Programming II
Introduction to Imperative Programming

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With thanks to Tristan Allwood and Nicolai Stawinoga

120.2

Autumn Term - 2017

Textbooks - none required

For beginner programmers:

- **Java Software Solutions: Foundations of Program Design**, John Lewis and William Loftus, Pearson Education, 2012.

For experienced programmers:

- **Learning the Java™ Language**, online at `http://download.oracle.com/javase/tutorial/java/`
- **Thinking in Java™, Bruce Eckel**, Prentice Hall, 2006.
- **Effective Java™ Second Edition**, Joshua Bloch, Addison-Wesley, 2008.
- **Java™ Puzzlers: Traps, Pitfalls and Corner Cases**, Joshua Bloch, Neal Gafter, Addison-Wesley, 2005
- **Java Language Specification**, online at `http://docs.oracle.com/javase/specs/`

We use Google's programming style. You can learn about it at https://google.github.io/styleguide/javaguide.html.

Assessment - two possibilities

For experienced imperative language programmers

- next Friday, 17 November, 14.00 – 16.00
- sign up at: https://doodle.com/poll/7qb65tf3hhu3ihmq before Thursday
- get over 80% and you get full marks for the assessment for imperative Java
- get less and there are important things that you still need to learn
- aimed at you
  - advanced programming lectures
  - extending the optional parts on the ppt exercises (get the most out of your UTA)

Main test

- Thursday, 14 December, 14.00 – 17.00
- for all students who have not got over 80% on the 17 November test

Details about the assessment process will be on Piazza.

Declarative vs Imperative Languages

Haskell

- declarative language
- basic unit - the expression
- Say 'what you want' and the computer works out how to do it.
- similar to mathematical functions and "high level" descriptions of algorithms
- *horses for courses*

Java

- imperative language
- basic unit - the statement
- Say 'what the computer should do'.
- similar to a cooking recipe / step by step instructions
- An imperative program executes a *sequence* of instructions that change the program's *state* to reach a desired result.

From Haskell functions to Java methods

Haskell To Java

Haskell

```haskell
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```java
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Argument Types

Haskell

```haskell
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```java
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Arguments

Haskell

```
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Result Type

Haskell

```
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Method body delimited by {}

Haskell

```
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Predicate (test) must be surrounded by ()s

Haskell

```haskell
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b     = a
 | otherwise = b
```

Java

```java
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Results are returned using the keyword `return`

Haskell

```
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Statements (e.g. `return`), must end in a ;

Haskell

```
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Haskell functions to Java methods

Single line comments start with //

Haskell

```haskell
bigger :: Int -> Int -> Int
-- post: returns the larger of two numbers
bigger a b
 | a > b      = a
 | otherwise = b
```

Java

```java
public static int bigger(int a, int b) {
  // post:  returns the larger of two numbers
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

From Functions To Methods

Calling Other Methods

Haskell

```
biggest :: Int -> Int -> Int -> Int
-- post: returns the largest of the 3 values
biggest a b c = bigger a (bigger b c)
```

Java

```
public static int biggest(int a, int b, int c) {
    // post: returns the largest of the 3 values
    return bigger(a, bigger( b, c ) );
}
```

From Functions To Methods

Called method must be followed by ()s

Haskell

```
biggest :: Int -> Int -> Int -> Int
-- post: returns the largest of the 3 values
biggest a b c = bigger a (bigger b c)
```

Java

```
public static int biggest(int a, int b, int c) {
    // post: returns the largest of the 3 values
    return bigger(a, bigger( b, c ) );
}
```

From Functions To Methods

Method arguments are inside the ()s

Haskell

```
biggest :: Int -> Int -> Int -> Int
-- post: returns the largest of the 3 values
biggest a b c = bigger a (bigger b c)
```

Java

```
public static int biggest(int a, int b, int c) {
    // post: returns the largest of the 3 values
    return bigger(a, bigger( b, c ) );
}
```

Java Library

Collecting methods together

In BigLibrary.java

```
public class BigLibrary {

  public static int bigger(int a, int b) {
    // post: returns the larger of two numbers
    if (a > b) {
      return a;
    } else {
      return b;
    }
  }

  public static int biggest(int a, int b, int c) {
    // post: returns the largest of the 3 values
    return bigger(a, bigger(b, c));
  }
}
```

Java Library

Class name matches file name. Java source files end in .java

In BigLibrary.java

```
public class BigLibrary {

  public static int bigger(int a, int b) {
    // post: returns the larger of two numbers
    if (a > b) {
      return a;
    } else {
      return b;
    }
  }

  public static int biggest(int a, int b, int c) {
    // post: returns the largest of the 3 values
    return bigger(a, bigger(b, c));
  }
}
```

Java Library

Class is `public` so it can be used by other Libraries and Programs

In `BigLibrary.java`

```
public class BigLibrary {

  public static int bigger(int a, int b) {
    // post: returns the larger of two numbers
    if (a > b) {
      return a;
    } else {
      return b;
    }
  }

  public static int biggest(int a, int b, int c) {
    // post: returns the largest of the 3 values
    return bigger(a, bigger(b, c));
  }
}
```

Java Library

Methods are public so they can be called by other Libraries and Programs

In BigLibrary.java

```
public class BigLibrary {

  public static int bigger(int a, int b) {
    // post: returns the larger of two numbers
    if (a > b) {
      return a;
    } else {
      return b;
    }
  }

  public static int biggest(int a, int b, int c) {
    // post: returns the largest of the 3 values
    return bigger(a, bigger(b, c));
  }
}
```

Java Program

A Program expresses precisely what the computer should do

In Big.java

```
public class Big {

   /* Susan Eisenbach
    * Prints the largest of 3 typed in numbers
    */
     public static void main(String[] args) {
     System.out.print("Type in your 3 numbers -> ");

     System.out.println(BigLibrary.biggest(IOUtil.readInt(),
                                           IOUtil.readInt(),
                                           IOUtil.readInt()));
  }
}
```

Java Program

Java programs always start in a `public static void main(String[] args)` method

In `Big.java`

```
public class Big {

   /* Susan Eisenbach
    * Prints the largest of 3 typed in numbers
    */
     public static void main(String[] args) {
     System.out.print("Type in your 3 numbers -> ");

     System.out.println(BigLibrary.biggest(IOUtil.readInt(),
                                           IOUtil.readInt(),
                                           IOUtil.readInt()));
  }
}
```

Java Program

The return type `void` means the method doesn't return anything.

In `Big.java`

```
public class Big {

   /* Susan Eisenbach
   * Prints the largest of 3 typed in numbers
   */
    public static void main(String[] args) {
    System.out.print("Type in your 3 numbers -> ");

    System.out.println(BigLibrary.biggest(IOUtil.readInt(),
                                          IOUtil.readInt(),
                                          IOUtil.readInt()));
  }
}
```

Java Program

Multi line comments start with a /* and finish with a */

In Big.java

```
public class Big {

   /* Susan Eisenbach
    * Prints the largest of 3 typed in numbers
    */
    public static void main(String[] args) {
    System.out.print("Type in your 3 numbers -> ");

    System.out.println(BigLibrary.biggest(IOUtil.readInt(),
                                          IOUtil.readInt(),
                                          IOUtil.readInt()));
  }
}
```

Java Program

Acknowledge it is your code

In Big.java

```
public class Big {

   /* Susan Eisenbach
    * Prints the largest of 3 typed in numbers
    */
     public static void main(String[] args) {
     System.out.print("Type in your 3 numbers -> ");

     System.out.println(BigLibrary.biggest(IOUtil.readInt(),
                                           IOUtil.readInt(),
                                           IOUtil.readInt()));
  }
}
```

Java Program

You can print out using `System.out.print( ... )` and `System.out.println( ... )`

In Big.java

```
public class Big {

   /* Susan Eisenbach
    * Prints the largest of 3 typed in numbers
    */
     public static void main(String[] args) {
     System.out.print("Type in your 3 numbers -> ");

     System.out.println(BigLibrary.biggest(IOUtil.readInt(),
                                           IOUtil.readInt(),
                                           IOUtil.readInt()));
  }
}
```

Java Program

To use static methods from other classes you need to prefix the method with the name of the class where they were defined.

In Big.java

```
public class Big {

   /* Susan Eisenbach
    * Prints the largest of 3 typed in numbers
    */
     public static void main(String[] args) {
     System.out.print("Type in your 3 numbers -> ");

     System.out.println(BigLibrary.biggest(IOUtil.readInt(),
                                           IOUtil.readInt(),
                                           IOUtil.readInt()));
  }
}
```

From your code to running code

- Integrated development environments (IDE) make developing code easier.
- They help with all sorts of thing such as helping you to remember what the parameters are for a method you are calling to debugging your code.
- We have chosen Intellij IDEA amongst the several available IDEs because it provides the best support.
- However, it does hide much of the process and computer scientists should know what is actually going on.
- You should be able to write and execute Java code without having Intellij around.

Compile and Run

Actually getting your computer to do something...

```
> ls
BigLibrary.java  Big.java  IOUtil.java

> javac *.java

> ls
BigLibrary.class  BigLibrary.java
Big.class  Big.java
IOUtil.class      IOUtil.java

> java -ea Big
Type in your 3 numbers -> 5 78 -23
78
```

Compile and Run

javac turns Java source (.java) into compiled class files (.class)

```
> ls
BigLibrary.java  Big.java  IOUtil.java

> javac *.java

> ls
BigLibrary.class  BigLibrary.java
Big.class  Big.java
IOUtil.class      IOUtil.java

> java -ea Big
Type in your 3 numbers -> 5 78 -23
78
```

Compile and Run

java runs a compiled class given its name (*without* the .class extension)

```
> ls
BigLibrary.java  Big.java  IOUtil.java

> javac *.java

> ls
BigLibrary.class  BigLibrary.java
Big.class  Big.java
IOUtil.class      IOUtil.java

> java -ea Big
Type in your 3 numbers -> 5 78 -23
78
```

Compile and Run

The -ea flag enables *assertions*, which we will shortly see.

```
> ls
BigLibrary.java  Big.java  IOUtil.java

> javac *.java

> ls
BigLibrary.class  BigLibrary.java
Big.class  Big.java
IOUtil.class      IOUtil.java

> java -ea Big
Type in your 3 numbers -> 5 78 -23
78
```

Exercise 1

- Create a library `Util.java` with a method `absolute` which takes an `int` and returns the absolute value of the `int`.
- Create a program, `Absolute.java` which reads in an integer and prints out the absolute value of that number.

Please make sure you use Google style for your Java programs.

Variable Declarations

- Variables are names of storage locations.
- They can be of many different types, e.g.
  - `boolean char int double String`
- They must be *declared* before they are used:

```
int j;
double cost;
String firstname;
```

- They can be *initialised* in the declaration:

```
int total = 0;
char answer = 'y';
boolean finish = false;
```

The Assignment Statement

- Initialisation is a form of *assignment*.
- Assignment gives a variable (named storage location) a value.
- Variables can have their values changed (re-assigned) throughout a method.

```
boolean answer = false;
int total = 0;

total = total + 1;
total = total * 2;
answer = total >= 2;
```

- Haskell doesn't let you change a variable's value.
  - (Haskell's variables are really *identifiers*).

Program with Assignment

An example

BigAssignment.java

```
public class BigAssignment {

  public static void main(String[] args) {
    System.out.print("Type in a number -> ");
    int in = IOUtil.readInt();
    int result = BigLibrary.bigger(in, 2 * in);
    System.out.println(result);

    System.out.print("Type in another number -> ");
    in = IOUtil.readInt();
    result = BigLibrary.bigger(in / in, in * 10);
    System.out.println(result);
  }
}
```

Program with Assignment

Declaring and assigning a variable for the input

BigAssignment.java

```
public class BigAssignment {

  public static void main(String[] args) {
    System.out.print("Type in a number -> ");
    int in = IOUtil.readInt();
    int result = BigLibrary.bigger(in, 2 * in);
    System.out.println(result);

    System.out.print("Type in another number -> ");
    in = IOUtil.readInt();
    result = BigLibrary.bigger(in / in, in * 10);
    System.out.println(result);
  }
}
```

Program with Assignment

Declaring and assigning a variable for the result

BigAssignment.java

```
public class BigAssignment {

  public static void main(String[] args) {
    System.out.print("Type in a number -> ");
    int in = IOUtil.readInt();
    int result = BigLibrary.bigger(in, 2 * in);
    System.out.println(result);

    System.out.print("Type in another number -> ");
    in = IOUtil.readInt();
    result = BigLibrary.bigger(in / in, in * 10);
    System.out.println(result);
  }
}
```

Program with Assignment

Assigning a new input value

BigAssignment.java

```
public class BigAssignment {

  public static void main(String[] args) {
    System.out.print("Type in a number -> ");
    int in = IOUtil.readInt();
    int result = BigLibrary.bigger(in, 2 * in);
    System.out.println(result);

    System.out.print("Type in another number -> ");
    in = IOUtil.readInt();
    result = BigLibrary.bigger(in / in, in * 10);
    System.out.println(result);
  }
}
```

Program with Assignment

Assigning a new result value

BigAssignment.java

```
public class BigAssignment {

  public static void main(String[] args) {
    System.out.print("Type in a number -> ");
    int in = IOUtil.readInt();
    int result = BigLibrary.bigger(in, 2 * in);
    System.out.println(result);

    System.out.print("Type in another number -> ");
    in = IOUtil.readInt();
    result = BigLibrary.bigger(in / in, in * 10);
    System.out.println(result);
  }
}
```

Program with Assignment

Don't need new variables for every subexpression

BigAssignment.java

```
public class BigAssignment {

  public static void main(String[] args) {
    System.out.print("Type in a number -> ");
    int in = IOUtil.readInt();
    int result = BigLibrary.bigger(in, 2 * in);
    System.out.println(result);

    System.out.print("Type in another number -> ");
    in = IOUtil.readInt();
    result = BigLibrary.bigger(in / in, in * 10);
    System.out.println(result);
  }
}
```

Exercise 2

- In `Util.java` write a method `sumOrProduct` that takes two `int` arguments and creates two variables containing the sum and the product of the arguments. The method should return the largest number of the two arguments, their sum and their product. (Make use of `BigLibrary` if it helps).
- Write a program `SOP.java` that asks the user for one number and prints out the result of `sumOrProduct` of that number as both arguments.

Summary

We have seen...

- Methods (in Haskell, functions), delimited by `{}`.
- Collecting methods into a library using `class`.
- Statement Terminators - `;`.
- Conditionals - `if (predicate) { ... } else { ... }`.
- Variables, Declarations, Assignments.
- Input and Output.
- The `main` method is special as it is the code that Java executes.
- The signature of main is `public static void main(String[] args)`.
- Compiling (`javac`) and running (`java -ea`) a program.

Recursive Static Methods

Revision from Haskell

- Define the base case(s).
- Define the recursive case(s).
  - Split the problem into simpler subproblems.
  - Solve the subproblems.
  - Combine the results to give the required answer.

Haskell Function To Java Method

Greatest Common Divisor

Haskell

```
divisor :: Int -> Int -> Int
-- pre: the arguments are both > 0
-- post: returns the greatest common divisor
divisor a b | a == b = a
            | a > b  = divisor b (a - b)
            | a < b  = divisor a (b - a)
```

Haskell Function To Java Method

Greatest Common Divisor

Java

```
public static int divisor(int a, int b) {
  assert (a > 0 &&  b > 0):
  "divisor must be given arguments > 0";
  //post: returns the greatest common divisor
  if (a == b) {
    return a;
  } else if (a > b) {
    return divisor(b, a - b);
  } else {
    return divisor(a, b - a);
  }
}
```

Haskell Function To Java Method

Multiple conditionals: `if ( p1 ) { ... } else if ( p2 ) { ... } else { ... }`

Java

```
public static int divisor(int a, int b) {
  assert (a > 0 &&  b > 0):
  "divisor must be given arguments > 0";
  //post: returns the greatest common divisor
  if (a == b) {
    return a;
  } else if (a > b) {
    return divisor(b, a - b);
  } else {
    return divisor(a, b - a);
  }
}
```

Haskell Function To Java Method

Preconditions expressed with `assert predicate : "message"`

Java

```
public static int divisor(int a, int b) {
  assert (a > 0 &&  b > 0):
  "divisor must be given arguments > 0";
  //post: returns the greatest common divisor
  if (a == b) {
    return a;
  } else if (a > b) {
    return divisor(b, a - b);
  } else {
    return divisor(a, b - a);
  }
}
```

What does `assert` do?

```
assert (a > 0 && b > 0) :
 "divisor must be given arguments > 0";
```

- If the predicate is `true` - continue as normal.
- If the predicate is `false` - stop the program with the an error and the message.
- The `: "message"` part is optional, but *strongly* recommended.

Exercise 3

Write the following as `assert` statements

- `/* pre: n is positive */`
- `/* pre: a is not 0 */`
- `/* pre: x and y are different */`
- `/* pre: calling foo(n) returns false */`
- ```
  /* pre: n is false and m is true,
          or n is true and m is false,
          or a > b */
  ```
  ```

When should you use an assertion?

- If you write a method that expects something special of its arguments then you need a *precondition* to state what should be true of the arguments.
- Where possible, use an `assert` to express the precondition.
- If the user has given method arguments that meet the precondition, and the code is correct, then the *postcondition* of the method will hold. Postconditions are written as comments at the top of the method using `//post: ...`.

Haskell Program To Java Method

Haskell

```haskell
fact :: Int -> Int
-- pre:  n >= 0
-- post: returns n!
fact 0 = 1
fact n = n * fact (n - 1)
```

Java

```java
public static int fact(int n) {
  assert n >= 0 : "factorial: n must be >= 0";
  //post: returns n!
  if (n == 0) {
    return 1;
  } else {
    return n * fact(n-1);
  }
}
```

Java Method To Java Program

First put your algorithmic methods in a suitable library.

RecursiveLib.java

```
public class RecursiveLib {

    public static int divisor(int a, int b) {
      ... as before ...
    }

    public static int fact(int n) {
      ... as before ...
    }
}
```

Java Method to Java Program

Create a `main` method for your program.

