);
   }
}
boolean a = b4.test(43431);
```

expression lambda

statement lambda

Need a Functional Interface to use them

- A functional interface has only one method in it
- (this is so the compiler knows which one to map the lambda on to)
- That’s it

Streams

Objectives:

- Give simple examples of processing a collection with a stream
- Explain the difference between map and mapToInt
- Explain why side-effects in functions passed to map can cause issues

Streams

- Collections can be made into streams (sequences)
- These can be **filter**ed or **map**ped!

```
List<Integer> list = ...

list.stream().map(x->x+10).collect(Collectors.toList());

list.stream().filter(x->x>5).collect(Collectors.toList());
```

create stream | element-wise operations | aggregation

Demo:streams

Design patterns

Objectives:

- Explain what a design pattern is
- Explain the open-closed principle and why it is a useful property of a design

Design Patterns

- A Design Pattern is a general reusable solution to a commonly occurring problem in software design
- Coined by Erich Gamma in his 1991 Ph.D. thesis
- Originally 23 patterns, now many more. Useful to look at because they illustrate some of the power of OOP (and also some of the pitfalls)
- We will only consider a subset
- It's not a competition to see how many you can use in a project!

The Open-Closed Principle

Classes should be open for extension but closed for modification

- i.e. we would like to be able to modify the behaviour without touching its source code
- This rule-of-thumb leads to more reliable large software and will help us to evaluate the various design patterns

Decorator pattern

Objectives:

- Describe the decorator pattern
- Recognise the decorator pattern when it has been used in a program
- Give the UML diagram for the pattern
- Explain why this pattern meets the open-closed principle

Decorator

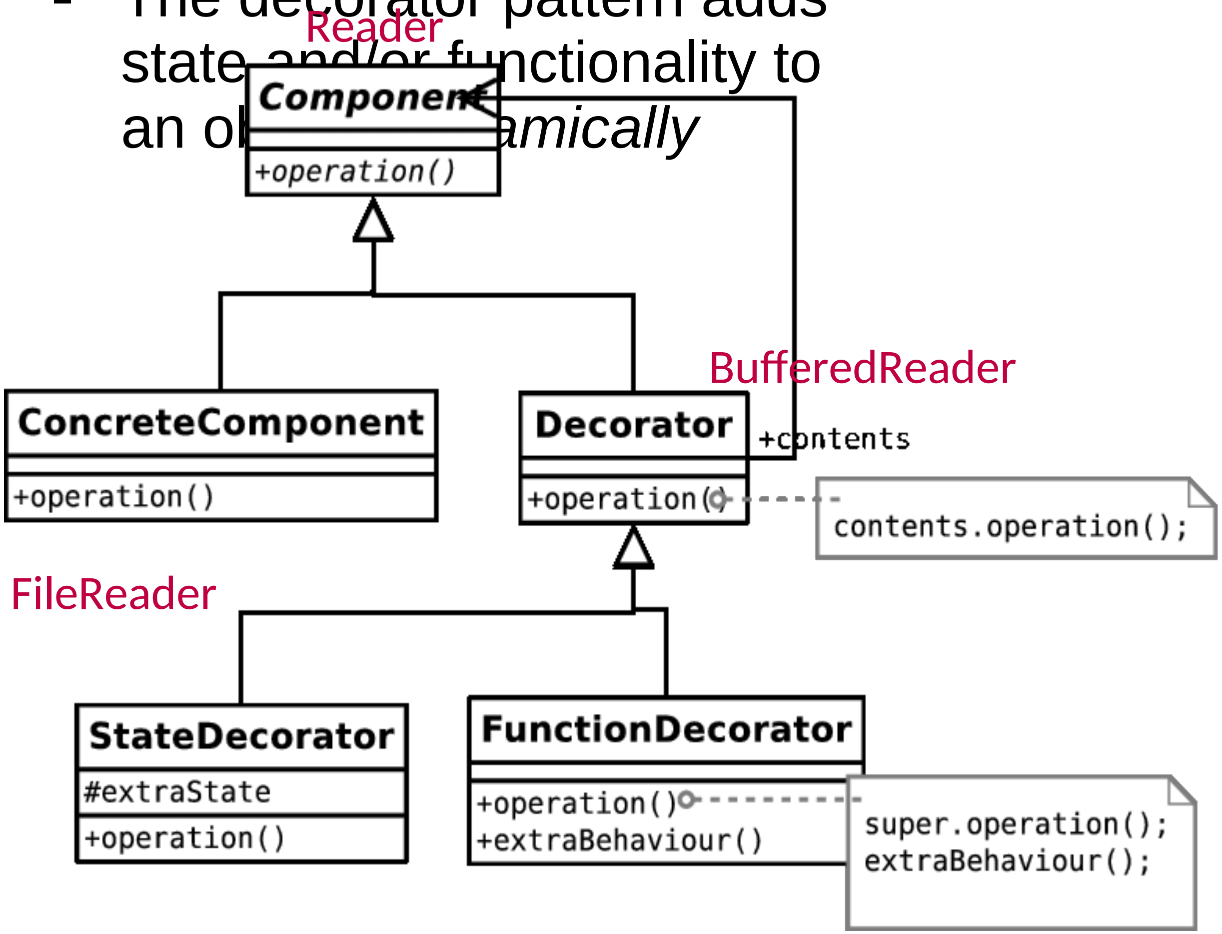
Abstract problem: How can we add state or methods at runtime?

