1 Lecture 1 — Welcome

1.1 Introduction

A program, and what can happen with it
In general

- A compiler translates the program into machine code
- Computer hardware runs the program

For Java in particular

- The compiler translates the program into Java class files
  - Like machine code, but not specific to any machine
- The Java virtual machine interpreter runs class files on your computer

And we have electronic textbook

- The server runs your code, and displays the result elsewhere on the same web page

**Parts of the program**

```java
public class Kilograms {
    public static void main (String [] args) {
        double pounds = 20;
        System.out.print(pounds);
        System.out.print(" pounds is ");
        System.out.print(pounds / 2.2);
        System.out.println(" kilograms.");
        return;
    }
}
```

**Add comments to describe what the program does**

```java
/**
 * Converter from pounds to kilograms.
 */
public class Kilograms {
    public static void main (String [] args) {
        double pounds = 20; // Amount to convert to kilograms
        System.out.print(pounds);
        System.out.print(" pounds is ");
        System.out.println(pounds / 2.2);
        System.out.println(" kilograms."); // End of this line
        return;
    }
}
```
The other thing that happens with a program — errors!

Compiler errors
- An error that keeps the compiler from translating your program to a class file
- Nothing to run, so no inputs consumed and no outputs produced

Runtime errors
- The compiler does not notice anything wrong
  - Or maybe it gives a warning, but lets us run it anyway — some times it does work out OK
- An error that comes up while the program runs
- Some input consumed, some output produced — but then it cannot continue

The six things a program can do
1. Get input
2. Give output
3. Do arithmetic
4. Update a stored value
5. Test a condition, and select an alternative
6. Repeat a group of actions

Only six things!
- If that’s all a computer can do, maybe that’s all we have to do this semester??
- There’s a whole bunch of detail and skill associated with each of these
- We will see common patterns of combining the Six Things
- There are also questions about organizing our programs and data...

Four ways Java will help you organize your work
1. Defining sequences of operations
2. Grouping related data together
3. Associating data with operations relevant to the particular data
4. Naming these groups, sequences and associations for easy and repeated use

Exercise 1.1. In Eclipse, create a new project called Hello World, and within it create a class called HelloWorld (note that there is a space in the project name, but there are no spaces in the class name). Create a main method for class HelloWorld, or fill in the main routine if it creates one for you, like this:

```java
public class HelloWorld {
    public static void main(String[] args) {
        System.out.println("Hello world! Welcome to Java!");
    }
}
```

2 Lecture 2 — Variables and methods

REVIEW: Four ways Java will help you organize your work

1. Defining sequences of operations
2. Grouping related data together
3. Associating data with operations relevant to the particular data
4. Naming these sequences, groups and associations for easy and repeated use

Declarations

• Creates a place in the computer for a value to be stored
  – Give the place a name
  – Specify what type of item goes there
    * Java is strongly typed - once we declare a particular type, we have to be consistent
      * So once an integer, always an integer; once a Scanner, always a Scanner
  – Assign an initial value to it

• We saw in the first lecture:

  Scanner scnr = new Scanner(System.in);
  int quantity = scnr.nextInt();

• In today’s reading:

  int litterSize = 3;
  int yearlyLitters = 5;
  int annualMice = 0;

Pick good names

• Use lower camel-case for variable names.
  – Named after the "humps" of upper-case letters in the middle of the name

• Descriptive names, but be reasonable with length

• Use letters, and maybe numbers at the very end

• Mnemonic - assisting the memory
  Consistent - ease understanding

Many types of numbers

You’ve seen already:

• int — Rounded integer values

• double — Real-number values

Java also has:

• long — Integer values from a larger range
  – int runs from -2,147,483,648 to 2,147,483,647
• long — Integer values from shorter ranges
• byte and short — Integer values from shorter ranges
  – byte runs from -128 to 127
  – short runs from -32,768 to 32,767
• float — Less accurate real-number values
  – There are limits not just in magnitude, but also in accuracy.
  – float runs from about $-10^{38}$ to $10^{38}$ with about 7 significant digits of accuracy
  – double runs from about $-10^{308}$ to $10^{308}$ with about 16 significant digits of accuracy

Generally:
• Use int or long normally
• Never use a floating-point type when an integer will do
• Only use byte or short to really make a point about the limited range