DivisorFactorial.java

```
public class DivisorFactorial {

  public static void main(String[] args) {
    System.out.print("Input two numbers greater than 0 -> ");
    int a = IOUtil.readInt();
    int b = IOUtil.readInt();

    int gcd = RecursiveLib.divisor(a,b);
    int result = RecursiveLib.fact(gcd);

    System.out.println("The gcd of " + a + " and " + b +
      " is  " + gcd + ".");
  }
}
```

Java Method to Java Program

You can glue `Strings` (and other values onto `Strings`) with `+`

DivisorFactorial.java

```
public class DivisorFactorial {

  public static void main(String[] args) {
    System.out.print("Input two numbers greater than 0 -> ");
    int a = IOUtil.readInt();
    int b = IOUtil.readInt();

    int gcd = RecursiveLib.divisor(a,b);
    int result = RecursiveLib.fact(gcd);

    System.out.println("The gcd of " + a + " and " + b +
      " is  " + gcd + ".");
  }
}
```

Exercise 4

Simple Haskell Fibonacci

```
simpleFibonacci :: Int -> Int
simpleFibonacci 0 = 0
simpleFibonacci 1 = 1
simpleFibonacci 2 = 1
simpleFibonacci n = simpleFibonacci (n-1)
                  + simpleFibonacci (n-2)
```

- Translate the above Haskell fibonacci function into a Java method.
- Write a Java program that asks the user to input a number and prints out `The nth fibonacci number is ...`

Helper Functions to Helper Methods

Haskell

```haskell
epsilon :: Float
epsilon = 0.00001

newtonSqrt :: Float -> Float
-- pre: x >= 0
newtonSqrt x = findSqrt ( x / 2 )
  where
    findSqrt :: Float -> Float
    findSqrt a | abs (x - a * a) < epsilon = a
               | otherwise = findSqrt ( (a + x / a) / 2 )
```

Helper Functions to Helper Methods

Java Library in `Newton.java`

```
public class Newton {

  private static final float EPSILON = 0.00001f;

  public static float newtonSqrt(float x) {
    assert x >= 0 : "newtonSqrt: x should be >= 0";
    return findSqrt(x, x/2);
  }

  private static float findSqrt(float x, float a) {
    if ( Math.abs(x - a * a) < EPSILON ) {
      return a;
    } else {
      return findSqrt(x, (a + x / a) / 2);
    }
  }
}
```

Helper Functions to Helper Methods

You can't directly nest methods, so the helper method needs the parameter x as well as a

```
public class Newton {

  private static final float EPSILON = 0.00001f;

  public static float newtonSqrt(float x) {
    assert x >= 0 : "newtonSqrt: x should be >= 0";
    return findSqrt(x, x/2);
  }

  private static float findSqrt(float x, float a) {
    if ( Math.abs(x - a * a) < EPSILON ) {
      return a;
    } else {
      return findSqrt(x, (a + x / a) / 2);
    }
  }
}
```

Helper Functions to Helper Methods

The helper method is private so it can only be seen by methods inside class Newton

```
public class Newton {

  private static final float EPSILON = 0.00001f;

  public static float newtonSqrt(float x) {
    assert x >= 0 : "newtonSqrt: x should be >= 0";
    return findSqrt(x, x/2);
  }

  private static float findSqrt(float x, float a) {
    if ( Math.abs(x - a * a) < EPSILON ) {
      return a;
    } else {
      return findSqrt(x, (a + x / a) / 2);
    }
  }
}
```

Helper Functions to Helper Methods

EPSILON is declared as a private constant

```
public class Newton {

  private static final float EPSILON = 0.00001f;

  public static float newtonSqrt(float x) {
    assert x >= 0 : "newtonSqrt: x should be >= 0";
    return findSqrt(x, x/2);
  }

  private static float findSqrt(float x, float a) {
    if ( Math.abs(x - a * a) < EPSILON ) {
      return a;
    } else {
      return findSqrt(x, (a + x / a) / 2);
    }
  }
}
```

Helper Functions to Helper Methods

float literals need to end with an f, otherwise they default to being double

```
public class Newton {

  private static final float EPSILON = 0.00001f;

  public static float newtonSqrt(float x) {
    assert x >= 0 : "newtonSqrt: x should be >= 0";
    return findSqrt(x, x/2);
  }

  private static float findSqrt(float x, float a) {
    if ( Math.abs(x - a * a) < EPSILON ) {
      return a;
    } else {
      return findSqrt(x, (a + x / a) / 2);
    }
  }
}
```

Helper Functions to Helper Methods

The built in `Math` library has lots of helpful methods, e.g. `Math.abs`

```
public class Newton {

  private static final float EPSILON = 0.00001f;

  public static float newtonSqrt(float x) {
    assert x >= 0 : "newtonSqrt: x should be >= 0";
    return findSqrt(x, x/2);
  }

  private static float findSqrt(float x, float a) {
    if ( Math.abs(x - a * a) < EPSILON ) {
      return a;
    } else {
      return findSqrt(x, (a + x / a) / 2);
    }
  }
}
```

Exercise 5

Assume the `Util.java` library below. What would the `Main.java` programs do on the following slides? For each, do they compile and why? If they compile and are run, what do they print out?

`Util.java`

```
public class Util {

  public static double twice(double x) {
    return add(x,x);
  }

  private static double add(double x, double y) {
    return x + y;
  }

}
```

Main1.java

```java
public class Main1 {
  public static void main(String[] args) {
    System.out.println(Util.twice(3));
  }
}
```

Main2.java

```java
public class Main2 {
  public static void main(String[] args) {
    System.out.println(Util.add(4,3));
  }
}
```

Main3.java

```
public class Main3 {
  private static final double MAGIC = 0.2;

  public static void main(String[] args) {
    System.out.println(Util.twice(MAGIC));
  }
}
```

Main4.java

```
public class Main4 {
  private static void main(String[] args) {
    System.out.println(Math.abs(Util.twice(0.2)));
  }
}
```

Main5.java

```
public class Main5 {
  private static final double MAGIC = -0.2;
  public static void main(String[] args) {
     double addResult = add(MAGIC, Math.abs(MAGIC));
     System.out.println(Util.twice(addResult));
   }

  private static double add(double x, double y) {
     return x + y;
     }
 }
```

Methods Summary

- Haskell has *functions* that return values.
- Java has *methods* that can return values.
- Java also has methods that don't return values.
  - They only execute code.
  - Their return type is `void`.
  - They frequently consume input and/or produce output.
- The starting method of a program must have the signature:
  `public static void main(String[] args)`.
- Java methods can be recursive. It is not wise to make `main` recursive.

A Calculator Program

An excuse to introduce more syntax...

Description

Write a simple calculator that prompts the user for an operation (+, -, *, /, negation), one or two numbers as appropriate, and prints out the result.

Stages

1. Presenting a menu to the user, and get their response.
2. Some control flow to work out if we need one or two arguments.
3. Implementations for the two argument operations.
4. Implementation for the one argument operation.
5. A `main` method to start the program.
6. A class to contain all the methods.

A Calculator Program

First, a method to present a menu to the user and to get their response

```
private static void presentMenu() {
  // post: Menu appears on the screen.
  System.out.println("Enter 0 to quit");
  System.out.println("Enter 1 to add");
  System.out.println("Enter 2 to subtract");
  System.out.println("Enter 3 to multiply");
  System.out.println("Enter 4 to divide");
  System.out.println("Enter 5 to negate");
 }
```

A Calculator Program

Second, a method to work out if we need one or two arguments

```
private static void processOperation( ) {

int reply = IOUtil.readInt();
assert (0 <= reply && reply<= 5):
  "A number between 0 and 5 must be entered.";

  switch(reply) {
    case 0: return;
    case 1:
    case 2:
    case 3:
    case 4: processTwoArguments(reply); return;
    case 5: processOneArgument(reply);
  }
}
```

A Calculator Program

Introducing the switch statement

```
private static void processOperation( ) {

int reply = IOUtil.readInt();
assert (0 <= reply && reply<= 5):
  "A number between 0 and 5 must be entered.";

  switch(reply) {
    case 0: return;
    case 1:
    case 2:
    case 3:
    case 4: processTwoArguments(reply); return;
    case 5: processOneArgument(reply);
  }
}
```

A Calculator Program

An expression of int, byte, short, char or String type*

```
private static void processOperation( ) {

int reply = IOUtil.readInt();
assert (0 <= reply && reply<= 5):
  "A number between 0 and 5 must be entered.";

  switch(reply) {
    case 0: return;
    case 1:
    case 2:
    case 3:
    case 4: processTwoArguments(reply); return;
    case 5: processOneArgument(reply);
  }
}
```

*Or an enum type, which we'll see later.

A Calculator Program

`case value:` which case to jump to

```
private static void processOperation( ) {

int reply = IOUtil.readInt();
assert (0 <= reply && reply<= 5):
  "A number between 0 and 5 must be entered.";

  switch(reply) {
    case 0: return;
    case 1:
    case 2:
    case 3:
    case 4: processTwoArguments(reply); return;
    case 5: processOneArgument(reply);
  }
}
```

A Calculator Program

Third, implementations for the two argument operations

```
private static void processTwoArguments(int reply) {
  assert (1 <= reply && reply <= 4);
  System.out.print("Please enter your two integers -> ");
  int x = IOUtil.readInt();
  int y = IOUtil.readInt();

  int result;
  String op;

  switch (reply) {
    case 1: result = x + y; op = " + "; break;
    case 2: result = x - y; op = " - "; break;
    case 3: result = x * y; op = " * "; break;
    case 4: result = x / y; op = " / "; break;
   default: assert false: "Should be impossible!"; return;
  }
  System.out.println(x + op + y + " = " + result);
}
```

A Calculator Program

`default` is a place to jump to if no other value matches and is optional.

```
private static void processTwoArguments(int reply) {
  assert (1 <= reply && reply <= 4);
  System.out.print("Please enter your two integers -> ");
  int x = IOUtil.readInt();
  int y = IOUtil.readInt();

  int result;
  String op;

  switch (reply) {
    case 1: result = x + y; op = " + "; break;
    case 2: result = x - y; op = " - "; break;
    case 3: result = x * y; op = " * "; break;
    case 4: result = x / y; op = " / "; break;
    default: assert false: "Should be impossible!"; return;
  }
  System.out.println(x + op + y + " = " + result);
}
```

A Calculator Program

break leaves the switch (stops *fall-through*)

```
private static void processTwoArguments(int reply) {
  assert (1 <= reply && reply <= 4);
  System.out.print("Please enter your two integers -> ");
  int x = IOUtil.readInt();
  int y = IOUtil.readInt();

  int result;
  String op;

  switch (reply) {
    case 1: result = x + y; op = " + "; break;
    case 2: result = x - y; op = " - "; break;
    case 3: result = x * y; op = " * "; break;
    case 4: result = x / y; op = " / "; break;
    default: assert false: "Should be impossible!"; return;
  }
  System.out.println(x + op + y + " = " + result);
}
```

A Calculator Program

Fourth and Fifth, One argument functions and a main method

```
public class Calculator {

  public static void main(String[] args) {
    presentMenu();
    processOperation();
  }

  private static void presentMenu( ) {
    ... as before ...
  }

  private static void processOperation( ) {
    ... as before ...
  }

  private static void processTwoArguments(int reply) {
    ... as before ...
  }

  private static void processOneArgument(int reply) {
    // TODO
    System.out.println("TODO: not implemented yet");
  }

}
```

An aside, Java's primitive types

Type	Size in bits	Notation	Use in switch
`byte`	8	0	Yes
`short`	16	0	Yes
`int`	32	0	Yes
`long`	64	0L	No
`float`	32	0.0f	No
`double`	64	0.0d	No
`boolean`	1	false / true	No
`char`	16	'\u0000' (or 'A', '\n' etc)	Yes

Exercise 6

1. What does `switchy` return when passed the arguments 0, 1, 2, 3, 4 and 5?

```
public static String switchy(int x) {
  String result = "???";

  switch (x) {
    case 0: return "A";
    case 2: result "B";
    case 1:
    case 3: result = "C"; break;
    case 4: result = "D";
    default: return "DEF" + result;
  }
  return result;

}
```

2. Complete the `Calculator` program.

Back to Recursion

Important things to remember:

- Base Cases
  - Guard your recursive calls.
  - Not guarding your recursive calls leads to infinite recursion.
- Recurse on simpler inputs.
  - Make sure there is progress towards the base cases between invocations of the recursive routine.
- Use comments to make things clearer if possible.

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = encodeInt(120 % 10);

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

```
x = 120;
remainder = encodeInt(0);
```

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = encodeInt(0);

x = 0;

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

```
x = 120;
remainder = encodeInt(0);
```

```
x = 0;
return "-----";
```

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;

remainder = "−−−−−";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "−−−−−";
rest = encodeInt(120 / 10);

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "−−−−−";
rest = encodeInt(12);

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "−−−−−";
rest = encodeInt(12);

x = 12;

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

```
x = 120;
remainder = "-----";
rest = encodeInt(12);
```

```
x = 12;
remainder = encodeInt(12 % 10);
```

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "-----";
rest = encodeInt(12);

x = 12;
remainder = encodeInt(2);

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "-----";
rest = encodeInt(12);

x = 12;
remainder = encodeInt(2);

x = 2;

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "-----";
rest = encodeInt(12);

x = 12;
remainder = encodeInt(2);

x = 2;
return "..---";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "-----";
rest = encodeInt(12);

x = 12;
remainder = "..---";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "−−−−−";
rest = encodeInt(12);

x = 12;
remainder = "..−−−";
rest = encodeInt(12 / 10);

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "−−−−−";
rest = encodeInt(12);

x = 12;
remainder = "..−−−";
rest = encodeInt(1);

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "-----";
rest = encodeInt(12);

x = 12;
remainder = "..---";
rest = encodeInt(1);

x = 1;

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

```
x = 120;
remainder = "-----";
rest = encodeInt(12);
```

```
x = 12;
remainder = "..---";
rest = encodeInt(1);
```

```
x = 1;
return ".----";
```

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "-----";
rest = encodeInt(12);

x = 12;
remainder = "..---";
rest = ".----";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "−−−−−";
rest = encodeInt(12);

x = 12;
remainder = "..−−−";
rest = ".−−−−";
return ".−−−−"+ ""+ "..−−−";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;
remainder = "-----";
rest = encodeInt(12);

x = 12;
remainder = "..---";
rest = ".----";
return ".---- ..---";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;

remainder = "-----";

rest = ".---- ..---";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

x = 120;

remainder = "−−−−−";

rest = ".−−−− ..−−−";

return ".−−−− ..−−−"+ ""+ "−−−−−";

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120)

```
x = 120;
remainder = "-----";
rest = ".---- ..---";
return ".---- ..--- -----";
```

Morse Code Encoder – Another Example

A recursive function with 10 base cases!

```
public class Encoder {

  public static String encodeInt(int x) {
    assert x >= 0 : "Can only encode non-negative integers";

    switch (x) {
      case 0: return "-----";
      case 1: return ".----";
      case 2: return "..---";
      case 3: return "...--";
      case 4: return "....-";
      case 5: return ".....";
      case 6: return "-....";
      case 7: return "--...";
      case 8: return "---..";
      case 9: return "----.";
      default:
        String remainder = encodeInt(x % 10);
        String rest      = encodeInt(x / 10);
        return rest + " " + remainder;
    }
  }
}
```

encodeInt(120) $\mapsto$ ".---- ..--- -----";

Summary

- A method that calls itself is called *recursive*.
- Recursive methods that produce a single result are just like Haskell functions.
- `void` methods do not produce a result.
  - They are used when you are interested in their *side effects*.
  - For example input / output.
  - In the next lectures you will see other forms of side effect.
- To ensure recursive calls will eventually terminate, every recursive method must be guarded by terminating conditions (base cases), and progression towards those conditions in the recursive calls.
- `switch` statements can be used rather than conditionals (`if (p1) { ... } else if (p2) { ... } else { ... }`) for choices based on `int`-like values.

Loops

The `while` loop

- A loop iterates or 'loops' over a block of code, executing it repeatedly.
- When you need repetition, but you don't know how many times the repetition will occur you can use recursion, or a *while loop*.
- Another type of loop, the `for` loop, is usually used when you know up front how many iterations are wanted. For example, to traverse all the elements of a list whose length you know.
- The choice between using loops or recursion is usually a matter of taste.
- Like recursion, generalised loops can repeat indefinitely. When writing code you must ensure that your loops will terminate.
- Unlike recursion, a non-terminating generalised loop does not cause *stack overflow*, as this is caused by having too many unfinished method calls.

The `while` loop

Keep re-executing code as long as a condition is `true`

```
while ( condition ) {
  ... loop body ...
}
```

The `while` loop

The loop body should include code that eventually makes the `condition` false

```
while ( condition ) {
  ... loop body ...
}
```

The `while` loop

Loops where the condition cannot become **false** are infinite loops

```
while ( condition ) {
  ... loop body ...
}
```

The `while` loop

For example, reading input until a condition is satisfied

```
public class WhileExample {

    public static void main(String[] args) {

        System.out.print("Please enter a number between 1 and 10 -> ");

        int input = IOUtil.readInt();

       while (input < 1 || input > 10){
           System.out.print("That wasn't between 1 and 10.  Try again -> ");
           input = IOUtil.readInt();}
        }

        System.out.println("Thank-you, you entered " + input);

    }
}
```

The `while` loop

The variable in the condition, `input`, is modified in the loop

```
public class WhileExample {

    public static void main(String[] args) {

        System.out.print("Please enter a number between 1 and 10 -> ");

        int input = IOUtil.readInt();

        while (input < 1 || input > 10){
            System.out.print("That wasn't between 1 and 10.  Try again -> ");
            input = IOUtil.readInt();}
        }

        System.out.println("Thank-you, you entered " + input);

    }
}
```

The `while` loop

We don't know in advance how many times the loop will need to be run

```
public class WhileExample {

    public static void main(String[] args) {

        System.out.print("Please enter a number between 1 and 10 -> ");

        int input = IOUtil.readInt();

       while (input < 1 || input > 10){
           System.out.print("That wasn't between 1 and 10.  Try again -> ");
           input = IOUtil.readInt();}
        }

        System.out.println("Thank-you, you entered " + input);

    }
}
```

The `while` loop

If the user enters a value between 1 and 10 immediately then the loop body will not be run at all

```
public class WhileExample {

    public static void main(String[] args) {

        System.out.print("Please enter a number between 1 and 10 -> ");

        int input = IOUtil.readInt();

       while (input < 1 || input > 10){
           System.out.print("That wasn't between 1 and 10.  Try again -> ");
           input = IOUtil.readInt();}
        }

        System.out.println("Thank-you, you entered " + input);

    }
}
```

When is the condition checked?

You can imagine a **while** loop as a potentially infinite stacking of **if** statements

```
while ( condition ) {
  ... loop body ...
}
```

```
if ( condition ) {
  ... loop body ...
  if ( condition ) {
    ... loop body ...
    if ( condition ) {
      ... loop body ...
      if ( condition ) {
        ... loop body ...
        ... etc ...
      }
    }
  }
}
```

Exercise 7

What will these while loops print out?

For each while loop below, will it compile, and if it does, what does it print when executed?

Meep

```
while(true) {
  System.out.println("Meep!");
}
```

Strung

```
String s = "";
while (s != s + 0) {
  System.out.println(s);
}
```

Exercise 8

Diagonal

```
int i = 0;
int j = 10;

while (i < j) {
  i = i + 1;
  j = j - 1;
  System.out.println(i + j);
}
```

From Recursion to Iteration

Recursive version of fact

```
public static int fact(int n) {
    assert n >= 0 : "factorial: n must be >= 0";
    // post: returns n!
    if (n == 0) {
        return 1;
    } else {
        return n * fact(n - 1);
    }
}
```

Recursive algorithm

- Base case: if n is 0, return 1
- Recursive case: multiply n by the factorial of n - 1.

From Recursion to Iteration

Iterative version of `fact`

```
public static int fact(int n) {
    assert n >= 0 : "factorial: n must be >= 0";
    // post: returns n!

    int result = 1;
    while (n != 0) {
        result *= n;
       n--;
    }
    return result;
}
```

Iterative algorithm

- Initialize the result to 1.
- Multiply the result by all the numbers between n and 1.

From Recursion to Iteration

The loop runs until the recursive base case is **true**

```
public static int fact(int n) {
    assert n >= 0 : "factorial: n must be >= 0";
    // post: returns n!

    int result = 1;
    while (n != 0) {
        result *= n;
        n--;
    }
    return result;
}
```

Iterative algorithm

- Initialize the result to 1.
- Multiply the result by all the numbers between n and 1.

From Recursion to Iteration

This means the loop condition is the negation of the recursive base case condition

```
public static int fact(int n) {
    assert n >= 0 : "factorial: n must be >= 0";
    // post: returns n!

    int result = 1;
    while (n != 0) {
        result *= n;
        n--;
    }
    return result;
}
```

Iterative algorithm

- Initialize the result to 1.
- Multiply the result by all the numbers between n and 1.