Example problem: How can we efficiently support gift-wrapped books in an online bookstore?

Demo: Readers

Decorator in General

- The decorator pattern adds state and/or functionality to an object *dynamically*



Singleton pattern

Objectives:

- Describe the singleton pattern
- Identify the shortcomings of this pattern
- Recognise the singleton pattern when it has been used in a program
- Give the UML diagram for the pattern

Singleton

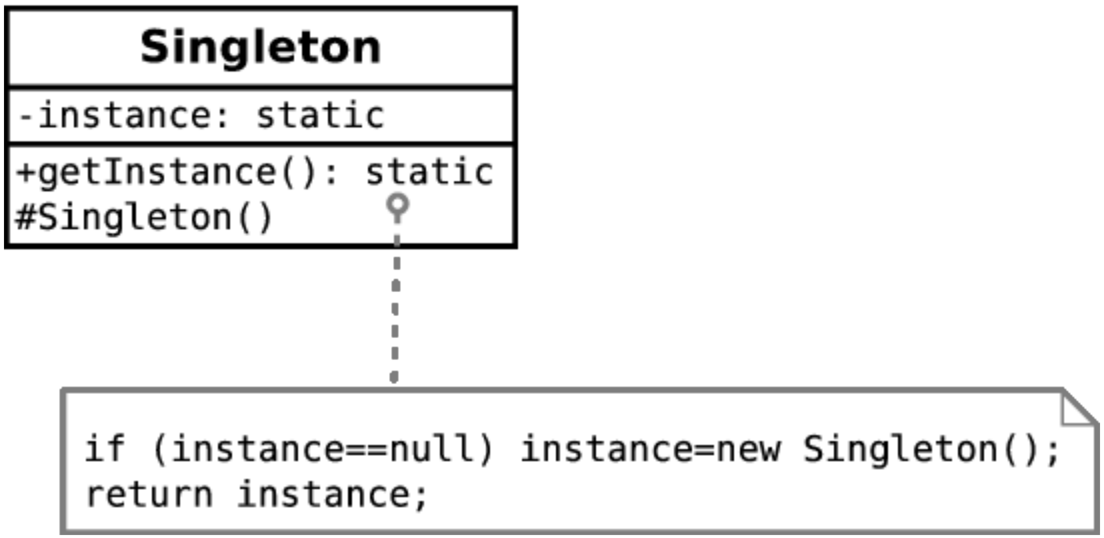
Abstract problem: How can we ensure only one instance of an object is created by developers using our code?

Example problem: You have a class that encapsulates accessing a database over a network. When instantiated, the object will create a connection and send the query. Unfortunately you are only allowed one connection at a time.

demo: SingletonConnection

Singleton in General

- The singleton pattern ensures a class has only one instance and provides global access to it



State pattern

Objective:

- Describe the state pattern
- Recognise the state pattern when it has been used in a program
- Give the UML diagram for the pattern
- Explain why this pattern meets the open-closed principle

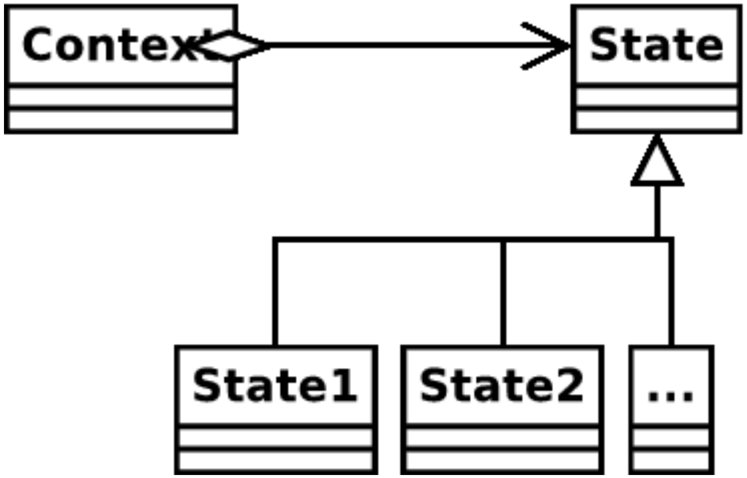
State

Abstract problem: How can we let an object alter its behaviour when its internal state changes?