Operations on numbers
• Usual arithmetic: +, -, *, /
  – But notice that integer division may not be what you expect!
  – Another basic operator: modulus %
• Many other mathematical function are provided as methods in a standard Java library
  – Its full name is java.lang.Math
  – Documentation is online:
    * Front page for all Java standard classes: https://docs.oracle.com/javase/8/docs/api/
    * The Math class page https://docs.oracle.com/javase/8/docs/api/java/lang/Math.html

Exercise 2.1. Answer these questions by writing short Java programs

• Does subtraction group to the left, or to the right? That is, when we ask Java to evaluate 100−50−10, will it evaluate (100−50)−10, or will it evaluate 100−(50−10)?
• Does division group to the left, or to the right?
• Does modulus group to the left, or to the right?
• Does multiplication take precedence over addition, as it does in school algebra? That is, when we ask Java to evaluate 100+50×10, will it evaluate (100+50)×10, or will it evaluate 100+(50×10)?

Exercise 2.2. Answer the following questions using the java.lang.Math documentation

• What methods does Java provide for logarithms?
• What methods does Java provide for trigonometry?
• What is the difference between floor and ceil?
• What is the difference between floor and round?
• What do the signum methods do? Why are there two of them?
Methods
Methods are groups of operations

- They have a name, and we can refer to them by name
- We can provide values to a method, and the method’s operations can use those values
  - Called parameters
  - Each of these values has a definite, specific type
- The method can provide a return value representing the result of its work
  - Also has a definite, specific type
  - Or, it should be declared void if it does not return a value

Exercise 2.3. Write a Java class TempConverter with a static method toCelsius, which takes a Fahrenheit temperature as a double value, and returns the equivalent Celsius temperature.

Where do we find methods?
- We can define our own methods
  - Like toCelsius
- Java provides many standard methods for us
  - Like the Math class

How do we use methods?
One method can be called from another method

- Methods help structure the programs we write

- For example:

  ```java
  public class Temperatures {
      public static double toCelsius(double degreesFahrenheit) {
          return (degreesFahrenheit - 32.0) * 5.0 / 9.0;
      }
      public static void main(String[] args) {
          System.out.println("75F is ");
          + toCelsius(75.0) + "C");
          System.out.println("sin(pi/2) is ");
          + Math.sin(Math.PI/2));
      }
  }
  ```

  prints

  75F is 23.88888888888889C
  sin(pi/2) is 1.0
Exercise 2.4. Write static methods \( f_1, f_2 \) and so on implementing the following mathematical functions on real numbers (double). Do not use methods from the \texttt{Math} class for these.

1. \( f_1(x) = 2x + 1 \)
2. \( f_2(x, y) = x^2 + 2xy + y^2 \)
3. \( f_3(u) = u^3 + 2u^2 - 3u + 10 \)
4. \( f_4(w) = \frac{w+1}{w-1} \)
5. \( f_5(z) = f_3(z) + f_4(2 + z^2) \)

What happens when we call \( f_4(1) \) from a \texttt{main} method?

Exercise 2.5. Write static methods \( g_1, g_2 \) and so on implementing the following mathematical functions on real numbers (double). Do use methods from the \texttt{Math} class for these.

1. \( g_1(x) = \sqrt{2x^2 + 1} \)
2. \( g_2(x, y) = \log_x y \)
3. \( g_3(w) = |w + 10| \)
4. \( g_4(z) = z^{200} \)

What happens when we call \( f_4(1) \) from a \texttt{main} method?

Exercise 2.6. Most cereals are made primarily of flour, sugar and high-fructose corn syrup. Write a class \texttt{CerealMaker} with a static method \texttt{announceComposition}. Your method should take three integer arguments, representing (respectively) the number of grams of flour, sugar and high-fructose corn syrup in a standard serving of some particular cereal. Your \texttt{announceComposition} method should print a well-formatted announcement of the total number of grams in a standard serving, repeat the number of grams and the name of each ingredient, and then print the total percentage of the standard serving which is sweetener. Your \texttt{announceComposition} method should not return any result.

Exercise 2.7. You have probably run across the \texttt{factorial} function in your math classes. It is defined by two rules:

\[
0! = 0
\]
\[
n! = n \cdot (n-1)! \quad \text{when } n > 0
\]

We have not yet learned enough Java to implement a factorial method. But we can get ready for when we implement factorial, by writing methods to test our implementation. Notice the difference with the example above — there, we checked what a method \textit{was already doing}; now, we are setting expectations for what a method \textit{will do}. This approach is called \textit{test-driven development} — we write tests first, so that our goals are clear, and so that we can know when our method is correct.