From Recursion to Iteration

The argument that changes during the recursive call (n) is modified in place (n--)

```
public static int fact(int n) {
    assert n >= 0 : "factorial: n must be >= 0";
    // post: returns n!

    int result = 1;
    while (n != 0) {
        result *= n;
       n--;
    }
    return result;
}
```

Iterative algorithm

- Initialize the result to 1.
- Multiply the result by all the numbers between n and 1.

From Recursion to Iteration - Another Example

Recursive version of `divisor`

```
public static int divisor(int a, int b) {
    assert (a > 0 && b > 0) :
        "divisor must be given arguments > 0";
    // post: returns the greatest common divisor
    if (a == b) {
        return a;
    } else if (a > b) {
        return divisor(a - b, b);
    } else {
        return divisor(a, b - a);
    }
}
```

Recursive algorithm

- If the values are the same, they are their own divisor - return that.
- Otherwise return the divisor of the smaller value and the difference of the values.

From Recursion to Iteration - Another Example

Iterative version of `divisor`

```
public static int divisor(int a, int b) {
    assert (a > 0 && b > 0) :
        "divisor must be given arguments > 0";
    // post: returns the greatest common divisor
    while (a != b) {
        if (a > b) {
            a = a - b;
        } else {
            b = b - a;
        }
    }
    return a;
}
```

Iterative algorithm

- Repeatedly make the larger value equal to the difference of the values.
- When the values are the same, we are done.

Exercise 9

Remember `newtonSqrt`? Write it iteratively...

```
public class Newton {

  private static final float EPSILON = 0.00001 f;

  public static float newtonSqrt(float x) {
    assert x >= 0 : "newtonSqrt: x should be >= 0";
    return findSqrt(x, x/2);
  }

  private static float findSqrt(float x, float a) {
    if ( Math.abs(x - a * a) < EPSILON ) {
      return a;
    } else {
      return findSqrt(x, (a + x / a) / 2);
    }
  }
}
```

Other kinds of loops

A method to simulate the roll of a die. The result is a random `int` between 1 and 6 (inclusive)

```
public static int rollDie() {
  return (int) (Math.random() * 6) + 1;
}
```

Thought experiment

- I roll one die. (⚀⚁⚂⚃⚄⚅)
- I then roll a second die until I get a number smaller than or equal to the first die.
- How many times will I have to roll the second die?

The `do { ... } while ( condition );` loop

Rolling a second die until it is `<=` the first one

With a `while` loop

```
int a = rollDie();
int b = rollDie();

int count = 1;

while (b > a) {
  b = rollDie();
  count++;
}

return count;
```

With a `do-while` loop

```
int a = rollDie();
int b;

int count = 0;

do {
  b = rollDie();
  count++;
} while (b > a);

return count;
```

The `do { ... } while ( condition );` loop

In the `while` loop version, we have to roll `b` both outside and inside the loop

With a `while` loop

```
int a = rollDie();
int b = rollDie();

int count = 1;

while (b > a) {
  b = rollDie();
  count++;
}

return count;
```

With a `do-while` loop

```
int a = rollDie();
int b;

int count = 0;

do {
  b = rollDie();
  count++;
} while (b > a);

return count;
```

The `do { ... } while ( condition );` loop

Frequently this pattern of code is better expressed as a `do-while` loop

With a `while` loop

```
int a = rollDie();
int b = rollDie();

int count = 1;

while (b > a) {
  b = rollDie();
  count++;
}

return count;
```

With a `do-while` loop

```
int a = rollDie();
int b;

int count = 0;

do {
  b = rollDie();
  count++;
} while (b > a);

return count;
```

The `do { ... } while ( condition );` loop

In a `do { code } while (condition);` loop, `code` is executed first, and then `condition` is checked before possibly looping back.

With a `while` loop

```
int a = rollDie();
int b = rollDie();

int count = 1;

while (b > a) {
  b = rollDie();
  count++;
}

return count;
```

With a `do-while` loop

```
int a = rollDie();
int b;

int count = 0;

do {
  b = rollDie();
  count++;
} while (b > a);

return count;
```

The `do { ... } while ( condition );` loop

Rolling a second die until it is `<=` the first one

```
public static int numberOfRolls() {
  int a = rollDie();
  int b;

  int count = 0;

  do {
    b = rollDie();
    count++;
  } while (b > a);

  return count;
}
```

- We can use this method to try to answer our thought experiment.
- We can call the method *n* times, and then average the results.

The `for ( init ; condition ; update ) { ... }` loop

Averaging `n` calls to `numberOfRolls`

With a `while` loop

```
double total = 0;

int i = 0;
while (i < n) {
  total += numberOfRolls();
  i++;
}

double average = total / n;
```

With a `for` loop

```
double total = 0;

for (int i = 0 ; i < n ; i++) {
    total += numberOfRolls();
}

double average = total / n;
```

The `for ( init ; condition ; update ) { ... }` loop

Using a `while` loop we can see when `init`, `condition` and `update` are executed in a `for` statement

With a `while` loop

```
double total = 0;

int i = 0;
while (i < n) {
  total += numberOfRolls();
  i++;
}

double average = total / n;
```

With a `for` loop

```
double total = 0;

for (int i = 0 ; i < n ; i++) {
    total += numberOfRolls();
}

double average = total / n;
```

The `for ( init ; condition ; update ) { ... }` loop

Be careful though, in the `for` version, `i` is out of scope after the loop, whereas in the `while` version it is in scope

With a `while` loop

```
double total = 0;

int i = 0;
while (i < n) {
  total += numberOfRolls();
  i++;
}

double average = total / n;
```

With a `for` loop

```
double total = 0;

for (int i = 0 ; i < n ; i++) {
    total += numberOfRolls();
}

double average = total / n;
```

The `for ( init ; condition ; update ) { ... }` loop

Usually the `for` behaviour is what you want - don't keep variables in scope that you don't need

With a `while` loop

```
double total = 0;

int i = 0;
while (i < n) {
  total += numberOfRolls();
  i++;
}

double average = total / n;
```

With a `for` loop

```
double total = 0;

for (int i = 0 ; i < n ; i++) {
    total += numberOfRolls();
}

double average = total / n;
```

The `for ( init ; condition ; update ) { ... }` loop

`i++` increments `i` by 1. It updates the variable - its counterpart, `++i`, updates first, then returns the updated value.

With a `while` loop

```
double total = 0;

int i = 0;
while (i < n) {
  total += numberOfRolls();
  i++;
}

double average = total / n;
```

With a `for` loop

```
double total = 0;

for (int i = 0 ; i < n ; i++) {
    total += numberOfRolls();
}

double average = total / n;
```

Exercise 10

- Remember the `fact` function? Re-write the function twice, using a `for` loop and a `do-while` loop instead.
- Write a function `public static void rectangle()` that prompts the user for a width and a height and draws a rectangle of stars. For example:

```
Please enter a width and a height -> 7 3
*******
*******
*******
```

You will need to use two *nested* loops. The outer loop will print out the rows, whereas the inner loop will print out each row.

`break` and `continue`

Jumping around or out of loops

- There might be times when you want to leave a loop early.
  - e.g. you are iterating through a list searching for a value, and you can finish the loop early if you find it.
- There might be times when you want to skip the current iteration of the loop, and go on to the next one
  - e.g. you only want to process even numbers in a list.
- In order to make writing this kind of code easier, there are two control flow constructs you can use in any of the loops seen so far:
  - `break`: which will exit the loop and carrying on execution from the next statement after the loop. You have seen `break` in switch statements.
  - `continue`: which will jump to the next iteration of the loop.

Consider a predicate `isPrime`

What if you don't want multiple exits from this method?

```
static boolean isPrime(int n) {
  double top = Math.sqrt(n);
  for (int i = 2; i <= top; i++) {
    if ((n % i) == 0) {
      return false;
    }
  }
  return true;
}
```

Another version of the predicate `isPrime`

You could use `break` to terminate the loop when you know the number is not prime.

```
static boolean isPrime2(int n) {
  boolean result = true;
  double top = Math.sqrt(n);
  for (int i = 2; i <= top; i++) {
    if ((n % i) == 0) {
      result = false;
      break;  //stops needlessly looping
    }
  }
  return result;
}
```

Yet another version of the predicate isPrime

You could use continue to jump to the next iteration of the loop.

```
 static boolean isPrime3(int n) {
    double top = Math.sqrt(n);
    for (int i = 2; i <= top; i++) {
      if (i % 2 == 0) {
        continue; //only check odd numbers
      }
      if ((n % i) == 0) {
        return false;
      }
    }
    return true;
  }
}
  }
```

`break` and `continue`

Rolling `n` sixes in a row, and reporting how many rolls it took

Exercise 11

- First use a `while` loop to solve this problem.
- Rewrite using a `for` loop for the attempts to roll `n` 6's in a row. If we get to the end of the `for` loop then we are done.
- However, if we don't roll a 6 within the `for` loop, then we have to try again.
- We may use `continue` to try the next iteration of a loop and `break` when we wish to terminate loop.
- We may use `return` to act like a `break`, but to also leave the method entirely.
- How would you change your code to just keep running?

Summary

- There are many different ways of performing repeated execution in Java.
- Recursion and `while` loops are the most general forms of repetition.
- Recursive methods can be written using a loop. However care must be taken to ensure they have the same behaviour.
- There are some common patterns that occur when using `while` statements, which gives rise to the `do-while` statement and the `for` statement.
- Sometimes you will want to skip an iteration of a loop, or to exit it early, in which case a `continue` or `break` statement is needed.

Arrays

Array?

What?

- Space for many items of the same type.
- Each element can be accessed via its index in the array.
- Arrays can be multi-dimensional.

Why?

- Sometimes you'll need to deal with large quantities of data.
- Sometimes you'll want to perform the same operations on lots of individual items.

Differences with Haskell Lists

- Every element of an array can be accessed in constant time.
- Arrays are of fixed size (they cannot grow like lists).
- You can't pattern match on arrays.

Example of an array variable initialization

Creating 10 `double`s in one go...

```
double[] vec = new double[10];
```

Example of an array variable initialization

To declare an array variable of a given type, we add [] after the type

```
double[] vec = new double[10];
```

Example of an array variable initialization

This variable is called vec

```
double[] vec = new double[10];
```

Example of an array variable initialization

`vec` therefore is a variable for an array of doubles

```
double[] vec = new double[10];
```

Example of an array variable initialization

To initialize `vec` we use the keyword `new` to ask for space

```
double[] vec = new double[10];
```

Example of an array variable initialization

Here we take space for 10 double values, by using `double[10]`

```
double[] vec = new double[10];
```

Example of an array variable initialization

The 10 new double values will all default to value 0.0

```
double[] vec = new double[10];
```

Example of an array variable initialization

The number of elements (10) can be any expression of type `int`

```
double[] vec = new double[10];
```

Initializing an array with known values

Arrays of Strings, ints, and chars

```
String[] judges = { "Craig", "Darcey", "Shirley", "Bruno" };
int[] scores = { 3, 7, 9, 9 };
String[] characters = { "Jerry", "Beth", "Summer", "Mort" };
char[] genders = { 'm', 'f', 'f', 'm' };
```

Initializing an array with known values

The items are listed between { }

```
String[] judges = { "Craig", "Darcey", "Shirley", "Bruno" };
int[] scores = { 3, 7, 9, 9 };
String[] characters = { "Jerry", "Beth", "Summer", "Mort" };
char[] genders = { 'm', 'f', 'f', 'm' };
```

Initializing an array with known values

Java automatically creates a new array of the right size and populates it

```
String[] judges = { "Craig", "Darcey", "Shirley", "Bruno" };
int[] scores = { 3, 7, 9, 9 };
String[] characters = { "Jerry", "Beth", "Summer", "Mort" };
char[] genders = { 'm', 'f', 'f', 'm' };
```

Exercise 12

- Write a statement to create a variable called `flags` that is an array with five `false` values;
- Write a statement to create a variable `empty` which points to an array of length 0 of ints.
- Write a class `AndOr` which has two methods, `and` and `or` which take an array of booleans and returns true if (respectively) all or any of the elements in the array are `true`. You could use a `break` to stop looping if you know the result before all of the elements have been processed.

Reading and Writing to Arrays

You can read the element at index `i` out of array `a` with the syntax `a[i]`

```
String[] judges = {"Craig", "Darcey", "Shirley", "Bruno"};
int[] scores = { 3, 7, 9, 9 };

String firstJudge = judges[0];

if (scores[0] < 5) {
  scores[0] = 5;
}

System.out.println(firstJudge + " gave: " + scores[0]);

System.out.println("The final judge, " + judges[3] +
                   ", gave: " + scores[3]);
```

Reading and Writing to Arrays

The first element of an array is at index 0

```
String[] judges = {"Craig", "Darcey", "Shirley", "Bruno"};
int[] scores = { 3, 7, 9, 9 };

String firstJudge = judges[0];

if (scores[0] < 5) {
  scores[0] = 5;
}

System.out.println(firstJudge + " gave: " + scores[0]);

System.out.println("The final judge, " + judges[3] +
                              ", gave: " + scores[3]);
```

Reading and Writing to Arrays

You can change the value of the element at index i in array a with the syntax
a[i] = newValue;

```
String[] judges = {"Craig", "Darcey", "Shirley", "Bruno"};
int[] scores = { 3, 7, 9, 9 };

String firstJudge = judges[0];

if (scores[0] < 5) {
  scores[0] = 5;
}

System.out.println(firstJudge + " gave: " + scores[0]);

System.out.println("The final judge, " + judges[3] +
                   ", gave: " + scores[3]);
```

Reading and Writing to Arrays

The last element of an array is at an index one smaller than the length of the array

```
String[] judges = {"Craig", "Darcey", "Shirley", "Bruno"};
int[] scores = { 3, 7, 9, 9 };

String firstJudge = judges[0];

if (scores[0] < 5) {
  scores[0] = 5;
}

System.out.println(firstJudge + " gave: " + scores[0]);

System.out.println("The final judge, " + judges[3] +
                   ", gave: " + scores[3]);
```

Iteration...

- Arrays exist in order to hold multiple values that should be treated similarly.
- Frequently the same operation needs to be performed on each array value.
- Traversing all the elements of an array can be achieved with a loop, using the loop variable to access each element of the array at `array[i]`.
- Alternatively, an *enhanced* `for` loop can be used.

Looping through Judges

Introducing The *Enhanced* `for` statement

```
String[] judges = {"Craig", "Darcey", "Shirley", "Bruno"};

for (String judge : judges) {
  System.out.println(judge);
}

/* In general:
 *
 * for (Type variable : array) {
 *    ... code using variable ...
 * }
 *
 */
```

Looping through Judges

The block of code will be executed once for each element in the array

```
String[] judges = {"Craig", "Darcey", "Shirley", "Bruno"};

for (String judge : judges) {
  System.out.println(judge);
}

/* In general:
 *
 * for (Type variable : array) {
 *    ... code using variable ...
 * }
 *
 */
```

Looping through Judges

Each time the block of code is executed, the loop variable will be bound to a successive element of the array.

```
String[] judges = {"Craig", "Darcey", "Shirley", "Bruno"};

for (String judge :  judges) {
  System.out.println(judge);
}

/* In general:
 *
 * for (Type variable : array) {
 *    ... code using variable ...
 * }
 *
 */
```

Enhanced for Example

Sum all the elements of an array

```
double[] vector = { 1.1, 2.2, 3.3 };

double sum = 0;

for (double elem : vector) {
  sum += elem;
}
```

Enhanced `for` Example

`elem` will be 1.1, then 2.2, then 3.3

```
double[] vector = { 1.1, 2.2, 3.3 };

double sum = 0;

for (double elem : vector) {
  sum += elem;
}
```

Enhanced for Example

`sum += elem` is a Java shortcut for `sum = sum + elem`

```
double[] vector = { 1.1, 2.2, 3.3 };

double sum = 0;

for (double elem : vector) {
  sum += elem;
}
```

Enhanced for Example

You might also want to use *=, -=, /= and %=

```
double[] vector = { 1.1, 2.2, 3.3 };

double sum = 0;

for (double elem : vector) {
  sum += elem;
}
```

Another `for` example

What are my Program's arguments?

```
public class Arguments {

  public static void main(String[] args) {

    System.out.println("The program arguments are:");

    for (String argument : args) {
      System.out.println(argument);
    }

  }
}
```

Output

```
> java -ea Arguments Hello World!
The program arguments are:
Hello
World!
```

Another `for` example

On the command line you can give your program extra arguments

```
public class Arguments {

  public static void main(String[] args) {

    System.out.println("The program arguments are:");

    for (String argument : args) {
      System.out.println(argument);
    }

  }
}
```

Output

```
> java -ea Arguments Hello World!
The program arguments are:
Hello
World!
```

Another `for` example

These get turned into a `String` array and passed into your `main` method

```
public class Arguments {

  public static void main(String[] args) {

    System.out.println("The program arguments are:");

    for (String argument : args) {
      System.out.println(argument);
    }

  }
}
```

Output

```
> java -ea Arguments Hello World!
The program arguments are:
Hello
World!
```

Getting the length of an array

Consider calculating the mean of an array of `double`.

```
public static double average(double[] values) {
  assert (values.length > 0)
    : "Cannot average an empty array";

  double sum = Sum.sum(values);

  double average = sum / values.length;

  return average;
}
```

Getting the length of an array

Every array knows its own size.

```
public static double average(double[] values) {
  assert (values.length > 0)
    : "Cannot average an empty array";

  double sum = Sum.sum(values);

  double average = sum / values.length;

  return average;
}
```

Getting the length of an array

To get the size of the array `a`, you write `a.length`.

```
public static double average(double[] values) {
  assert (values.length > 0)
    : "Cannot average an empty array";

  double sum = Sum.sum(values);

  double average = sum / values.length;

  return average;
}
```

Getting the length of an array

This is called a *field lookup*, where `length` is a *field* of every array.

```
public static double average(double[] values) {
  assert (values.length > 0)
    : "Cannot average an empty array";

  double sum = Sum.sum(values);

  double average = sum / values.length;

  return average;
}
```

Getting the length of an array

This is not a method call, you don't put () after length.

```
public static double average(double[] values) {
  assert (values.length > 0)
    : "Cannot average an empty array";

  double sum = Sum.sum(values);

  double average = sum / values.length;

  return average;
}
```

Getting the length of an array

The `length` field is read only, and is of type `int`.

```
public static double average(double[] values) {
  assert (values.length > 0)
    : "Cannot average an empty array";

  double sum = Sum.sum(values);

  double average = sum / values.length;

  return average;
}
```

Getting the length of an array

Once created, an array cannot change its size.

```
public static double average(double[] values) {
  assert (values.length > 0)
    : "Cannot average an empty array";

  double sum = Sum.sum(values);

  double average = sum / values.length;

  return average;
}
```

Bounded Iteration

Using the `for ( init ; condition ; update ) { ... }` loop

- Sometimes we need to traverse the array in a different order than first to last.
- Sometimes we want to talk about the elements at the same index in different arrays.

Bounded Iteration

Using the `for ( init ; condition ; update ) { ... }` loop

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}
```

```
for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration

These are two common patterns for using `for` loops.

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}
```

```
for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration

The variable i is in scope within the loop.

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}

for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration

i++ is shorthand for i = i+1, similarly i-- is shorthand for i = i-1.

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}

for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration

Remember: `for ( init ; condition ; update ) { body }` - `init` is executed, then `condition ; body; update` is repeatedly executed as long as `condition` evaluates to `true`.