Example problem: Representing academics as they progress through the rank

State in General

- The state pattern allows an object to cleanly alter its behaviour when internal state changes



Strategy pattern

Objective:

- Describe the strategy pattern
- Recognise the strategy pattern when it has been used in a program
- Give the UML diagram for the pattern
- Explain why this pattern meets the open-closed principle

Strategy

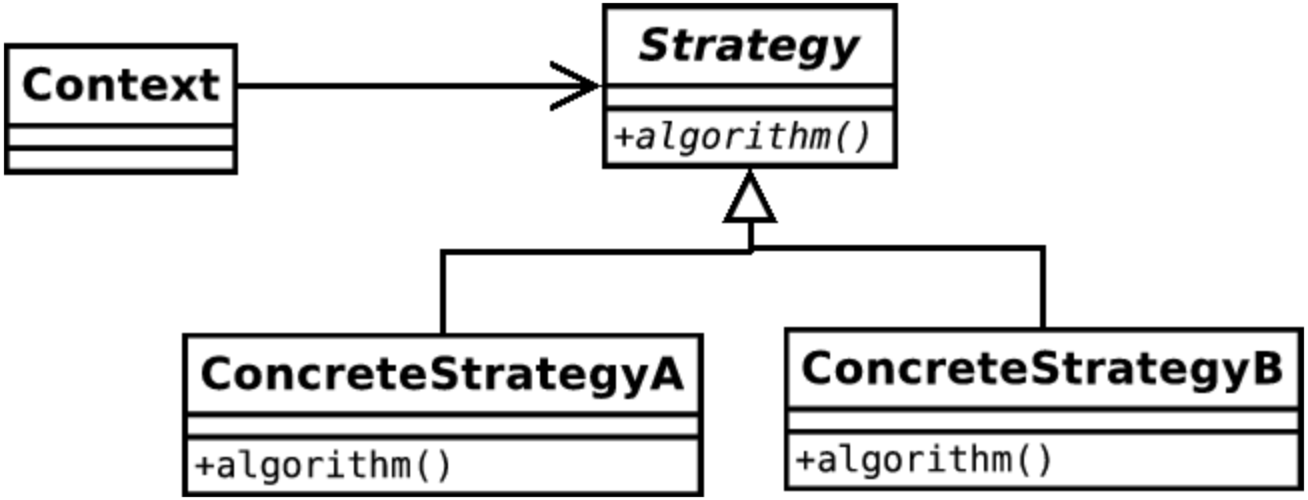
Abstract problem: How can we select an algorithm implementation at runtime?

Example problem: We have many possible change-making implementations. How do we cleanly change between them?

Demo: ComparatorStrategy

Strategy in General

- The strategy pattern allows us to cleanly interchange between algorithm implementations



Composite pattern

Objectives:

- Describe the composite pattern
- Recognise the composite pattern when it has been used in a program
- Give the UML diagram for the pattern
- Explain why this pattern meets the open-closed principle

Composite

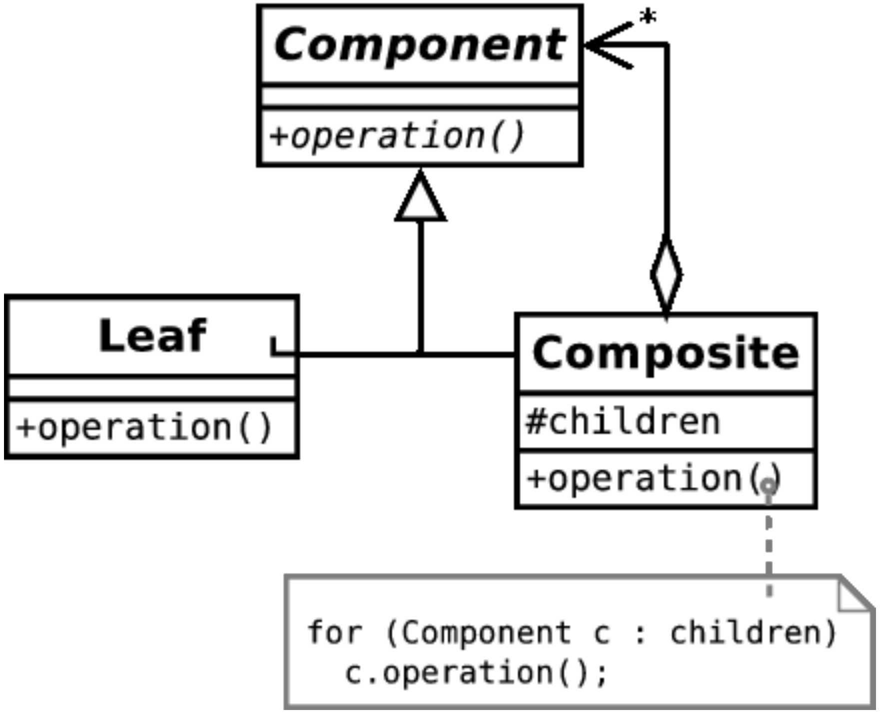
Abstract problem: How can we treat a group of objects as a single object?