We \textit{stub} the \texttt{factorial} method by writing an implementation which we know is wrong, but which will compile and run with our tests. By making our tests compile and run (albeit with incorrect results), when we do develop the \texttt{factorial} method, we can do so without worrying that our test infrastructure is lacking.

```java
public class FactorialTester {
    public long factorial(int n) {
        // TODO --- later we will implement factorial correctly
        return -1;
    }
}
```

So starting from the above class, add a \texttt{main} method which tests \texttt{factorial} on several different values.
Exercise 2.8. Write a class `NumberLengthFinder` with static method `lengthInDigits` which takes a number as its argument, and returns the number of digits it takes to write down that number (in base-10). Your `lengthInDigits` method should

- Take a single `long` argument, and
- Return a `long` result.

(For a hint, see p. [58])

3 Lecture 3 — Our discipline

Our approach to software design

There is more to software design than just programming!

- Implementing methods in Java is a key step, but it is **not** the beginning and end of what this class is about

In this class we will follow a specific four-step *methodology* (or *discipline*) for producing quality software

0. **Stub your goal methods**

- Almost all of the problems we solve will ask for a class and methods with particular behavior
- We will always start off by writing a Java class with *stub versions* of the methods which are the goal of an exercise
  - With the right argument and result types
  - But with only a "dummy" result
  - (Or empty, if the method is void)
- Make it compile!
  - We start right here at the beginning making sure our code always compiles

1. **Codify your understanding of the problem as tests**

How do you know if your work is correct?

In other words, how do you know that your methods behave as the specification says they should?

- By running them, and checking the results!
- But we need to run each method with several different arguments to check for special cases
- And we would need to run them every time we make a change to make sure that didn’t break anything
- So we will need to run several tests several times as we develop our solution
  - All this sounds very tedious!

The solution: put the tests, all of them one after the next, in the `main` method

- We set up our tests **before** writing the methods
  - Testing is not an afterthought
  - It drives our software development process
  - When we see tests that fail, we pick one, and fix it
  - When all the tests pass, the program is finished
- Since we have set up stub versions of the methods, we can already compile and run our tests
  - They will all fail at first — but who cares!?
  - We always keep our code able to compile and run
2. Design the methods

It is time to think about the methods — but we do not start by just cranking out Java.

We first write a design for the method body

- In plain English, not formal Java
  - And not just rephrasing Java statements in English!
- As comments in the method body
  - Use the // - form of comments
- Explain why we preform certain statements, in term of achieving method goals
- As the semester proceeds, we will see certain patterns of how we combine statements — we name these patterns in particular as part of the design

3. Implement the methods

At this final step we are in a position to implement the Java statements in our goal method bodies

- Place statements immediately below the particular design comment to which they correspond
- What if your original design idea is not quite correct?
  - That’s OK — but be sure update the design to correspond to the actual implementation
  - At first, the design comments are your roadmap to the implementation
  - Later, the design comments, explain and justify your implementation

Exercise 3.1. Write a Java class DoubleIt with

- A method getDoubled which takes as parameters a single int value, and which returns the int value which is twice the value of the argument.
- A main method which makes at least three different test calls to getDoubled, and which prints for each the test argument, the expected output from the call to getDoubled with that argument, and the result returned by getDoubled.

Follow our discipline of software design, and complete this work in four steps in order:

0. Stubs of all methods.
1. Tests in the main method.
2. A design — but no implementation — for getDoubled.
3. The implementation for getDoubled.

Make sure your code compiles and runs at each step (add an empty stub for the main method at Step 0).

Exercise 3.2. A TwoMult sequence is a sequence of numbers where each number (after the first two) is the product of the two prior numbers. Set up a Java class TwoMult with

- A void method printTwoMult which takes as parameters the first two numbers of a TwoMult sequence, and which when completed will print the next three numbers of the sequence.
- A main method which makes at least five different test calls to printTwoMult, and which displays for each the test arguments, the expected output from a call to printTwoMult with those values, and then calls printTwoMult.