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}
```

```
for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration

When the loop is being used to traverse an array `a`, `lowerbound` is typically `0`, and `upperbound` is typically `a.length`.

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}

for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration

The first loop counts up, and is useful if an array needs to be traversed in order.

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}

for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration

The second loop counts down, and is useful if an array needs to be traversed in reverse order.

```
for (int i = lowerbound ; i < upperbound ; i++ ) {
  loop body
}

for (int i = upperbound - 1 ; i >= lowerbound ; i- ) {
  loop body
}
```

Bounded Iteration Example

Printing judges and their scores.

```
public static void printScores(String[] judges, int[] scores) {
  assert judges.length == scores.length : "Judge/Score mismatch";

  int total = 0;

  for (int i = 0 ; i < judges.length ; i++) {
    System.out.println(judges[i] + " scored:  " + scores[i]);
    total += scores[i];
  }

  System.out.println("For a total of: " + total);
}
```

Bounded Iteration Example

We use a `for` loop to walk through successive elements of the `judges` and `scores` arrays.

```
public static void printScores(String[] judges, int[] scores) {
  assert judges.length == scores.length : "Judge/Score mismatch";

  int total = 0;

  for (int i = 0 ; i < judges.length ; i++) {
    System.out.println(judges[i] + " scored:  " + scores[i]);
    total += scores[i];
  }

  System.out.println("For a total of: " + total);
}
```

Bounded Iteration Example

On each execution of the body, i will be incremented due to the i++.

```
public static void printScores(String[] judges, int[] scores) {
  assert judges.length == scores.length : "Judge/Score mismatch";

  int total = 0;

  for (int i = 0 ; i < judges.length ; i++) {
    System.out.println(judges[i] + " scored:  " + scores[i]);
    total += scores[i];
  }

  System.out.println("For a total of: " + total);
}
```

Bounded Iteration Example

This means we can access a judge's name, and their score at the same time in the loop body.

```
public static void printScores(String[] judges, int[] scores) {
  assert judges.length == scores.length : "Judge/Score mismatch";

  int total = 0;

  for (int i = 0 ; i < judges.length ; i++) {
    System.out.println(judges[i] + " scored:  " + scores[i]);
    total += scores[i];
  }

  System.out.println("For a total of: " + total);
}
```

Bounded Iteration Example

After the `for` loop, `i` is no longer in scope, so you cannot refer to it.

```
public static void printScores(String[] judges, int[] scores) {
  assert judges.length == scores.length : "Judge/Score mismatch";

  int total = 0;

  for (int i = 0 ; i < judges.length ; i++) {
    System.out.println(judges[i] + " scored:  " + scores[i]);
    total += scores[i];
  }

  System.out.println("For a total of: " + total);
}
```

Bounded Iteration in Reverse

Printing the program arguments in reverse

```
public static void main(String[] args) {

    for (int i = args.length - 1 ; i >= 0 ; i-) {
        System.out.println(i + ": " + args[i]);
    }
}
```

Output

```
> java -ea ArgumentsReversed Hello World!
1: World!
0: Hello
```

Bounded Iteration in Reverse

The loop starts at `args.length - 1`, which is the index of the last element in the array

```
public static void main(String[] args) {

    for (int i = args.length - 1 ; i >= 0 ; i-) {
        System.out.println(i + ": " + args[i]);
    }
}
```

Output

```
> java -ea ArgumentsReversed Hello World!
1: World!
0: Hello
```

Bounded Iteration in Reverse

The loop continues as long as `i` is non-negative, decrementing each time round.

```
public static void main(String[] args) {

    for (int i = args.length - 1 ; i >= 0 ; i-) {
        System.out.println(i + ": " + args[i]);
    }
}
```

Output

```
> java -ea ArgumentsReversed Hello World!
1: World!
0: Hello
```

Exercise 13

Write a method `fibArray`, which, given an `int n` produces an array of length `n` filled with the first `n` fibonacci numbers.

Arrays can be multidimensional

Creating an array of arrays.

```
double[][] matrix = { { 1.0, 2.0, 3.0 }
                    , { 1.5, 2.5, 3.5 }
                    };

double[][] transpose = new double[3][2];
```

Arrays can be multidimensional

`matrix` is an array of length 2, where each element is an array of doubles of length 3

```
double[][] matrix = { { 1.0, 2.0, 3.0 }
                    , { 1.5, 2.5, 3.5 }
                    };

double[][] transpose = new double[3][2];
```

Arrays can be multidimensional

transpose is an array of length 3, where each element is an array of doubles of length 2

```
double[][] matrix = { { 1.0, 2.0, 3.0 }
                    , { 1.5, 2.5, 3.5 }
                    };

double[][] transpose = new double[3][2];
```

Traversing a multi-dimensional array

for loops can be nested

```
public static double[][] createTranspose(double[][] matrix) {
  // pre:  matrix is a rectangular matrix

  double[][] transpose
    = new double[matrix[0].length][matrix.length];

  for (int i = 0; i < matrix.length; i++) {
    for (int j = 0; j < matrix[i].length; j++) {
      transpose[j][i] = matrix[i][j];
    }
  }

  return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Traversing a multi-dimensional array

Accessing the `length` of a multimensional array will give the number of sub-arrays within it. i.e. the size of that dimension of the array

```
public static double[][] createTranspose(double[][] matrix) {
  // pre: matrix is a rectangular matrix

  double[][] transpose
    = new double[matrix[0].length][matrix.length];

  for (int i = 0; i < matrix.length; i++) {
    for (int j = 0; j < matrix[i].length; j++) {
      transpose[j][i] = matrix[i][j];
    }
  }

  return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Traversing a multi-dimensional array

Each inner array will also have its own `length`

```
public static double[][] createTranspose(double[][] matrix) {
  // pre:  matrix is a rectangular matrix

   double[][] transpose
     = new double[matrix[0].length][matrix.length];

   for (int i = 0; i < matrix.length; i++) {
     for (int j = 0; j < matrix[i].length; j++) {
       transpose[j][i] = matrix[i][j];
     }
   }

   return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Traversing a multi-dimensional array

Here we require as a precondition that the `matrix` parameter is rectangular

```
public static double[][] createTranspose(double[][] matrix) {
  // pre:  matrix is a rectangular matrix

  double[][] transpose
    = new double[matrix[0].length][matrix.length];

  for (int i = 0; i < matrix.length; i++) {
    for (int j = 0; j < matrix[i].length; j++) {
      transpose[j][i] = matrix[i][j];
    }
  }

  return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Traversing a multi-dimensional array

What happens if `matrix.length` is 0?

```
public static double[][] createTranspose(double[][] matrix) {
  // pre:  matrix is a rectangular matrix

   double[][] transpose
     = new double[matrix[0].length][matrix.length];

   for (int i = 0; i < matrix.length; i++) {
     for (int j = 0; j < matrix[i].length; j++) {
       transpose[j][i] = matrix[i][j];
     }
   }

   return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Traversing a multi-dimensional array

In order to build the transpose array, we use nested for loops, one for traversing each dimension of `matrix`

```
public static double[][] createTranspose(double[][] matrix) {
  // pre: matrix is a rectangular matrix

  double[][] transpose
    = new double[matrix[0].length][matrix.length];

  for (int i = 0; i < matrix.length; i++) {
    for (int j = 0; j < matrix[i].length; j++) {
      transpose[j][i] = matrix[i][j];
    }
  }

  return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Traversing a multi-dimensional array

For the inner loop, we can't write `int i = 0` again, (we've already got a variable called `i`!) so the convention is to use `j`, then `k`, etc.

```
public static double[][] createTranspose(double[][] matrix) {
  // pre:  matrix is a rectangular matrix

  double[][] transpose
    = new double[matrix[0].length][matrix.length];

  for (int i = 0; i < matrix.length; i++) {
    for (int j = 0; j < matrix[i].length; j++) {
      transpose[j][i] = matrix[i][j];
    }
  }

  return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Traversing a multi-dimensional array

Since our `i` and `j` loops are traversing over `matrix` and `matrix[i]` respectively, inside the body of the loop the element we are interested in will be at `matrix[i][j]`

```
public static double[][] createTranspose(double[][] matrix) {
  // pre:  matrix is a rectangular matrix

  double[][] transpose
    = new double[matrix[0].length][matrix.length];

  for (int i = 0; i < matrix.length; i++) {
    for (int j = 0; j < matrix[i].length; j++) {
      transpose[j][i] = matrix[i][j];
    }
  }

  return transpose;
}
```

How would you write a `print` method that would print out both the matrix and its transpose?

Exercise 14

Write a method `sumAll` that takes a three-dimensional array of `int` as an argument and returns the sum of all the numbers in the array.

Initializing multi-dimensional arrays with known values...

Pascal's Triangle

```
int[][] triangle = {         { 1 }
                   ,       { 1, 1 }
                   ,     { 1, 2, 1 }
                   ,   { 1, 3, 3, 1 }
                   };
```

Initializing multi-dimensional arrays with known values...

Useful for tabulating binomial expansions and combinations

```
int[][] triangle = {         { 1 }
                   ,       { 1, 1 }
                   ,     { 1, 2, 1 }
                   ,   { 1, 3, 3, 1 }
                   };
```

Initializing multi-dimensional arrays with known values...

In the triangle, the edges are always 1, and inner numbers are the sum of the two values above them

```
int[][] triangle = {          { 1 }
                   ,        { 1, 1 }
                   ,      { 1, 2, 1 }
                   ,    { 1, 3, 3, 1 }
                   };
```

Initializing multi-dimensional arrays with known values...

In the array form, the maths is a little different - don't *ever* trust indentation - Java doesn't care about it at all!

```
int[][] triangle = {        { 1 }
                   ,      { 1, 1 }
                   ,    { 1, 2, 1 }
                   ,   { 1, 3, 3, 1 }
                   };
```

Initializing multi-dimensional arrays with known values...

The triangle is represented as an array of arrays, but each of the inner arrays has a different length

```
int[][] triangle = {          { 1 }
                   ,        { 1, 1 }
                   ,      { 1, 2, 1 }
                   ,    { 1, 3, 3, 1 }
                   };
```

Initializing multi-dimensional arrays with known values...

Such arrays are called *jagged*

```
int[][] triangle = {         { 1 }
                   ,       { 1, 1 }
                   ,     { 1, 2, 1 }
                   ,   { 1, 3, 3, 1 }
                   };
```

Traversing a jagged multi-dimensional array

Printing out Pascal's Triangle

```
public static void printTriangle(int[][] triangle) {
     for (int i = 0 ; i < triangle.length ; i++ ) {
          for (int j = 0 ; j < triangle[i].length ; j++) {
               System.out.print(triangle[i][j]);

               if (j < triangle[i].length - 1) {
                    System.out.print(" ");
               }
          }
          System.out.println();
     }
 }
```

Traversing a jagged multi-dimensional array

We use nested loops to walk through each part of the triangle.

```
public static void printTriangle(int[][] triangle) {
    for (int i = 0 ; i < triangle.length ; i++ ) {
        for (int j = 0 ; j < triangle[i].length ; j++) {
            System.out.print(triangle[i][j]);

            if (j < triangle[i].length - 1) {
                System.out.print(" ");
            }
        }
        System.out.println();
    }
}
```

Traversing a jagged multi-dimensional array

Each of the inner arrays has its own length, so we can use that to get the right number of elements.

```
public static void printTriangle(int[][] triangle) {
     for (int i = 0 ; i < triangle.length ; i++ ) {
          for (int j = 0 ; j < triangle[i].length ; j++) {
               System.out.print(triangle[i][j]);

               if (j < triangle[i].length - 1) {
                    System.out.print(" ");
               }
          }
          System.out.println();
     }
 }
```

Traversing a jagged multi-dimensional array

```
public static void printTriangle(int[][] triangle) {
     for (int i = 0 ; i < triangle.length ; i++ ) {
          for (int j = 0 ; j < triangle[i].length ; j++) {
               System.out.print(triangle[i][j]);

               if (j < triangle[i].length - 1) {
                    System.out.print(" ");
               }
          }
          System.out.println();
     }
 }
```

Traversing a jagged multi-dimensional array

To put spaces between the elements, but not at the end, we use an `if` check to see if `j` is before its last index

```
public static void printTriangle(int[][] triangle) {
     for (int i = 0 ; i < triangle.length ; i++ ) {
          for (int j = 0 ; j < triangle[i].length ; j++) {
               System.out.print(triangle[i][j]);

               if (j < triangle[i].length - 1) {
                    System.out.print(" ");
               }
          }
          System.out.println();
     }
 }
```

Traversing a jagged multi-dimensional array

Challenge: how would you print out the triangle centered and not left aligned?

```
public static void printTriangle(int[][] triangle) {
    for (int i = 0 ; i < triangle.length ; i++ ) {
        for (int j = 0 ; j < triangle[i].length ; j++) {
            System.out.print(triangle[i][j]);

            if (j < triangle[i].length - 1) {
                System.out.print(" ");
            }
        }
        System.out.println();
    }
}
```

Exercise 15

Rewrite `printTriangle` so that it prints out as an isosceles rather than a right triangle.

Building a jagged multi-dimensional array

Building the first n layers of Pascal's Triangle

```
public static int[][] makeTriangle(int n) {
  int[][] triangle = new int[n][];

  for (int i = 0 ; i < n ; i++) {
    triangle[i] = new int[i+1];

    triangle[i][0] = 1;

    for (int j = 1 ; j < i ; j++) {
      triangle[i][j] = triangle[i-1][j] +
                       triangle[i-1][j-1];
    }

    triangle[i][i] = 1;
  }

  return triangle;
}
```

Building a jagged multi-dimensional array

We can ask for space for n arrays of arrays, but not give the size of the inner arrays (yet)

```
public static int[][] makeTriangle(int n) {
  int[][] triangle = new int[n][];

  for (int i = 0 ; i < n ; i++) {
    triangle[i] = new int[i+1];

    triangle[i][0] = 1;

    for (int j = 1 ; j < i ; j++) {
      triangle[i][j] = triangle[i-1][j] +
                       triangle[i-1][j-1];
    }

    triangle[i][i] = 1;
  }

  return triangle;
}
```

Building a jagged multi-dimensional array

The i loop traverses the rows of the triangle. Row i has i + 1 columns

```
public static int[][] makeTriangle(int n) {
  int[][] triangle = new int[n][];

  for (int i = 0 ; i < n ; i++) {
    triangle[i] = new int[i+1];

    triangle[i][0] = 1;

    for (int j = 1 ; j < i ; j++) {
      triangle[i][j] = triangle[i-1][j] +
                       triangle[i-1][j-1];
    }

    triangle[i][i] = 1;
  }

  return triangle;
}
```

Building a jagged multi-dimensional array

You can create sub arrays and assign them to their parent array. For example, `triangle[i]` can be assigned `int[]` values.

```
public static int[][] makeTriangle(int n) {
  int[][] triangle = new int[n][];

  for (int i = 0 ; i < n ; i++) {
    triangle[i] = new int[i+1];

    triangle[i][0] = 1;

    for (int j = 1 ; j < i ; j++) {
      triangle[i][j] = triangle[i-1][j] +
                       triangle[i-1][j-1];
    }

    triangle[i][i] = 1;
  }

  return triangle;
}
```

Building a jagged multi-dimensional array

The innermost j loop traverses from index 1 to one less than the row length

```
public static int[][] makeTriangle(int n) {
  int[][] triangle = new int[n][];

  for (int i = 0 ; i < n ; i++) {
    triangle[i] = new int[i+1];

    triangle[i][0] = 1;

    for (int j = 1 ; j < i ; j++) {
      triangle[i][j] = triangle[i-1][j] +
                       triangle[i-1][j-1];
    }

    triangle[i][i] = 1;
  }

  return triangle;
}
```

One small syntax gotcha

Declaration vs Assignment / Creation of known array values

Declaration

```
    String[] reallyImportantGames
       = {"Minecraft", "Mario", "Candy Crush"};
```

Assignment

```
String[] reallyImportantGames;
    reallyImportantGames
      = new String[] {"Minecraft", "Mario", "Candy Crush"};
```

Method Call

```
 buyGames(
      new String[] {"Minecraft",  "Mario", "Candy Crush"});
```

One small syntax gotcha

If you declare and initialize an array in one line, then the compiler knows the type of the array, and you can just use `{ }` as we've been doing so far

Declaration

```
    String[] reallyImportantGames
       = {"Minecraft", "Mario", "Candy Crush"};
```

Assignment

```
String[] reallyImportantGames;
    reallyImportantGames
      = new String[] {"Minecraft", "Mario", "Candy Crush"};
```

Method Call

```
 buyGames(
      new String[] {"Minecraft",  "Mario", "Candy Crush"});
```

One small syntax gotcha

However if you are creating a new array, and e.g. assigning it, or calling a method, then you need to say that you want a `new` something, and then use `{ }`s to build it

Declaration

```
String[] reallyImportantGames
   = {"Minecraft", "Mario", "Candy Crush"};
```

Assignment

```
String[] reallyImportantGames;
    reallyImportantGames
      = new String[] {"Minecraft", "Mario", "Candy Crush"};
```

Method Call

```
 buyGames(
      new String[] {"Minecraft",  "Mario", "Candy Crush"});
```

Summary

- Arrays are data structures suitable for problems dealing with large quantities of identically typed data where similar operations need to be performed on every element.
- Elements of an array are accessed through their index values. Arrays using a single index are sometimes called vectors, those using *n* indexes are *n-dimensional*. A two-dimensional array is really an array of arrays.
- The number of items in an array can be found through the length field, `array.length`. For multi-dimensional arrays, `array.length` will contain the number of sub arrays, and `array[i].length` will be the number of elements in sub-array `i`.
- Array indexes are `int` expressions. The first element is always at index `0`, and the last at `array.length - 1`.
- Arrays need space to be allocated for them. This is either done implicitly with values given for all their elements, or explicitly using `new` to take space in the heap.
- Repetition of the same operation is called `iteration` or `looping`. A `for` loop can be used to do the same operation on every element of an array.

In-Place Array Operations

Pass by Value

- We have been passing arguments to methods.
- Java methods can accept primitive types as arguments (`int`, `boolean`, `double`, etc).
- They can also accept more complicated types (called *reference types*, for reasons we'll shortly see) such as arrays and `String`s.
- In Java, all method parameters are *passed by value*. This means a copy of the *value* of a parameter is made before the method receives it.
- If the method makes changes to the parameter values, they are not visible to the method's caller.
- However the *value* could point to some shared memory through which changes could be seen.

Not a swap method

```
public class NotSwap {

  public static void main(String[] args) {
    int a = 1;
    int b = 2;
    System.out.println("Before swap: " + a + ", " + b);
    swap(a,b);
    System.out.println("After swap: " + a + ", " + b);
  }

  public static void swap(int x, int y) {
    // this method doesn't do very much!
    int temp = x;
    x = y;
    y = temp;
    System.out.println("Inside swap: " + x + ", " + y);
  }
}
```

Output

```
Before swap: 1, 2
Inside swap: 2, 1
After swap:
```

Not a swap method

```java
public class NotSwap {

  public static void main(String[] args) {
    int a = 1;
    int b = 2;
    System.out.println("Before swap: " + a + ", " + b);
    swap(a,b);
    System.out.println("After swap: " + a + ", " + b);
  }

  public static void swap(int x, int y) {
    // this method doesn't do very much!
    int temp = x;
    x = y;
    y = temp;
    System.out.println("Inside swap: " + x + ", " + y);
  }
}
```

Output

```
Before swap: 1, 2
Inside swap: 2, 1
After swap: 1, 2
```

An Array Swap

```
public class ArraySwap {

  public static void main(String[] args) {
    int[] a = { 1, 2 };

    System.out.println("Before arraySwap: " + a[0] + ", " + a[1]);
    arraySwap(a);
    System.out.println("After arraySwap: " + a[0] + ", " + a[1]);
  }

  public static void arraySwap(int[] array) {
    assert array.length == 2 : "Can only swap 2 elements";
    int temp = array[0];
    array[0] = array[1];
    array[1] = temp;
    System.out.println("In arraySwap: " + array[0] + ", " + array[1]);
  }
}
```

Output

```
Before arraySwap: 1, 2
In arraySwap: 2, 1
After arraySwap:
```

An Array Swap

```
public class ArraySwap {

  public static void main(String[] args) {
    int[] a = { 1, 2 };

    System.out.println("Before arraySwap: " + a[0] + ", " + a[1]);
    arraySwap(a);
    System.out.println("After arraySwap: " + a[0] + ", " + a[1]);
  }

  public static void arraySwap(int[] array) {
    assert array.length == 2 : "Can only swap 2 elements";
    int temp = array[0];
    array[0] = array[1];
    array[1] = temp;
    System.out.println("In arraySwap: " + array[0] + ", " + array[1]);
  }
}
```

Output

```
Before arraySwap: 1, 2
In arraySwap: 2, 1
After arraySwap: 2, 1
```

Update in place

- Even though methods can't alter the caller's parameters directly, they can modify their contents if they are a reference type.
- For arrays, this means a method can alter the contents of the array, without having to allocate space for and then returning a new one.
- It is very important that the documentation (postcondition) of methods makes it clear when they perform such updates.
- Note that even though `String`s are a reference type, they are *immutable*, and their contents can never change.

Exercise 16

What do the stack and heap look like when execution reaches each line of the following?