Example problem: Representing a DVD box-set as well as the individual films without duplicating info and with a 10% discount

Demo: DVDs

Composite in General

- The composite pattern lets us treat objects and groups of objects uniformly



Observer pattern

Objectives:

- Describe the observer pattern
- Recognise the observer pattern when it has been used in a program
- Give the UML diagram for the pattern
- Explain why this pattern meets the open-closed principle

Observer

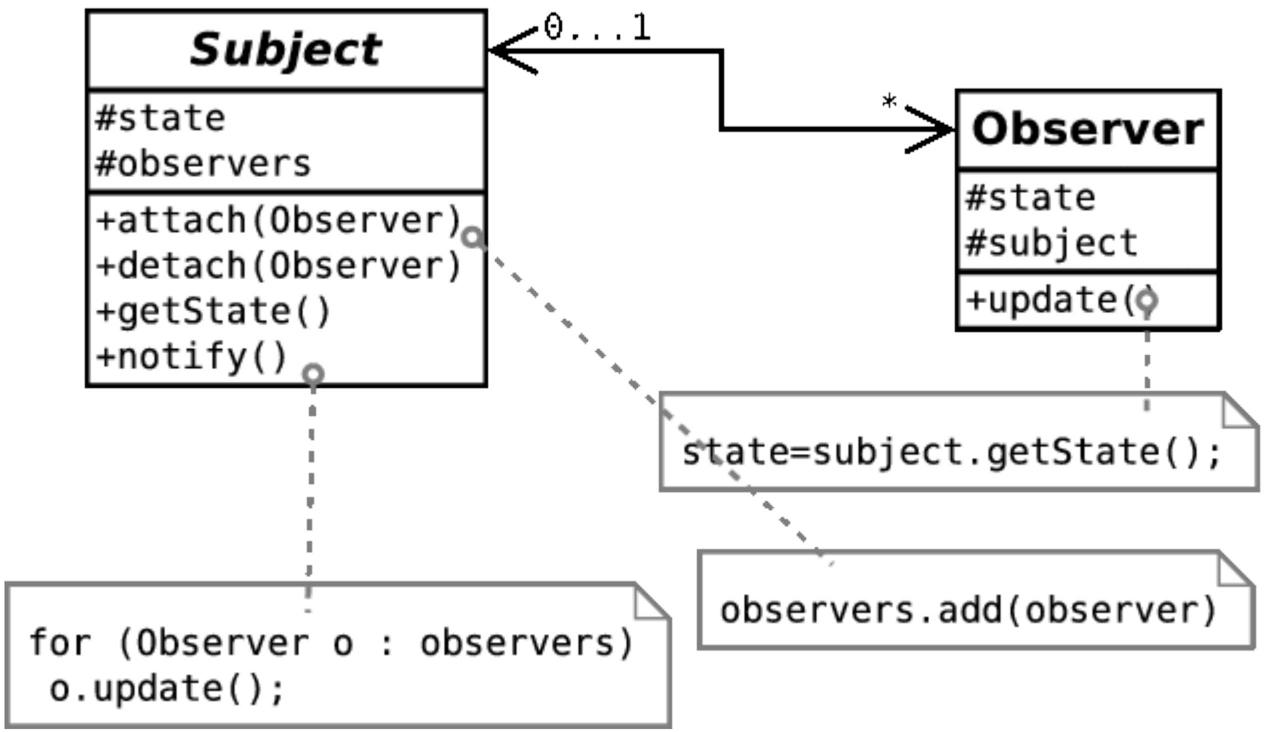
Abstract problem: When an object changes state, how can any interested parties know?

Example problem: How can we write phone apps that react to accelerator events?

Demo: ActionListener

Observer in General

- The observer pattern allows an object to have multiple dependents and propagates updates to the dependents automatically.



Final remarks

Remember OOP is about helping with scale

- You'll have a chance to apply this in the 1B group project next year
- Some of the ideas in this course apply to non-OOP languages too
    - e.g. The OCaml module system provides mechanisms for you to hide your implementation

Keep practising your programming

- Do the exercises on Chime
- Remember the take home test
    - 27 April 2021, 9:00am – 29 April 2021, 9:00am
    - This will be done using Chime

Lots more Java to come next year

- Further Java course
- Networking and distributed systems
- Concurrency (multi-threaded)
- Reflection