Follow our discipline of software design, and complete this work in four steps in order, as in Exercise 3.1.
Strings

- We’ve printed strings, but in fact they are values just like numbers and booleans
  
  ```java
  final String greeting = "hello";
  final String name = "Jim";
  ```

- The built-in operator on strings is *concatenation*, written with the + sign
  
  ```java
  final String greetingAndName = greeting + name;
  System.out.println(greetingAndName);
  ```

  would print out *helloJim* — no space! We must explicitly include a space if we want one

  ```java
  final String greetingAndSpaceAndName = greeting + " " + name;
  ```

Converting numbers into strings

So we have two meanings for + in Java

- It denotes adding numbers
- It also denotes concatenating strings
- We say that addition is an *overloaded* operator

So what if we write + between a number and a string?

```java
final String name = "Jim";
final int number = 2000;
System.out.println(name + number);
```

In this case, Java assumes that we want to *convert the number into a String*

- We could also write
  
  ```java
  final String name = "Jim";
  final int number = 2000;
  final String combo = name + number;
  System.out.println(combo);
  ```

**Exercise 3.3.** Extend Exercise 3.1 to add another method `printDoubled`. This method should also take as parameters a single `int` value, but `printDoubled` should print a nice message with the argument and its double, and return no result. So for example, when calling `printDoubled(3)`, your method might print

```
3 doubled is 6.
```

Follow our discipline of software design as usual:

1. First add a stub for `printDoubled` to class `DoubleIt`.
2. Add tests for `printDoubled` to the `main` method. Do *not* remove the old tests for `getDoubled` — old tests let us make sure we do not break old code when adding new code!
3. A design — but no implementation — for `printDoubled`
4. The implementation for `printDoubled`

Again, make sure your code compiles and runs at each step.
Exercise 3.4.  Write a class `ClockTime` with a method `getClockTime` which

• Take a single `int` argument representing a number of seconds, and

• Returns a string representing the given length of time as a number of hours, minutes and seconds written with a colon between them in the way we usually write clock times.

For example, the result of calling `getClockTime(5025)` would be `1:23:45`. Follow our discipline of software design as usual (so your class `ClockTime` will contain a `main` method in addition to `getClockTime`).

What happens when you run your program on input `7260`? Is the output what you would write (or expect to read) for a clock time? If not, why not? We will come back later to this program and fix this problem.

4 Lecture 4 — Selection

PITFALL: About exceptions

Some errors occur at compile time

• In these cases, Eclipse will not even let us run the program

Some error cannot be detected at compile time, and show up only when the program is running

• The program stops with an error message

• Later, we’ll look at code that generates or catches exceptions

• For now, you should keep this in mind when your program does not behave as you expect

Exercise 4.1.  Use (alter if you need) one of the programs from the book or an exercise to make Eclipse throw an exception. What does it look like?

REVIEW: From the book

You’ve read about how Java allows us to describe the fifth Thing that a Computer Can Do: selection

if (CONDITION) {
    // SOME STATEMENTS
} else {
    // SOME OTHER STATEMENTS
}

Today we will look at some examples of using if-statements

Exercise 4.2.  Write a class `Grader` with static method `getLetterGrade` which takes an integer argument representing to a percentage grade from 0 to 100, and returns a string representing the corresponding letter grade,

<table>
<thead>
<tr>
<th>Numeric</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>95 ≤ g</td>
<td>A</td>
</tr>
<tr>
<td>92 ≤ g &lt; 95</td>
<td>AB</td>
</tr>
<tr>
<td>86 ≤ g &lt; 92</td>
<td>B</td>
</tr>
<tr>
<td>82 ≤ g &lt; 86</td>
<td>BC</td>
</tr>
<tr>
<td>73 ≤ g &lt; 82</td>
<td>C</td>
</tr>
<tr>
<td>60 ≤ g &lt; 73</td>
<td>D</td>
</tr>
<tr>
<td>g &lt; 60</td>
<td>F</td>
</tr>
</tbody>
</table>

As a first step, write a `main` method with examples and expected grade calculations.
Exercise 4.3. WidgetCo manufactures several different kinds of widgets for re-sale by various vendors. Based on past relationships, sales targets, and other factors, certain vendors are given discount codes which entitle them to a particular discount on their purchases. Write a class WidgetCoDiscounts with a static method getDiscountedPrice which takes two arguments, a string discount code and an integer base purchase price, and returns the price which should be charged given the particular discount code.