```
String[] dancers = { "Susan", "Konstantinos", "Tony" };
int[] scores = new int[3];
// <here>
scores[0] = 1;
scores[2] = 2;
// <here>
int[] scores2 = { 2,3,4 };
scores = scores2;
// <here>
scores2[2] = 10000;
// <here>
```

Exercise 17

Hand execute the following code in the presence of method `m`, below. Draw the state of the stack and the heap before and after the call to `m(a)`.

```
int[] a = {1, 2, 3};
m(a);
```

Method m

```
public static void m(int[] xs) {
  int[] ys = xs;
  ys[0] = xs[1];
  xs = null;
  ys = null;
}
```

Array Utility Methods

- Java comes with a utility library of helpful methods that act on arrays, called `Arrays`.
- To use it, you will have to `import java.util.Arrays;` at the top of your source file (before the `public class ... {` line).
- It features methods to perform searches, equality checks and pretty printing on arrays.
- It also has methods to sort and fill arrays. These methods are `void` as they update the argument array in place.
- For the complete API see https://docs.oracle.com/javase/7/docs/api/java/util/Arrays.html.
- Next term you'll learn in-place algorithms for binary searching and sorting in your Reasoning course.
- In this rest of this lecture we'll look at two other algorithms:
  - Reverse an array.
  - A Fisher-Yates Shuffle.

Using java.util.Arrays

Sorting numbers from the user

```
import java.util.Arrays;

public class InputSorter {

  public static void main(String[] args) {
    System.out.print("How many numbers " +
                     "do you wish to sort? ");
    int number = IOUtil.readInt();
    // TODO: check number is valid

    int[] data = new int[number];
    for (int i = 0 ; i < number ; i++) {
      data[i] = IOUtil.readInt();
    }
    Arrays.sort(data);
    System.out.println(Arrays.toString(data));
  }
}
```

Using java.util.Arrays

We have to explicitly import the Arrays class at the top of our file.

```
import java.util.Arrays;

public class InputSorter {

  public static void main(String[] args) {
    System.out.print("How many numbers " +
                     "do you wish to sort? ");
    int number = IOUtil.readInt();
    // TODO: check number is valid

    int[] data = new int[number];
    for (int i = 0 ; i < number ; i++) {
      data[i] = IOUtil.readInt();
    }
    Arrays.sort(data);
    System.out.println(Arrays.toString(data));
  }
}
```

Using `java.util.Arrays`

The `sort` method sorts our array of `int` for us, modifying it in place.

```
import java.util.Arrays;

public class InputSorter {

  public static void main(String[] args) {
    System.out.print("How many numbers " +
                              "do you wish to sort? ");
    int number = IOUtil.readInt();
    // TODO: check number is valid

    int[] data = new int[number];
    for (int i = 0 ; i < number ; i++) {
      data[i] = IOUtil.readInt();
    }
    Arrays.sort(data);
    System.out.println(Arrays.toString(data));
  }
}
```

Using java.util.Arrays

The utility method toString returns a pretty printed version of the array as a String which we can print out.

```
import java.util.Arrays;

public class InputSorter {

  public static void main(String[] args) {
    System.out.print("How many numbers " +
                     "do you wish to sort? ");
    int number = IOUtil.readInt();
    // TODO: check number is valid

    int[] data = new int[number];
    for (int i = 0 ; i < number ; i++) {
      data[i] = IOUtil.readInt();
    }
    Arrays.sort(data);
    System.out.println(Arrays.toString(data));
  }
}
```

A slightly more general swap

Another example of update in place

```
private static void swap(int[] array, int x, int y) {
  int temp = array[x];
  array[x] = array[y];
  array[y] = temp;
}
```

Exercise 18

Draw the stack and the heap after each assignment.

Reverse

Algorithm

- Iterate through the first half of the array.
- For each element in the first half, swap it with its corresponding element in the second half.

Reverse

Java Implementation

```
public static void reverse(int[] array) {
  for (int i = 0 ; i < array.length / 2 ; i++) {
    swap(array , i , array.length - 1 - i);
  }
}
```

Reverse

The for loop only traverses the first half of the array

```
public static void reverse(int[] array) {
  for (int i = 0 ; i < array.length / 2 ; i++) {
    swap(array, i, array.length - 1 - i);
  }
}
```

Reverse

If the array has an odd length we don't visit the middle element, since `int` division rounds down

```
public static void reverse(int[] array) {
  for (int i = 0 ; i < array.length / 2 ; i++) {
    swap(array, i, array.length - 1 - i);
  }
}
```

Reverse

If the first element is at index 0, then the last element (the one we swap it with) is at `array.length - 1`

```
public static void reverse(int[] array) {
  for (int i = 0 ; i < array.length / 2 ; i++) {
    swap(array, i, array.length - 1 - i);
  }
}
```

Don't forget to test!

```
import java.util.Arrays;

public class ReverseTests {

  public static void main(String[] args) {

    int[] test = { 5, 4, 3, 2, 1 };
    ReverseShuffle.reverse(test);
    assert Arrays.equals(new int[]  1, 2, 3, 4, 5 , test);

    test = new int[] { 4, 3, 2, 1 };
    ReverseShuffle.reverse(test);
    assert Arrays.equals(new int[]  1, 2, 3, 4 , test);

  }
}
```

There are several different notions of equality for arrays.

Are they the same array in the heap (pointer equality)?

```
import java.util.Arrays;
public class EqualityTests {
  public static void main(String[] args) {
  // no assertions to show the differences in equality tests.
    int[][] m1 = { { 1, 2, 3 }, {4, 5, 6} };
    int[][] m2 = { { 1, 2, 3 }, {4, 5, 6} };

    if (m1 == m2) {
      System.out.println("pointer equality: same array");
    } else {
      System.out.println("pointer equality: different array");
    }

    if (Arrays.equals(m1, m2)) {
      System.out.println("one level equality: same array");
    } else {
      System.out.println("one equality: different array");
    }

    if (Arrays.deepEquals(m1, m2)) {
      System.out.println("deep equality: same array");
    } else {
      System.out.println("deep equality: different array");
    }
  }
}
```

There are several different notions of equality for arrays.

Do they have the same elements (shallow structural equality)?

```
import java.util.Arrays;
public class EqualityTests {
  public static void main(String[] args) {
  // no assertions to show the differences in equality tests.
    int[][] m1 = { { 1, 2, 3 }, {4, 5, 6} };
    int[][] m2 = { { 1, 2, 3 }, {4, 5, 6} };

    if (m1 == m2) {
      System.out.println("pointer equality: same array");
    } else {
      System.out.println("pointer equality: different array");
    }

    if (Arrays.equals(m1, m2)) {
      System.out.println("one level equality: same array");
    } else {
      System.out.println("one equality: different array");
    }

    if (Arrays.deepEquals(m1, m2)) {
      System.out.println("deep equality: same array");
    } else {
      System.out.println("deep equality: different array");
    }
  }
}
```

There are several different notions of equality for arrays.

For nested arrays, are the deeply nested values the same (deep structural equality)?

```
import java.util.Arrays;
public class EqualityTests {
  public static void main(String[] args) {
  // no assertions to show the differences in equality tests.
    int[][] m1 = { { 1, 2, 3 }, {4, 5, 6} };
    int[][] m2 = { { 1, 2, 3 }, {4, 5, 6} };

    if (m1 == m2) {
      System.out.println("pointer equality: same array");
    } else {
      System.out.println("pointer equality: different array");
    }

    if (Arrays.equals(m1, m2)) {
      System.out.println("one level equality: same array");
    } else {
      System.out.println("one equality: different array");
    }

    if (Arrays.deepEquals(m1, m2)) {
      System.out.println("deep equality: same array");
    } else {
      System.out.println("deep equality: different array");
    }
  }
}
```

There are several different notions of equality for arrays.

Pointer equality can be tested with `array1 == array2`.

```
import java.util.Arrays;
public class EqualityTests {
  public static void main(String[] args) {
  // no assertions to show the differences in equality tests.
    int[][] m1 = { { 1, 2, 3 }, {4, 5, 6} };
    int[][] m2 = { { 1, 2, 3 }, {4, 5, 6} };

    if (m1 == m2) {
      System.out.println("pointer equality: same array");
    } else {
      System.out.println("pointer equality: different array");
    }

    if (Arrays.equals(m1, m2)) {
      System.out.println("one level equality: same array");
    } else {
      System.out.println("one equality: different array");
    }

    if (Arrays.deepEquals(m1, m2)) {
      System.out.println("deep equality: same array");
    } else {
      System.out.println("deep equality: different array");
    }
  }
}
```

There are several different notions of equality for arrays.

Shallow structural equality can be tested with `Arrays.equals(array1, array2)`

```
import java.util.Arrays;
public class EqualityTests {
  public static void main(String[] args) {
  // no assertions to show the differences in equality tests.
    int[][] m1 = { { 1, 2, 3 }, {4, 5, 6} };
    int[][] m2 = { { 1, 2, 3 }, {4, 5, 6} };

    if (m1 == m2) {
      System.out.println("pointer equality: same array");
    } else {
      System.out.println("pointer equality: different array");
    }

    if (Arrays.equals(m1, m2)) {
      System.out.println("one level equality: same array");
    } else {
      System.out.println("one equality: different array");
    }

    if (Arrays.deepEquals(m1, m2)) {
      System.out.println("deep equality: same array");
    } else {
      System.out.println("deep equality: different array");
    }
  }
}
```

There are several different notions of equality for arrays.

Deep structural equality can be tested (on 2-or-higher dimensional arrays) with `Arrays.deepEquals(array1, array2)`

```
import java.util.Arrays;
public class EqualityTests {
  public static void main(String[] args) {
  // no assertions to show the differences in equality tests.
    int[][] m1 = { { 1, 2, 3 }, {4, 5, 6} };
    int[][] m2 = { { 1, 2, 3 }, {4, 5, 6} };

    if (m1 == m2) {
      System.out.println("pointer equality: same array");
    } else {
      System.out.println("pointer equality: different array");
    }

    if (Arrays.equals(m1, m2)) {
      System.out.println("one level equality: same array");
    } else {
      System.out.println("one equality: different array");
    }

    if (Arrays.deepEquals(m1, m2)) {
      System.out.println("deep equality: same array");
    } else {
      System.out.println("deep equality: different array");
    }
  }
}
```

Fisher-Yates Shuffle - Another Example

Algorithm

- Loop from the end of the array towards the start.
- At each step, swap the current element for a random array element between the first and the current (inclusive).

Fisher-Yates Shuffle

Java Implementation

```
public static void shuffle(int[] array) {
  for (int i = array.length - 1; i >= 0; i-) {
    int index = (int) (Math.random() * (i + 1));
    swap(array, index, i);
  }
}
```

Fisher-Yates Shuffle

The loop starts at the end of the array and walks backwards toward the front

```
public static void shuffle(int[] array) {
  for (int i = array.length - 1; i >= 0; i-) {
    int index = (int) (Math.random() * (i + 1));
    swap(array, index, i);
  }
}
```

Fisher-Yates Shuffle

The utility method `Math.random()` returns a `double` value that is uniformly distributed between 0 (inclusive) and 1 (exclusive)

```
public static void shuffle(int[] array) {
  for (int i = array.length - 1; i >= 0; i-) {
    int index = (int) (Math.random() * (i + 1));
    swap(array, index, i);
  }
}
```

Fisher-Yates Shuffle

To produce a random number between 0 and i inclusive we multiply the random value by i + 1.

```
public static void shuffle(int[] array) {
  for (int i = array.length - 1; i >= 0; i-) {
    int index = (int) (Math.random() * (i + 1));
    swap(array, index, i);
  }
}
```

Fisher-Yates Shuffle

To convert a `double` to an `int`, we *cast* it, by writing `(int)`. This will round the `double` towards 0.

```
public static void shuffle(int[] array) {
  for (int i = array.length - 1; i >= 0; i-) {
    int index = (int) (Math.random() * (i + 1));
    swap(array, index, i);
  }
}
```

Fisher-Yates Shuffle

i.e. for positive **double** values like we have here, it will round *down*. To round rather than round down add 0.5 before rounding.

```
public static void shuffle(int[] array) {
  for (int i = array.length - 1; i >= 0; i-) {
    int index = (int) (Math.random() * (i + 1));
    swap(array, index, i);
  }
}
```

Exercise 19

Write a method `rotate` that is given an `int[]` and an `int n`, and that rotates the elements of the array `n` steps to the right. For example:

```
int[] xs = { 10, 20, 30, 40 };
rotate(xs, 3);
assert Arrays.equals(new int[] { 20, 30, 40, 10 }, xs);
```

Summary

- Java has *pass by value* semantics. Methods receive a copy of their arguments and changes made are not passed back to the calling method.
- However, Java also has *reference types*, which a method can make changes to. These changes are seen by the calling method.
- Reference types, like arrays and `String`s live on the *heap*, unlike primitive values, which live on the *stack*.
- For arrays, there is an API `java.util.Arrays` with a very large number of utility methods. The utility methods perform updates in place, for example sorting, without needing to create space for a new array.
- Arrays have several different forms of equality, and you must be careful about using `==`, as it compares if two arrays are the same thing in the heap, not if they have the same values.
- There are utility methods in `java.util.Arrays` for checking the structural equality of two arrays.

Objects

Programming II

The story so far...

- So far we have been using Java to develop methods that could be placed into utility libraries.
- These tend to be small and self contained, usually performing a single job. e.g.
  - `biggest` : returning the largest of three numbers.
  - `encodeInt` : converting an `int` into its Morse code representation.
  - `reverse` : reversing the contents of an array
- This is a *procedural* style of program writing.
- However Java is primarily an *Object Oriented* programming language, and has many sophisticated language features for creating and working with *Objects*.

Classes and Objects

Things that have State, Behaviour and Identity

- A class is a type (for example, `class String`).
- An object is an *instance* of a class (for example, the actual String `"Hello World"`).
- There can be many objects of the same type
- Objects can have fields and methods, which capture and define their *state*, *behaviour*, and *identity*.

Objects

Things that have State, Behaviour and Identity

State

- Internal information that the object uses to know how to behave.
- Usually hidden, or only accessed / updated through a well defined interface.
- For example, a watch knows the current time, traffic lights know how long until they change to red.
- State is modelled in Java by using *fields*. These are variables that persist across multiple method calls on the object.

Objects

Things that have State, Behaviour and Identity

Behaviour

- This is the external stimuli an object can respond to.
- Usually publicly available, this is the well defined interface that the object lets the rest of the world interact with it by.
- For example, if asked to change, a traffic light can tell you the next colours it will display.
- Behaviour is modelled in Java by *instance methods*. These can:
  - Accept arguments.
  - Read and write to the object's state.
  - Return results.

Objects

Things that have State, Behaviour and Identity

Identity

- There can be many different objects, each with different internal state and possessing different behaviours.
- We may want to create many similar objects that have the same state and behaviour descriptions, but can co-exist in different states at the same time.
- For example, most traffic lights in London look the same, but they don't all show red at the same time.
- In Java, the description of an object is called its *class*, and an object that follows the description given by a class is said to be an *instance* of that class.
- Classes are described by the `class` construct, and instances are created using `new`.

A Clicky Counter

An example of an Object

Imagine a simple device with two buttons labelled `tick` and `getTicks`. The `tick` button increments a count of how many times it has been pressed. The `getTicks` button tells you how many times the `tick` button has been pressed.

State

- The number of times the button has been pressed.
- Can be stored in an `int` called `count`.

Behaviour

- `tick` will accept no arguments, increment the state, and return no results.
- `getTicks` will accept no arguments, read the state and return it.

Identity

- We could create many counters and increment them separately.

Classes describe Objects

The description of a counter

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

`public class Counter` must live in a file called `Counter.java`

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

`private int count` is an *instance field* of the class. It is declared within the class but not inside any method.

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

Each `Counter` instance that is created will get its own `count` value that will store its value as long as the instance exists.

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

The `=` `0` is optional (as `int` fields default to `0`), but makes things clearer.

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

We make the `count` variable `private` to keep it hidden. Only methods declared within the class `Counter` can access it.

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

The `public void tick()` is an *instance method* declaration. It can access the field `count` and modify it. Note the *lack* of the `static` keyword.

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

Since we only care about the side effect of incrementing the count, `tick` is a `void` method. It doesn't return anything.

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Classes describe Objects

The getTicks instance method reads the current value of count and returns it.

```
public class Counter {

    private int count = 0;

    public void tick() {
        count++;
    }

    public int getTicks() {
        return count;
    }
}
```

Creating *instances* of Objects

Making a Counter tick

```
public class TickTock {

  public static void main(String[] args) {

    Counter counter = new Counter();
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    {System.out.println(counter.getTicks());

  }

}
```

Creating *instances* of Objects

To create a new `Counter` object, write `new Counter()`

```
public class TickTock {

  public static void main(String[] args) {

    Counter counter = new Counter();
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    {System.out.println(counter.getTicks());

  }

}
```

Creating *instances* of Objects

This will create space in the heap for the fields of Counter and return a pointer to it that we store in the counter variable.

```
public class TickTock {

  public static void main(String[] args) {

    Counter counter = new Counter();
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    {System.out.println(counter.getTicks());

  }

}
```

Creating *instances* of Objects

In order to invoke the instance methods `tick` and `getTicks` we have to say which instance of `Counter` we want to call them on.

```
public class TickTock {

  public static void main(String[] args) {

    Counter counter = new Counter();
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    {System.out.println(counter.getTicks());

  }

}
```

Creating *instances* of Objects

This specification happens through the use of a `.`, e.g. `counter.getTicks()` or `counter.tick()`

```
public class TickTock {

  public static void main(String[] args) {

    Counter counter = new Counter();
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    {System.out.println(counter.getTicks());

  }

}
```

Creating *instances* of Objects

You can read `counter.tick()` as, on the instance of `Counter` pointed to by `counter`, invoke the `tick` method with no arguments.

```
public class TickTock {

  public static void main(String[] args) {

    Counter counter = new Counter();
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    {System.out.println(counter.getTicks());

  }

}
```

Exercise 20

Create a variation of the `Counter` class that has a method `hasBeenTicked` which returns `true` if `tick` has been called.

- One way is to use an extra `boolean` field.
- Another way it to look at the value of the existing `count` field.

A more flexible counter

- We can write a description of more flexible counter that also allows you to fix the value of `count`.
- To do this, we'll add a new behaviour, `setTicks` that accepts an `int` argument and uses that as the new value of `count`.

A more flexible counter

An example of an instance method accepting an argument and writing to the state

```
public class ResettableCounter {

  private int count = 0;

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

  public void setTicks(int i)  {
    count = i;
  }
}
```

A more flexible counter

The setTicks method accepts a single argument.

```
public class ResettableCounter {

  private int count = 0;

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

  public void setTicks(int i)  {
    count = i;
  }
}
```

A more flexible counter

Again, we are only interested in the side effect of updating the state of ResettableCounter, so it is also a void method.

```
public class ResettableCounter {

  private int count = 0;

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

  public void setTicks(int i)  {
    count = i;
  }
}
```

A more flexible counter

In Java, if a private field is to be updatable, it is a common pattern to use methods named `get*` and `set*` (getters and setters).

```
public class ResettableCounter {

  private int count = 0;

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

  public void setTicks(int i)  {
    count = i;
  }
}
```

Creating several instances

An example of multiple `ResettableCounter`s with different values.

```
public class TickTockTwo {
   public static void main(String[] args) {
    ResettableCounter c1 = new ResettableCounter();
    ResettableCounter c2 = new ResettableCounter();

    for(int i = 0 ; i < 5 ; i++) {
         c1.tick();
    }

    System.out.println("c1:  " + c1.getTicks());

    for(int i = 0 ; i < 10 ; i++) {
      c1.tick();
      c2.tick();
    }
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
    c1.setTicks(0);
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
  }
}
```

Creating several instances

We first create two different counters, and store pointers to them in c1 and c2.

```
public class TickTockTwo {
   public static void main(String[] args) {
    ResettableCounter c1 = new ResettableCounter();
    ResettableCounter c2 = new ResettableCounter();

    for(int i = 0 ; i < 5 ; i++) {
         c1.tick();
    }

    System.out.println("c1:  " + c1.getTicks());

    for(int i = 0 ; i < 10 ; i++) {
      c1.tick();
      c2.tick();
    }
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
    c1.setTicks(0);
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
  }
}
```

Creating several instances

We then tick c1 five times and print out it's getTicks

```
public class TickTockTwo {
   public static void main(String[] args) {
    ResettableCounter c1 = new ResettableCounter();
    ResettableCounter c2 = new ResettableCounter();

    for(int i = 0 ; i < 5 ; i++) {
        c1.tick();
    }

    System.out.println("c1:  " + c1.getTicks());

    for(int i = 0 ; i < 10 ; i++) {
      c1.tick();
      c2.tick();
    }
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
    c1.setTicks(0);
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
  }
}
```

Creating several instances

Next we tick both counters ten times. Printing out their ticks will give different internal counts.

```
public class TickTockTwo {
   public static void main(String[] args) {
    ResettableCounter c1 = new ResettableCounter();
    ResettableCounter c2 = new ResettableCounter();

    for(int i = 0 ; i < 5 ; i++) {
         c1.tick();
    }

    System.out.println("c1:  " + c1.getTicks());

    for(int i = 0 ; i < 10 ; i++) {
      c1.tick();
      c2.tick();
    }
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
    c1.setTicks(0);
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
  }
}
```

Creating several instances

Finally we reset c1 back to a count of 0.

```
public class TickTockTwo {
   public static void main(String[] args) {
    ResettableCounter c1 = new ResettableCounter();
    ResettableCounter c2 = new ResettableCounter();

    for(int i = 0 ; i < 5 ; i++) {
        c1.tick();
    }

    System.out.println("c1:  " + c1.getTicks());

    for(int i = 0 ; i < 10 ; i++) {
      c1.tick();
      c2.tick();
    }
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
    c1.setTicks(0);
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
  }
}
```

Creating several instances

Again, printing out the ticks of c1 and c2 will have different results.

```
public class TickTockTwo {
   public static void main(String[] args) {
    ResettableCounter c1 = new ResettableCounter();
    ResettableCounter c2 = new ResettableCounter();

    for(int i = 0 ; i < 5 ; i++) {
         c1.tick();
    }

    System.out.println("c1:  " + c1.getTicks());

    for(int i = 0 ; i < 10 ; i++) {
      c1.tick();
      c2.tick();
    }
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
    c1.setTicks(0);
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
  }
}
```

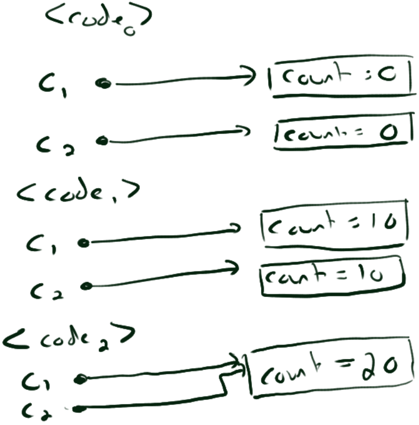
Creating several instances

What happens if instead of writing `new ResettableCounter()` we put `ResettableCounter c2 = c1;`?

```
public class TickTockTwo {
   public static void main(String[] args) {
    ResettableCounter c1 = new ResettableCounter();
    ResettableCounter c2 = new ResettableCounter();

    for(int i = 0 ; i < 5 ; i++) {
         c1.tick();
    }

    System.out.println("c1:  " + c1.getTicks());

    for(int i = 0 ; i < 10 ; i++) {
      c1.tick();
      c2.tick();
    }
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
    c1.setTicks(0);
    System.out.println("c1:  " + c1.getTicks());
    System.out.println("c2:  " + c2.getTicks());
  }
}
```

Exercise 21

Given the following snapshots of the stack and heap, what could `code0`, `code1` and `code2` be?



Static vs Instance

Static

- Static methods and fields are not associated with any instance.
- If they are `public` you can call or read/write to them from anywhere - within instances or static methods.
- They are denoted by the keyword `static`.
- Think “there can only be one”.

Instance

- Instance methods and fields are associated with an instance of a class.
- If they are `public` they can be called or read/written to only if you have an instance of that class already.
- They are denoted by the *absence* of the keyword `static`.

Objects: Another Example

A Simple Calculator

Imagine a small simple calculator. It should start at zero, and it has methods to add or multiply its current value by an `int`. It should also be able to represent its current calculation as a `String`.

State

- The current value of the calculation, represented by an `int` field called `total`.
- The `String` representing the calculation so far. Call it `concat`.

Behaviour

- Methods `plus` and `multiply` that accept an int and update the `total` and `concat` fields accordingly.
- A method `getTotal` to return the current `total`.
- A method `reset` to reset the current `total` and `concat` back to `0`.
- A method `toString` which will represent the state of the calculator as a `String`.

Using the Calculator

With only the previous description of the behaviour we can say what our calculator should do.

```
public class Main {

  public static void main(String[] args) {
    Calculator c1 = new Calculator();

    c1.plus(5);
    c1.multiply(3);
    c1.plus(7);
    System.out.println("c1 total:  " + c1.getTotal());
    System.out.println(c1);

    c1.reset();
    System.out.println(c1);
  }
}
```

Using the Calculator

The class that describes our calculator will be called Calculator.

```
public class Main {

  public static void main(String[] args) {
    Calculator c1 = new Calculator();

    c1.plus(5);
    c1.multiply(3);
    c1.plus(7);
    System.out.println("c1 total:  " + c1.getTotal());
    System.out.println(c1);

    c1.reset();
    System.out.println(c1);
  }
}
```

Using the Calculator

We should be able to call plus and multiply methods upon it, and it should build up the correct total.

```
public class Main {

  public static void main(String[] args) {
    Calculator c1 = new Calculator();

    c1.plus(5);
    c1.multiply(3);
    c1.plus(7);
    System.out.println("c1 total:  " + c1.getTotal());
    System.out.println(c1);

    c1.reset();
    System.out.println(c1);
  }
}
```

Using the Calculator

In Java, if a class describes a method with the signature `public String toString()` then `println` will use that instead of the default one provided for all objects.

```
public class Main {

  public static void main(String[] args) {
    Calculator c1 = new Calculator();

    c1.plus(5);
    c1.multiply(3);
    c1.plus(7);
    System.out.println("c1 total:  " + c1.getTotal());
    System.out.println(c1);

    c1.reset();
    System.out.println(c1);
  }
}
```

The Calculator

The implementation

```
public class Calculator {

  private int total = 0;
  private String concat = "0";

  public void plus(int amount) {
    total += amount;
    bracket();
    concat += " + " + amount;
  }

 public void multiply(int amount) {
    total *= amount;
    bracket();
    concat += " * " + amount;
  }

   private void bracket() {
       concat = "(" + concat + ")";
   }

  public int getTotal() {
    return total;
  }

  public void reset() {
    total = 0;
    concat = "0";
  }

  public String toString() {
    return concat +
      " = " + total;
  }
}
```

The `Calculator`

Both `plus` and `multiply` need to put brackets around `concat`, so we create a `private` helper method.

```
public class Calculator {

  private int total = 0;
  private String concat = "0";

  public void plus(int amount) {
    total += amount;
    bracket();
    concat += " + " + amount;
  }

 public void multiply(int amount) {
    total *= amount;
    bracket();
    concat += " * " + amount;
  }

   private void bracket() {
       concat = "(" + concat + ")";
   }
```

```
  public int getTotal() {
    return total;
  }

  public void reset() {
    total = 0;
    concat = "0";
  }

  public String toString() {
    return concat +
      " = " + total;
  }
}
```

The Calculator

bracket() is this private instance method. It can only be called by other methods defined withing Calculator.

```
public class Calculator {

  private int total = 0;
  private String concat = "0";

  public void plus(int amount) {
    total += amount;
    bracket();
    concat += " + " + amount;
  }

  public void multiply(int amount) {
    total *= amount;
    bracket();
    concat += " * " + amount;
  }

  private void bracket() {
    concat = "(" + concat + ")";
  }

  public int getTotal() {
    return total;
  }

  public void reset() {
    total = 0;
    concat = "0";
  }

  public String toString() {
    return concat +
      " = " + total;
  }
}
```

The `Calculator`

Within an instance method, you can call other instance methods on the same instance *implicitly*, i.e. without needing the `instance.` syntax.

```
public class Calculator {

  private int total = 0;
  private String concat = "0";

  public void plus(int amount) {
    total += amount;
    bracket();
    concat += " + " + amount;
  }

 public void multiply(int amount) {
    total *= amount;
    bracket();
    concat += " * " + amount;
  }

   private void bracket() {
       concat = "(" + concat + ")";
   }

  public int getTotal() {
    return total;
  }

  public void reset() {
    total = 0;
    concat = "0";
  }

  public String toString() {
    return concat +
      " = " + total;
  }
}
```

Constructors

Executing code when creating an instance

- Sometimes when you create an instance you would like some custom code to execute.
- Frequently this is used to initialize the fields of the object to a known state, to make sure some property of the fields holds.
- You may also wish to pass into the object some initial values to use for the fields.
- This code is specified by a special method called a *constructor*. Constructors can accept arguments and modify the fields of an instance, but they *can't* return results.

InitializedCounter

Note the `InitializedCounter` constructor method. Constructors use the same name as the class itself.

```
public class InitializedCounter {

  private int count;

  public InitializedCounter(int count) {
      this.count = count;
  }

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

}
```

InitializedCounter

The constructor doesn't have a return type, as it doesn't return results.

```
public class InitializedCounter {

  private int count;

  public InitializedCounter(int count) {
     this.count = count;
  }

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

}
```

InitializedCounter

Frequently the parameter names of the constructor will *shadow* the names of fields. To get around this, fields can be referred to by prefixing with `this.`

```
public class InitializedCounter {

  private int count;

  public InitializedCounter(int count) {
     this.count = count;
  }

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

}
```

InitializedCounter

this is a variable that refers to the current instance.

```
public class InitializedCounter {

  private int count;

  public InitializedCounter(int count) {
      this.count = count;
  }

  public void tick() {
    count++;
  }

  public int getTicks() {
    return count;
  }

}
```

TickTock - Constructors II

If a class constructor expects arguments, you can pass them to it during the **new** call.

```
public class TickTockInitialized {

  public static void main(String[] args) {

    InitializedCounter counter = new InitializedCounter(10);
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    System.out.println(counter.getTicks());

  }

}
```

TickTock - Constructors II

The arguments are passed between ( )s after the class name.

```
public class TickTockInitialized {

  public static void main(String[] args) {

    InitializedCounter counter = new InitializedCounter(10);
    System.out.println(counter.getTicks());

    System.out.println("Tick!");
    counter.tick();

    System.out.println(counter.getTicks());

  }

}
```

Exercise 22

Write a class `IntHolder` that would make the following `assert` statements pass.

```
public class Main {
  public static void main(String[] args) {
    IntHolder ih = new IntHolder(10);
    assert ih.size() == 10;
    ih.put(0, 3);
    assert ih.get(0) == 3;
    ih.fill(6);
    assert ih.get(4) == 6;
  }
}
```

Exercise 23

What does the following program print?

```
public class Main {
  public static void main(String[] args) {
    InitializedCounter a = new InitializedCounter(10);
    InitializedCounter b = new InitializedCounter(20);

    a = b;
    a.tick();
    System.out.println("The counters have ticked " +
      a.getTicks() + " and " + b.getTicks() + " times");
  }
}
```

Mutable and immutable objects

- So far, we have seen *mutable* objects – their state can change, and when it does, every variable using the object will see the change.
- Instead of changing the state of an object, a method can return a new object with the desired new state, while the state of the current object remains unchanged.
- In this approach, we can declare all the object's fields as **`final`**, to guarantee that its state will never change. This is called an *immutable* object.
- The choice between the two is often a matter of taste, and depends on the situation. However, objects that primarily carry 'data' are often immutable (e.g. `String`s).
- Haskell data structures are immutable.

ImmutableCounter

This example shows how `InitializedCounter` can be implemented as an immutable object

```
public class ImmutableCounter {

  private final int count;

  public ImmutableCounter(int count) {
    this.count = count;
  }

  public ImmutableCounter tick() {
    return new ImmutableCounter(count + 1);
  }

 public int getTicks() {
    return count;
  }

}
```

ImmutableCounter

The constructor and getTicks() method are as before.

```
public class ImmutableCounter {

  private final int count;

  public ImmutableCounter(int count) {
    this.count = count;
  }

  public ImmutableCounter tick() {
    return new ImmutableCounter(count + 1);
  }

 public int getTicks() {
    return count;
  }

}
```

ImmutableCounter

The `private int count` field has been made `final`, making this class an immutable object.

```
public class ImmutableCounter {

  private final int count;

  public ImmutableCounter(int count) {
    this.count = count;
  }

  public ImmutableCounter tick() {
    return new ImmutableCounter(count + 1);
  }

 public int getTicks() {
    return count;
  }

}
```

ImmutableCounter

`public void tick()` has been changed to `public ImmutableCounter tick()`, and instead of updating the state returns a new object with the desired state.

```
public class ImmutableCounter {

  private final int count;

  public ImmutableCounter(int count) {
    this.count = count;
  }

  public ImmutableCounter tick() {
    return new ImmutableCounter(count + 1);
  }

 public int getTicks() {
    return count;
  }

}
```

Exercise 24

What does the following program print?

```
public class Main {
  public static void main(String[] args) {
    ImmutableCounter a = new ImmutableCounter(10);
    ImmutableCounter b = new ImmutableCounter(20);

    a = b;
    a = a.tick(); // assign back to a
    System.out.println("The counters have ticked " +
      a.getTicks() + " and " + b.getTicks() + " times");
  }
}
```

More on `final`

Declaring something as `final` means its value cannot be changed after the initial assignment. The following declarations can be made final:

- Variables inside a function.
- Fields of an object, such that their value cannot change throughout the lifetime of the object. They must be initialised with an assignment *or* inside a constructor method.
- Method arguments, meaning their value cannot be changed/re-assigned inside the method body. Note, that Java by default allows re-assigning to a method argument, though it is commonly considered bad practice.

The DragonsBreath Dungeons – Another Example

Working with Objects

The DragonsBreath Dungeons

We are going to build up a slightly larger example, with several classes and lots of different instances working together in a single program.
Our program is going to be a very simple dungeon game, which features four classes:

- The `Player` class. This describes our hero, who braves the fearsome dungeon, fighting monsters and gaining experience, while trying not too lose to much health.
- The `Monster`s. This describes the template of a monster, which attacks our hero and dies when they run out of health.
- The `Dungeon`. This holds a player and the monsters within. It also co-ordinates the attack phases between monsters and players, and signals when the game is over.
- `DragonsBreath`. Contains the static `main` method, and manages the main game loop and input routines.

Monsters

We wish to create several different variations of `Monster`, for example Orcs, Dragons and Bunnies.

State

- Their `name`, a `String` that will not change after the instance is created.
- Their `attackStrength`, an `int` that will not change after the instance has been created.
- Their `health`, an `int` that will be initialized to a set value.

Monster

Behaviour

- `getName` - returns the name of the Monster
- `isAlive` - returns whether the health of the monster is > 0.
- `takeDamage` - receives an amount of damage to take and reduces health by that amount.
- `toString` - represents the monster as a `String`
- `attack` - accepts a `Player` as an argument, and attacks them.

Player

State

- `int health` - the remaining health of the Player.
- `int experience` - This is increased by killing monsters, and will make the player tougher and stronger.
- `final int attackStrength` - The base attack damage the player does. It will be multiplied by their experience.

Behaviour

- `attack` - attacks a monster. If they succeed in killing the monster, the player gains experience.
- `takeDamage` - reduces the players health by an amount of damage, modified by `experience`.
- `isAlive` - returns whether the player's health is `>0`.
- `toString` - returns a `String` representation of the player.

Dungeon

Holds a player and some monsters. Coordinates the attacking of creatures held within, and knows when the game is over.

State

- `final Player player` - The `Player` that has braved the dungeon.
- `final Monster[] monsters` - An array of dead and alive `Monster`s that live in the dungeon.
- `final Random random` - An instance of a Java utility class that provides more flexible random numbers than just using `Math.random()`.

Note that although all the state is `final`, the states of the individual `Player` and `Monsters` can change, just that the `Dungeon` cannot change which `Player` instance it knows about.

Dungeon

Behaviour

- `printDungeon` - Print out a representation of the dungeon to the console.
- `isGameOver` - The game is over if the player dies, or all the monsters have died.
- `randomMonsterAttack` - Causes a random monster to attack the player.
- `playerAttack` - Causes the player to attack a particular monster.

DragonsBreath

Tying it all together.

This class has two static methods:

- The `main` method that runs the game loop
- and a helper method, `checkDifficultyAndGetPlayer` which prints out a menu to choose the difficulty of the game.

The difficulty setting changes the initial strength and health of the `Player` which is put into the dungeon.

Testing

Testing Static Methods

- When testing functions in Haskell and simple static methods in Java it was enough to enumerate simple test cases matching inputs to expected outputs.
- For example:

```
public static void sumSquareDigitsTests() {
        checkSumSquareDigits(10, 1);
        checkSumSquareDigits(103, 10);
        ...
}
```

- These test cases represented the fact that `sumSquareDigits(10)` should equal `1`, and that `sumSquareDigits(103)` should equal `10`.

Testing Objects?

- Testing objects is different. You can't think of an object as being a mapping from inputs to outputs.
- Recall that an object consists of three parts: State, Behaviour and Identity.
  - Identity - this is managed for us by Java. New, unique things are created via `new`.
  - State - this is internal and hidden and used only by the object.
  - Behaviour - this is external and visible to others using the object.

Testing Objects?

State

- From outside an object you can't see its internal state.
- Furthermore, we don't really want to - we want the state to be *encapsulated* (e.g. hidden).
- We don't care how the object does what it does, only that it does it correctly.
- This means it should be safe to change how an object works internally.
  - e.g. `Monster`s could store a `boolean` field saying if they are dead or alive and update and use that instead of checking if `health > 0` in `isAlive`.
- That is, we don't want to test the state directly.

Testing Objects?

Behaviour

- The behaviour of an object is specified by its public instance methods.
- We can observe the return values of these methods and whether they are what we expect.
  - e.g. if we have just created a `Monster` with `10` health, we expect `isAlive` to return `true`.
- Some methods are `void`. However we can also observe their side effects on the current object.
  - e.g. After calling `takeDamage(20)` on a `Monster` that has been created with `10` health, we'd expect a subsequent call of `isAlive` to return `false`.
- We can also observe the side effects of `void` methods on other objects.
  - e.g. After calling `attack(player)` on a `Monster` that has been created with an attack damage of 5, we'd expect a newly created `Player` with health `10` to still be alive after the call.

Testing Objects - Examples

Testing Monster

```
  public class MonsterTests {

 /* Monster behaviour from lecture slides
  * getName - returns the name of the Monster
  * isAlive - returns whether the health of the monster is > 0.
  * takeDamage - receives an amount of damage to take and
  *              reduces health by that amount.
  * toString - represents the monster as a String
  * attack - accepts a Player as an argument, and attacks them
  */
  public static void main(String[] args) {
    System.out.println("Running tests...");

    canRememberName();
    canBeAliveOrNot();
    canBeDamaged();
    attacksPlayers();
    hasReadableStringRepresentation();

    System.out.println("...tests complete");
  }

...
}
```

Testing Objects - Examples

We begin with a small program that contains some tests, at least one for each behaviour.

```
  public class MonsterTests {

 /* Monster behaviour from lecture slides
  * getName - returns the name of the Monster
  * isAlive - returns whether the health of the monster is > 0.
  * takeDamage - receives an amount of damage to take and
  *              reduces health by that amount.
  * toString - represents the monster as a String
  * attack - accepts a Player as an argument, and attacks them
  */
  public static void main(String[] args) {
    System.out.println("Running tests...");

    canRememberName();
    canBeAliveOrNot();
    canBeDamaged();
    attacksPlayers();
    hasReadableStringRepresentation();

    System.out.println("...tests complete");
  }

...
}
```

Testing Objects - Examples

The different tests have names that describe behaviour monsters can exhibit. So you would say 'A monster attacks players.' hence the `attack` method could be tested by a method called `attackPlayers`.

```
public class MonsterTests {

/* Monster behaviour from lecture slides
 * getName - returns the name of the Monster
 * isAlive - returns whether the health of the monster is > 0.
 * takeDamage - receives an amount of damage to take and
 *              reduces health by that amount.
 * toString - represents the monster as a String
 * attack - accepts a Player as an argument, and attacks them
 */
public static void main(String[] args) {
  System.out.println("Running tests...");

  canRememberName();
  canBeAliveOrNot();
  canBeDamaged();
  attacksPlayers();
  hasReadableStringRepresentation();

  System.out.println("...tests complete");
}

...
```

Testing Objects - Examples

For more complicated objects it may be important to test the interaction of multiple methods, and so new categories could be created for them.

```
  public class MonsterTests {

 /* Monster behaviour from lecture slides
  * getName - returns the name of the Monster
  * isAlive - returns whether the health of the monster is > 0.
  * takeDamage - receives an amount of damage to take and
  *                 reduces health by that amount.
  * toString - represents the monster as a String
  * attack - accepts a Player as an argument, and attacks them
  */
  public static void main(String[] args) {
    System.out.println("Running tests...");

    canRememberName();
    canBeAliveOrNot();
    canBeDamaged();
    attacksPlayers();
    hasReadableStringRepresentation();

    System.out.println("...tests complete");
  }

...
}
```

Testing Objects - Examples

Two Helper Methods

```
static void assertIsAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if (!actual) {
     System.out.println("m.isAlive() returned:" + actual + ", expected:  true");
   }
 }

 static void assertIsNotAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if  (actual) {
      System.out.println("m.isAlive() returned:" + actual + ", expected:  false");
   }
 }
```

Testing Objects - Examples

These methods only print out if results are unexpected.

```
static void assertIsAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if (!actual) {
     System.out.println("m.isAlive() returned:" + actual + ", expected:  true");
   }
 }

 static void assertIsNotAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if  (actual) {
      System.out.println("m.isAlive() returned:" + actual + ", expected:  false");
   }
 }
```

Testing Objects - Examples

If we run large numbers of tests, it is clearer to only see those that fail than going through lots of output trying to work out which pass and which fail.

```
static void assertIsAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if (!actual) {
     System.out.println("m.isAlive() returned:" + actual + ", expected:  true");
   }
 }

 static void assertIsNotAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if  (actual) {
      System.out.println("m.isAlive() returned:" + actual + ", expected:  false");
   }
 }
```

Testing Objects - Examples

Note that there is no modifier. This means that this method is available in the entire **package** or *package visible*. Anyone can see **public** methods and only within a class are **private** methods visible. For now, a package can be thought of as all the files you can see at once in the IJ ide.

```
static void assertIsAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if (!actual) {
     System.out.println("m.isAlive() returned:" + actual + ", expected:  true");
   }
 }

 static void assertIsNotAlive(Monster m) {
 //  a simple for procedure for checking a particular case

   boolean actual = m.isAlive();
   if  (actual) {
      System.out.println("m.isAlive() returned:" + actual + ", expected:  false");
   }
 }
```

Testing Objects - Examples

Testing Monster's takeDamage method

```
// takeDamage tests

  static void canBeDamaged() {
    Monster testMonster;

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(5);
    assertIsAlive(testMonster);

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(10);
    assertIsNotAlive(testMonster);

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(5);
    testMonster.takeDamage(5);
    assertIsNotAlive(testMonster);
  }
```

Testing Objects - Examples

Here are three of many possible examples of testing the takeDamage method here

```
// takeDamage tests

  static void canBeDamaged() {
    Monster testMonster;

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(5);
    assertIsAlive(testMonster);

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(10);
    assertIsNotAlive(testMonster);

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(5);
    testMonster.takeDamage(5);
    assertIsNotAlive(testMonster);
  }
```

Testing Objects - Examples

The simplest cases are tested first (just calling takeDamage once), and then a more complicated example calling takeDamage twice.

```
// takeDamage tests

  static void canBeDamaged() {
    Monster testMonster;

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(5);
    assertIsAlive(testMonster);

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(10);
    assertIsNotAlive(testMonster);

    testMonster = new Monster("test", 5, 10);
    testMonster.takeDamage(5);
    testMonster.takeDamage(5);
    assertIsNotAlive(testMonster);
  }
```

Testing Objects - Examples

Testing Monster's attack method

```
private static void attacksPlayers() {
    Monster testMonster;
    Player testPlayer;

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(5, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsNotAlive(testPlayer);

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(10, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsAlive(testPlayer);
}
```

Testing Objects - Examples

The `attack` method should change the health status of the `testPlayer`. To see its effect, we check whether the player is alive or not after the attack.

```
private static void attacksPlayers() {
    Monster testMonster;
    Player testPlayer;

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(5, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsNotAlive(testPlayer);

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(10, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsAlive(testPlayer);
}
```

Testing Objects - Examples

Again notice that before each test, we recreate the Monster and Player, so that the tests are as minimal as possible.

```
private static void attacksPlayers() {
    Monster testMonster;
    Player testPlayer;

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(5, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsNotAlive(testPlayer);

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(10, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsAlive(testPlayer);
}
```

Testing Objects - Examples

We could also add some tests that `attack` doesn't change our expectations of whether the `testMonster` is alive.

```
private static void attacksPlayers() {
    Monster testMonster;
    Player testPlayer;

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(5, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsNotAlive(testPlayer);

    testMonster = new Monster("test", 5, 10);
    testPlayer = new Player(10, 10);
    testMonster.attack(testPlayer);
    PlayerTests.assertIsAlive(testPlayer);
}
```

When should you write tests

- Before writing the code that implements it.
  - You'll know when you've implemented the feature because the tests all pass.
  - Writing the tests can sometimes guide the design of your object.
- Before fixing a bug found in a program.
  - If you have a test that isolates the bug, then debugging gets easier.
  - If you already have a test suite, then adding new test cases should make this easy.
  - If when you introduce a bug you find it, fix it and add a test for it (not necessarily in that order!), you'll never have to worry that the bug might come back. (This does happen!)
- Before changing/restructuring the internal workings of an object.
  - Arrange to have passing tests before making the change.
  - Once you've changed the code, you can rerun the tests.
  - If any fail then you've changed the behaviour of the object, as-well as its state.

Note

- This is just scratching the surface of testing Java code.
- Next term you'll see more features of Java that will make it possible to create modular, flexible test suites in a disciplined way.
- You will also get to see (and create!) much larger codebases and be exposed to different forms of testing, for example:
  - *Integration Testing* - testing a whole program from end to end.
  - *Unit Testing* - testing the individual components (in this case objects).
  - *Regression Testing* - using existing tests to check changed or new code still works.
  - *Automated Testing* - using tools to help you create tests.

Summary

- To test static methods one enumerates simple test cases, (so mapping inputs to outputs).
- Objects have identity, state and behaviour. We need to test the behaviour - that it does what it is supposed to do.
- For each object produce a set of tests that see whether the object behaves properly or not. You need at least one test for each different behaviour.
- To make it easier to see what has gone wrong only print out when a test shows that an object is *not* behaving properly.
- Accumulate your tests for an object. Do not write a test, see that the behaviour is correct and then throw it away. Always run the tests you have written every time you test your code.

Enumerations

Enumerations

- An *enumerated type* is a type whose legal values consist of a fixed set of constants.
- If your program needs a fixed set of constants then using an enumerated type makes your program more readable and more maintainable.
- In Java, the values in the enumerated type are also objects, which means they can have constructors and instance methods which makes it easy to have per-constant behaviour.

Simplest Examples

Haskell and Java enumerated types

In Haskell

```haskell
data Day = Sunday | Monday | Tuesday | Wednesday
         | Thursday | Friday | Saturday
```

In Java

```java
public enum Day {
   SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY,FRIDAY, SATURDAY;
}
```

Simplest Examples

In Java, `enum` is bit like `class`.

In Haskell

```
data Day = Sunday | Monday | Tuesday | Wednesday
         | Thursday | Friday | Saturday
```

In Java

```
public enum Day {
    SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY,FRIDAY, SATURDAY;
}
```

Simplest Examples

The Day enum must live in a file called Day.java

In Haskell

```
data Day = Sunday | Monday | Tuesday | Wednesday
         | Thursday | Friday | Saturday
```

In Java

```
public enum Day {
   SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY,FRIDAY, SATURDAY;
}
```

Simplest Examples

By convention, Java constants (and enumeration constants) are written in all capital letters

In Haskell

```
data Day = Sunday | Monday | Tuesday | Wednesday
         | Thursday | Friday | Saturday
```

In Java

```
public enum Day {
   SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY,FRIDAY, SATURDAY;
}
```

Simplest Examples

Note: enums were added in Java 1.5 (or Java 5).

In Haskell

```
data Day = Sunday | Monday | Tuesday | Wednesday
         | Thursday | Friday | Saturday
```

In Java

```
public enum Day {
   SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY,FRIDAY, SATURDAY;
}
```

Other Examples

- Compass Directions (North, East, South and West)
- Days of the week
- Months of the year
- Ranks and Suits in a deck of cards
- Planets in our solar system

Using an enumerated type

Working with Days

```
public class DayExample {

  public static void main(String[] args) {
    Day today = Day.MONDAY;
    System.out.println(today);

    System.out.println("The week: ");

    for (Day day : Day.values()) {
     String tail = today == day ? " <- Today!" : "";
     System.out.println(day + tail);
    }

    System.out.println("Today's index:");
    System.out.println(today.ordinal());
  }
}
```

Using an enumerated type

To reference an enum constant you have to prefix it with the name of the enum. i.e. `Day.MONDAY`

```
public class DayExample {

  public static void main(String[] args) {
    Day today = Day.MONDAY;
    System.out.println(today);

    System.out.println("The week: ");

    for (Day day : Day.values()) {
     String tail = today == day ? " <- Today!" : "";
     System.out.println(day + tail);
    }

    System.out.println("Today's index:");
    System.out.println(today.ordinal());
  }
}
```

Using an enumerated type

By default, when you convert an enum constant to a String it will return its name ("MONDAY")

```
public class DayExample {

  public static void main(String[] args) {
    Day today = Day.MONDAY;
    System.out.println(today);

    System.out.println("The week: ");

    for (Day day : Day.values()) {
     String tail = today == day ? " <- Today!" :  "";
     System.out.println(day + tail);
    }

    System.out.println("Today's index:");
    System.out.println(today.ordinal());
  }
}
```

Using an enumerated type

Enum classes (e.g. `Day`) have some `static` methods automatically declared for them, for example `values()` which returns all of that enum's constants, in an array, in order.

```
public class DayExample {

  public static void main(String[] args) {
    Day today = Day.MONDAY;
    System.out.println(today);

    System.out.println("The week: ");

    for (Day day : Day.values()) {
     String tail = today == day ? " <- Today!" : "";
     System.out.println(day + tail);
    }

    System.out.println("Today's index:");
    System.out.println(today.ordinal());
  }
}
```

Using an enumerated type

You are guaranteed by Java that there will only ever be one instance of the enum for each enum constant. This means that == will work on them.

```
public class DayExample {

  public static void main(String[] args) {
    Day today = Day.MONDAY;
    System.out.println(today);

    System.out.println("The week: ");

    for (Day day : Day.values()) {
     String tail = today == day ? " <- Today!" : "";
     System.out.println(day + tail);
    }

    System.out.println("Today's index:");
    System.out.println(today.ordinal());
  }
}
```

Using an enumerated type

If you wish to know what the index of an enum value is in the array, you can call its instance method `.ordinal()`

```
public class DayExample {

  public static void main(String[] args) {
    Day today = Day.MONDAY;
    System.out.println(today);

    System.out.println("The week: ");

    for (Day day : Day.values()) {
     String tail = today == day ? " <- Today!" : "";
     System.out.println(day + tail);
    }

    System.out.println("Today's index:");
    System.out.println(today.ordinal());
  }
}
```

Using an enumerated type

Setting a single variable to one of two states based on a single condition is such a common use of if-else that a shortcut has been devised for it, the conditional operator, ?:.

```
public class DayExample {

  public static void main(String[] args) {
    Day today = Day.MONDAY;
    System.out.println(today);

    System.out.println("The week: ");

    for (Day day : Day.values()) {
     String tail = today == day ?  " <- Today!" :  "";
     System.out.println(day + tail);
    }

    System.out.println("Today's index:");
    System.out.println(today.ordinal());
  }
}
```

Using an enumerated type

Enumerations work with case expressions

```
public static String whatToDoToday(Day day) {
 switch (day) {
   case MONDAY:
     return "Give Lectures";
   case TUESDAY:
     return "Play Prison Architect";
   case WEDNESDAY:
     return "Run Tutorial";
   case THURSDAY:
     return "Give Lecture";
   case FRIDAY:
     return "Play Suduko and Solitaire";
   case SATURDAY:
   case SUNDAY:
     return "Watch Strictly Come Dancing";
   default:
       return "not possible";
 }
}
```

Using an enumerated type

The cases aren't prefixed with Day.

```
public static String whatToDoToday(Day day) {
  switch (day) {
    case MONDAY:
      return "Give Lectures";
    case TUESDAY:
      return "Play Prison Architect";
    case WEDNESDAY:
      return "Run Tutorial";
    case THURSDAY:
      return "Give Lecture";
    case FRIDAY:
      return "Play Suduko and Solitaire";
    case SATURDAY:
    case SUNDAY:
      return "Watch Strictly Come Dancing";
    default:
        return "not possible";
  }
}
```

Using an enumerated type

Even if the `switch` is exhaustive, Java will still require you to put a default case in or an extra return statement.

```
public static String whatToDoToday(Day day) {
 switch (day) {
   case MONDAY:
     return "Give Lectures";
   case TUESDAY:
     return "Play Prison Architect";
   case WEDNESDAY:
     return "Run Tutorial";
   case THURSDAY:
     return "Give Lecture";
   case FRIDAY:
     return "Play Suduko and Solitaire";
   case SATURDAY:
   case SUNDAY:
     return "Watch Strictly Come Dancing";
   default:
       return "not possible";
 }
}
```

Exercise 25

Write a static method `isWeekDay` that takes a `Day` arguments and returns `true` if the given day is a weekday (`Monday` – `Friday`).

- One way is to use a `switch` statement.
- Another is to use the `.ordinal()` method.

Giving enumerated types behaviour

Because enums are actually objects, they can have constructors, fields, and methods.

```
public enum EnhancedDay {

  SUNDAY("Watch Strictly Come Dancing"),
  MONDAY("Give Lectures"),
  TUESDAY("Play Prison Architect"),
  WEDNESDAY("Run Tutorial"),
  THURSDAY("Prepare Labs"),
  FRIDAY("Play Suduko and Solitaire"),
  SATURDAY("Watch Strictly Come Dancing");

  private final String whatToDo;

  EnhancedDay(String whatToDo) {
     this.whatToDo = whatToDo;
  }

  public String whatToDo() {
    return whatToDo;
  }
}
```

Giving enumerated types behaviour

The constructor arguments are written between ( )s after the enum constant's name, to be passed to the constructor.

```
public enum EnhancedDay {

  SUNDAY("Watch Strictly Come Dancing"),
  MONDAY("Give Lectures"),
  TUESDAY("Play Prison Architect"),
  WEDNESDAY("Run Tutorial"),
  THURSDAY("Prepare Labs"),
  FRIDAY("Play Suduko and Solitaire"),
  SATURDAY("Watch Strictly Come Dancing");

  private final String whatToDo;

  EnhancedDay(String whatToDo) {
     this.whatToDo = whatToDo;
  }

  public String whatToDo() {
    return whatToDo;
  }
}
```

Giving enumerated types behaviour

If you declare a constructor, it is **private**, and you cannot write program code to call it. It doesn't need to be explicitly declared as private. It is executed automatically.

```
public enum EnhancedDay {

  SUNDAY("Watch Strictly Come Dancing"),
  MONDAY("Give Lectures"),
  TUESDAY("Play Prison Architect"),
  WEDNESDAY("Run Tutorial"),
  THURSDAY("Prepare Labs"),
  FRIDAY("Play Suduko and Solitaire"),
  SATURDAY("Watch Strictly Come Dancing");

  private final String whatToDo;

  EnhancedDay(String whatToDo) {
     this.whatToDo = whatToDo;
  }

  public String whatToDo() {
    return whatToDo;
  }
}
```

Giving enumerated types behaviour

Within the definition of an enum you can also create fields and methods.

```
public enum EnhancedDay {

  SUNDAY("Watch Strictly Come Dancing"),
  MONDAY("Give Lectures"),
  TUESDAY("Play Prison Architect"),
  WEDNESDAY("Run Tutorial"),
  THURSDAY("Prepare Labs"),
  FRIDAY("Play Suduko and Solitaire"),
  SATURDAY("Watch Strictly Come Dancing");

  private final String whatToDo;

  EnhancedDay(String whatToDo) {
     this.whatToDo = whatToDo;
  }

  public String whatToDo() {
    return whatToDo;
  }
}
```

Using an enumerated type's behaviour

```
public class EnhancedDayExample {

    public static void main(String[] args) {

        EnhancedDay today = EnhancedDay.MONDAY;
        String activity = today.whatToDo();

        System.out.println(activity);

    }

}
```

Exercise 26

Extend `EnhancedDay` with an `isWeekDay` instance method.

Summary

- Enums are lists of constants (or `static final`). Use an enum when you need a small predefined list of values.
- Using enums appropriately both makes your program more readable (hence less error prone) and it may run faster.
- Enums can contain constructors, methods, fields, and constant class bodies.
- `MyEnum.values()` returns an array containing the `MyEnum` values.
- `anEnum.ordinal()` returns the index of `anEnum` in `MyEnum.values()`.
- Enums can be compared with `==`, `.equals()`, and case statements. Even if there is a case for every value in an enumerated type you must either have a `default` or after the swtich statement a separate return in case there is no match (which would be impossible).

Bits and Pieces – Rounding off your Java, ready for next term

Method and constructor overloading

Multiple definitions of the same function

- In a single program a function can be redefined with the same name and same return type, but with strictly different arguments. This is called *overloading*.
- For example, the `System.out.println()` method exists multiple times taking different arguments (or none): `println()`, `println(3)`, `println(false)`.
- Overloading is useful to enable methods to deal with different kinds of arguments, and also to allow the specification of default values.
- Constructors can also be overloaded. This enables the provider of a class to have a default initialisation without parameters and another initialisation with parameters.

Counter

Note the two constructor methods.

```
public class Counter {
  private int count;

  public Counter() {
    this(0);
  }
  public Counter(int count) {
    this.count = count;
  }
  public void tick() {
    tick(1);
  }
  public void tick(int n) {
    count += n;
  }
  public int getTicks() {
    return count;
  }
}
```

Counter

Constructor methods that can be called with no arguments are called *default constructors*.

```
public class Counter {
  private int count;

  public Counter() {
    this(0);
  }
  public Counter(int count) {
    this.count = count;
  }
  public void tick() {
    tick(1);
  }
  public void tick(int n) {
    count += n;
  }
  public int getTicks() {
    return count;
  }
}
```

Counter

The default constructor uses **this** to call another *overloaded* constructor method, passing a default value of zero.

```
public class Counter {
  private int count;

  public Counter() {
    this(0);
  }
  public Counter(int count) {
    this.count = count;
  }
  public void tick() {
    tick(1);
  }
  public void tick(int n) {
    count += n;
  }
  public int getTicks() {
    return count;
  }
}
```

Counter

The tick method can tick a single time, or n times.

```java
public class Counter {
  private int count;

  public Counter() {
    this(0);
  }
  public Counter(int count) {
    this.count = count;
  }
  public void tick() {
    tick(1);
  }
  public void tick(int n) {
    count += n;
  }
  public int getTicks() {
    return count;
  }
}
```

Counter

We could implement the no-argument version of tick by writing count++, but instead we chose to call the overloaded version with a default argument of 1

```
public class Counter {
  private int count;

  public Counter() {
    this(0);
  }
  public Counter(int count) {
    this.count = count;
  }
  public void tick() {
    tick(1);
  }
  public void tick(int n) {
    count += n;
  }
  public int getTicks() {
    return count;
  }
}
```

this

or self-referencing

- `this(...)` references another constructor method.
- `this` followed by a `.` allows us to reference fields and functions of the current object
- `this` can also be used to pass a self-reference to another object. For instance, in a tree-like structure:

```
Node n = new Node();
n.setParent(this);
```

Generics

Java generics

Creating a pair class in Java

```
public class Pair<F, S> {

  private final F first;
  private final S second;

  public Pair(F first, S second) {
    this.first = first;
    this.second = second;
  }

  public F getFst() {
     return first;
  }

  public S getSnd() {
     return second;
  }

  public void println() {
    System.out.println("<" + first + "," + second + ">");
  }
}
```

Java generics

The type parameters to a class are put between < >'s

```
public class Pair<F, S> {

  private final F first;
  private final S second;

  public Pair(F first, S second) {
    this.first = first;
    this.second = second;
  }

  public F getFst() {
     return first;
  }

  public S getSnd() {
     return second;
  }

  public void println() {
    System.out.println("<" + first + "," + second + ">");
  }
}
```

Java generics

Within the definition of the class Pair, you can use F and S as types.

```
public class Pair<F, S> {

  private final F first;
  private final S second;

  public Pair(F first, S second) {
    this.first = first;
    this.second = second;
  }

  public F getFst() {
     return first;
  }

  public S getSnd() {
     return second;
  }

  public void println() {
    System.out.println("<" + first + "," + second + ">");
  }
}
```

Java generics

So, for example, they are used as the types of the first and second fields.

```
public class Pair<F, S> {

  private final F first;
  private final S second;

  public Pair(F first, S second) {
    this.first = first;
    this.second = second;
  }

  public F getFst() {
     return first;
  }

  public S getSnd() {
     return second;
  }

  public void println() {
    System.out.println("<" + first + "," + second + ">");
  }
}
```

Java generics

They are also used as the types of the `first` and `second` parameters to the constructor.

```
public class Pair<F, S> {

  private final F first;
  private final S second;

  public Pair(F first, S second) {
    this.first = first;
    this.second = second;
  }

  public F getFst() {
     return first;
  }

  public S getSnd() {
     return second;
  }

  public void println() {
    System.out.println("<" + first + "," + second + ">");
  }
}
```

Java generics

They are also the return types of the getFst and getSnd methods.

```
public class Pair<F, S> {

  private final F first;
  private final S second;

  public Pair(F first, S second) {
    this.first = first;
    this.second = second;
  }

  public F getFst() {
     return first;
  }

  public S getSnd() {
     return second;
  }

  public void println() {
    System.out.println("<" + first + "," + second + ">");
  }
}
```

Using a generic class

Creating an instance of a Pair

```
public class PairHelloWorld {

    public static void main(String[] args) {
        Pair<String, String> helloWorld
            = new Pair<>("Hello", "World");

        System.out.println(helloWorld.getFst());

    }

}
```

Using a generic class

When calling `new`, you must show that it is generic by creating a `Pair<>`

```
public class PairHelloWorld {

    public static void main(String[] args) {
        Pair<String, String> helloWorld
            = new Pair<>("Hello", "World");

        System.out.println(helloWorld.getFst());

    }

}
```

Using a generic class

helloWorld.getFst() will have a return type of String in this example.

```
public class PairHelloWorld {

    public static void main(String[] args) {
        Pair<String, String> helloWorld
            = new Pair<>("Hello", "World");

        System.out.println(helloWorld.getFst());

    }

}
```

Exercise 27

1. Create a static method `equalAllThree` which takes three arguments of the same type, and returns true if they are all `.equals(...)` to each other. The syntax for the signature is:

```
static <T> boolean equalAllThree(T first, T second, T third)
```

2. Now create a similar method but this time as an instance method rather than as a static method. In this case it should only take two parameters, because it should compare with itself.

3. Consider the function `makeDuplicate` in Haskell:

```
makeDuplicate :: a -> (a, a)
makeDuplicate x = (x, x)
```

Write a similar method in Java.

Reminder: Primitive and Reference Types

Java's Primitive Types

- `byte`, `short`, `int`, `long`, `float`, `double`, `boolean`, `char`
- Values of primitive types live on the *stack*, and are *copied* when assigning to variables/fields or when passed into / out of methods.
- By convention they start with a lowercase letter.

Java's Reference Types

- `String`, arrays of anything and instances of classes.
- Their contents live in the *heap*, and variables / fields get a pointer to their contents. This pointer is copied, but the contents themselves are not. So if their contents are changed every use of them will see the change.
- By convention they start with a capital letter.
- Variables and fields of reference type can have the value `null` which means they don't point to a value (yet).

Type Variables can only represent reference types

- This means you cannot use `Pair<String, int>` as a type for a variable, for example, as `int` is a primitive type.
- However, Java has a set of reference types that *box* the primitive types.
- These boxes live on the heap like other reference types, but are immutable (i.e. they always point to the same place on the heap).

Primitive Type	Reference Type
`byte`	`Byte`
`short`	`Short`
`int`	`Integer`
`long`	`Long`
`float`	`Float`
`double`	`Double`
`boolean`	`Boolean`
`char`	`Character`

Boxes for Primitive Types

- You can create instances of the box classes using their constructors, as per normal classes. You can then use the box's instance methods to unwrap the primitive they contain. For example:

```
Integer i = new Integer(2);
int j = i.intValue();
```

- In many cases, Java can work out when you need to do the wrapping / unwrapping and can do it for you. This is a feature called *autoboxing*. The above example could equally be written as:

```
Integer i = 2;
int j = i;
```

- The box classes have lots of useful `static` and instance methods.
- Be aware, that autoboxing will crash your program if you try and convert a `null` box into a primitive, e.g.

```
Integer i = null;

//this line will crash
int j = i;
```

Exercise 28

What do the stack and heap look like during the execution of the following code:

```
int i = 0;
Integer ii = i;

// << here >>

int j = ii.intValue() + 1;
Integer jj = new Integer(j);

// << here >>

Integer kk = null;

// << here >>

int k = kk.intValue();

// << here? >>
```

Using Generics with Boxed Types

```
public class PairExample {

  public static void main(String[] args) {

    Pair<Integer, Integer> twoInts = new Pair<>(1, 1);
    twoInts.println();

    Pair<Character, Integer> charInt = new Pair<>('x', 1);
    charInt.println();

    Pair<String, Integer> keyValue = new Pair<>("Susan", 569);
    keyValue.println();
  }
}
```

Parametric Polymorphism

- Haskell has polymorphism where you use type variables to write data structures that are can be used to hold elements of any type.
- Java has generics where you use type variables to write data structures that are can be used to hold elements of any type.
- This functionality is called *parametric polymorphism* because it takes type variables as parameters and lets you create data structures (or classes) of the same shape, independent of the types of the elements to be held in the data structure. It makes a language much more expressive. That is it takes less code, to say more and the code is more understandable to read.
- If we did not have parametric polymorphism in Java, instead of a single class `Pair<F,S>`, we would have needed separate classes `StrStrPair`, `IntIntPair`, `ChrIntPair`, `ChrChrPair`, and `StrIntPair` *etc., etc.* each with their own constructor and other methods.

Collections and Interfaces

Collections

- A *collection* is an object that holds a group of objects. Methods are provided to manage the stored objects (such as storing and retrieving elements).
- Modern programming languages provide large libraries (or api's - application program interface) of collections.
- Examples of these are lists, sets, and maps - and there are many, many more and many variations of each of these.
- The api `java.util.Collections` contains the api's for the most commonly used data structures. See https://docs.oracle.com/javase/9/docs/api/java/util/package-summary.html.

Collections

- Parametric polymorphism (using generics) make the collections libraries very expressive. For example, if one had a class `Student` then the `List<E>` class could be used if you wanted a list data structure for your `Student`s, whereas before Java had generics, programmers had to write all the methods for accessing a `StudentList` themselves.
- As is very good programming practice, Java separates each data structure into two - what it does and how it is implemented.
- To use a data structure in your code, you need to know what it does. This is the data structure's specification and you can see what it does by looking at its `interface`.

The `List<E>` interface

Lists in Java

- Use the `List` interface to store a list of elements
- Elements can be added to the end of the list (default), or at a specific position.
- Lists do not have a fixed size, and support behaviour for removing elements.
- `https://docs.oracle.com/javase/9/docs/api/java/util/List.html` shows that there are over 30 methods in the `List` interface. Each method is described.

The `List<E>` interface

Important methods in the interface

```
public interface List<E> {
  boolean add(E e);
  void add(int index, E element);
  void clear();
  boolean contains(Object o);
  boolean equals(Object o);
  E get(int index);
  int indexOf(Object o);
  boolean isEmpty();
  E remove(int index);
  int size();
  ...
}
```

The `Set<E>` interface

- A list has ordered, possibly duplicated elements. Sometimes this level of structure is not needed and a set models the problem better.
- Use the `Set` interface to hold a unique set of values.
- Sets do not have a way of retrieving an individual element, as they do not commit to storing items in the order they are added.
- https://docs.oracle.com/javase/9/docs/api/java/util/Set.html shows the methods in the `Set` interface.

The `Set<E>` interface

Important methods in the interface

```
public interface Set<E> {
  boolean add(E e);
  void clear();
  boolean contains(Object o);
  boolean equals(Object o)
  boolean isEmpty();
  boolean remove(Object o);
  int size();
  ...
}
```

The `Map<K,V>` interface - lookup tables

- Another very useful data structure is a map. Maps contain key-value pairs.
- The key is used to access the key-value pair (or entry), so each key has to be unique. A key is an object that you use to retrieve a value at a later date. Here is an example where a map would be an appropriate data structure:

Key	Value
Susan	569
Tony	354
Alastair	422
Alessandra	560
Marc	304
Konstantinos	228
Mark	228

- Adding entries into a `Map<K,V>` requires the user to call `void put(K key, V value)`, which will add the key-value pair to the map if the key does not exist, or replace the `value` of the given `key` if it is already present. This ensures the set of keys will always be unique.
- https://docs.oracle.com/javase/9/docs/api/java/util/Map.html shows the methods in the `Map` interface.

The `Map<K,V>` interface - lookup tables

Values do not need to be unique in a map.

- Another very useful data structure is a map. Maps contain key-value pairs.
- The key is used to access the key-value pair (or entry), so each key has to be unique. A key is an object that you use to retrieve a value at a later date. Here is an example where a map would be an appropriate data structure:

Key	Value
Susan	569
Tony	354
Alastair	422
Alessandra	560
Marc	304
Konstantinos	228
Mark	228

- Adding entries into a `Map<K,V>` requires the user to call `void put(K key, V value)`, which will add the key-value pair to the map if the key does not exist, or replace the `value` of the given `key` if it is already present. This ensures the set of keys will always be unique.
- `https://docs.oracle.com/javase/9/docs/api/java/util/Map.html` shows the methods in the `Map` interface.

The `Map<K,V>` interface - lookup tables

Important methods in the interface

```
public interface Map<K,V> {
  void clear();
  boolean containsKey(Object key);
  boolean containsValue(Object value);
  Set<Map.Entry<K,V>> entrySet();
  boolean equals(Object o)
  V get(Object key);
  boolean isEmpty();
  Set<K> keySet();
  V put(K key, V value);
  V remove(Object key);
  int size();
  ...
}
```

Interfaces and Implementations

- Interfaces say *what* is implemented but not *how* it should be implemented. They contain *no* method bodies, just fields and method headers.
- Java provides over 2500 interfaces, see `http://docs.oracle.com/javase/9/docs/api/`
- Some you might find useful are in:
  - `java.lang.Math` - util methods for mathematics.
  - `java.util.Arrays` - util methods for handling arrays.
  - `java.util.Collections` - util methods for handling `Collection`s
- A class can implement an interface (the *how*). It must provide methods for each of the method headers in the interface.
- For example, the interfaces for the data structures `list, set,` and `map` have a `size()` method and so any class that implements one of these data structures must have a `size()` method.

Interfaces and Implementations

- For the interfaces that Java provides, it also provides a variety of classes that can be chosen to implement it and they are listed in the documentation for the interfaces themselves.
- It is usual that there are several ways one can implement a given interface, the *how*.
- For example, look up `List` and see 'All Known Implementing Classes:'
- There are ten implementing classes including:
  `ArrayList, LinkedList, Stack, Vector`
- What the programmer has to do after they decide which interface they wish to use, is to choose which class they want to use to implement it.
- Choose an implementing class that has the features you want for your application. For lists, if you cannot decide I suggest you use an `ArrayList`.
- Next term you will learn how to write your own interfaces in Java, but you can go a long way with the interfaces and implementing classes that Java provides already.

Using a collection type

List is the interface used (twice) and it is implemented (both times) by the ArrayList class.

```
public class ListExample {
  public static void main(String[] args) {
    List<String> data = new ArrayList<String>();
    data.add("Hello World");
    data.add("Foo");
    String s = data.get(0);

    List<Integer> nums = new ArrayList<Integer>();
    nums.add(Integer.MAX_VALUE);
    Integer first = nums.get(0);

    printSize(data);
    printSize(nums);
  }

  public static void printSize(List data) {
    System.out.println("Stored " + data.size() + " items");
  }
}
```

Using a collection type

The type parameters for both interface and implementation appear between < >'s

```
public class ListExample {
  public static void main(String[] args) {
    List<String> data = new ArrayList<String>();
    data.add("Hello World");
    data.add("Foo");
    String s = data.get(0);

    List<Integer> nums = new ArrayList<Integer>();
    nums.add(Integer.MAX_VALUE);
    Integer first = nums.get(0);

    printSize(data);
    printSize(nums);
  }

  public static void printSize(List data) {
    System.out.println("Stored " + data.size() + " items");
  }
}
```

Using a collection type

Only reference types are allowed as type parameters, no primitive types.

```
public class ListExample {
  public static void main(String[] args) {
    List<String> data = new ArrayList<String>();
    data.add("Hello World");
    data.add("Foo");
    String s = data.get(0);

    List<Integer> nums = new ArrayList<Integer>();
    nums.add(Integer.MAX_VALUE);
    Integer first = nums.get(0);

    printSize(data);
    printSize(nums);
  }

  public static void printSize(List data) {
    System.out.println("Stored " + data.size() + " items");
  }
}
```

Using a collection type

Using a `Map<K,V>` inteface implemented by a `Hashmap` class.

```
import java.util.*;

public class MapExample {

  public static void main(String[] args) {
    Map<String, Integer> officeDB = new HashMap<String, Integer>();
    officeDB.put("Susan", 569);
    officeDB.put("Tony", 354);
    officeDB.put("Alastair", 422);
    officeDB.put("Alessandra", 560);
    officeDB.put("Marc", 304);
    officeDB.put("Konstantinos", 228);
    officeDB.put("Mark", 228);

    System.out.println("Susan is in " + officeDB.get("Susan"));
  }
}
```

Exercise 29

What will the following print? What would the output be if we used a list instead of a set?

```
public class SetExample {

  public static void main(String[] args) {
    Set<Integer> nums = new TreeSet<Integer>();
    nums.add(5);
    nums.add(10);
    nums.add(3);
    nums.add(5);

    for (Integer i : nums) {
      System.out.println(i);
    }
  }
}
```

Summary

- Methods and constructors can be overloaded. For example, `print` can print any type because it is overloaded. Two overloaded methods or constructors take parameters of different types.
- `this` is used to reference an individual object.
- Java has a generics capability, but that we cannot use primitives as the types of the elements. Fortunately, primitives can be boxed so they can be used in generic data structures.
- Java has a large library of interfaces, and these provide a very rich library of data structures or collections.
- We have looked into three of these in a little detail. They are lists, sets, and maps.
- The interfaces are generic so there are `List<Integer>`s and `List<String>`s for example.
- Interfaces need to be implemented by classes and Java also provides a large collection of classes that implement the interfaces that are provided.
- It is good to use interfaces when declaring your data structures and the declarations are of the form:

```
List<String> myList = new ArrayList<String>();
```