<table>
<thead>
<tr>
<th>Code</th>
<th>Discount</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>10%</td>
</tr>
<tr>
<td>R</td>
<td>12%</td>
</tr>
<tr>
<td>T</td>
<td>15%</td>
</tr>
<tr>
<td>M</td>
<td>3%</td>
</tr>
<tr>
<td>E</td>
<td>8%</td>
</tr>
</tbody>
</table>

If the discount code is an empty string or does not match any in the above table, then the method should return the original base purchase price.

As a first step, write a `main` method with examples and expected price calculations, for example

```java
System.out.println("For code S and purchase $100, expect 90, got "+getDiscountedPrice("S", 100));
```

Remember that we compare strings with `.equals`, but compare numbers with `==`.

Exercise 4.4. Write a class MonthNamer with a static method getMonthName which

- Takes a single integer corresponding to a month of the year, 1 representing January through 12 representing December, and
- Returns a string for the name of the month.

Exercise 4.5. Square Deal Credit Union offers a program for first-time home buyers to save on the downpayment required for their loan. The downpayment is calculated according to the following table:

<table>
<thead>
<tr>
<th>Purchase price of home</th>
<th>Downpayment required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under $50,000</td>
<td>4% of price</td>
</tr>
<tr>
<td>$50,000-$124,999</td>
<td>$2,000 plus 8% of price over $50,000</td>
</tr>
<tr>
<td>$125,000-$175,000</td>
<td>$8,000 plus 12% of price over $125,000</td>
</tr>
<tr>
<td>Over $175,000</td>
<td>Not eligible for this program</td>
</tr>
</tbody>
</table>

Write a class SquareDeal with static method getProgramDownpayment which takes one integer argument representing the home purchase price, and returns an integer representing the required downpayment under this program, or -1 if either the home is not eligible or a negative price is entered. As a first step, write a `main` method with examples and expected downpayment calculations.

Exercise 4.6. Write a class ThreeSorter with static method printInOrder which

- Takes three arguments of type `int`,
- Returns nothing, and
- Prints the three numbers in ascending numeric order.

As a first step, write a `main` method with examples and expected output.
Exercise 4.7. The Wisconsin Wants Walnuts company buys black walnuts from individuals, and shells them for sale to restaurants. Sellers’ walnuts are loaded into baskets which hold about one pound of unshelled nuts, and WWW pays $0.15 for each full basket of nuts. If the final, partially-filled basket is more than half-full, WWW pays the full $0.15 for that basket; otherwise they pay $0.05 for the partial basket. Write a class WalnutBuyer with a static method getPurchaseOffer which

• Takes a single double representing the number of baskets of black walnuts brought by a seller (so for example, 3.25 represents three full baskets and an additional basket which is one-quarter full), and

• Returns the amount that WWW will pay for those baskets.

As a first step, write a main method with examples and expected payments.

5 Lecture 5 — Select again

Boolean operators

• Conditions are not allowed just in if statements

• Just as there are types for numbers, there is a type for boolean values

  final boolean flag = x<5;

• There are two boolean constants, true and false

• Just as there are operators for integers, there are operators for boolean values

  || or, disjunction

  && and, conjunction

  ! not

Exercise 5.1. Write a class ParityChecker and static method isOdd which

• Takes one parameter of type int, and

• Returns a result of type boolean which is true exactly when the argument is odd.

Do not use any of the methods in the Math class for your method. As a first step, write a main method with examples and expected results.

Exercise 5.2. Write a class TripleChecker with a static method isTriple which

• Takes a single integer, and

• Returns true when the integer argument is exactly divisible by 3.

Exercise 5.3. Consider three sticks of length two inches, three inches and six inches. We could not form a triangle with these sticks, because one stick is longer than the other two put together. But if instead the sticks had lengths two inches, three inches and four inches, we could make a triangle from those sticks. Write a class TriangleLengthsChecker and static method isTrianglePossible which

• Takes three arguments of type int.

• Returns a result of type boolean which is true exactly when sticks of the three lengths could form a triangle.

If one of the lengths is zero or negative, your method should return false. As a first step, write a main method with examples and expected results.
Exercise 5.4. Write a class `EvenSquares` and two static methods `isEvenAndSquare` and `isEvenOrSquare` where

- Both methods take one parameter of type `int` and have a result of type `boolean`,
- `isEvenAndSquare` returns `true` when the argument is *both* an even number and a perfect square, and
- `isEvenOrSquare` returns `true` when the argument is *either* an even number or a perfect square.

You are free to use any of the methods in the `Math` class for this exercise. As a first step, write a `main` method with examples and expected results for both methods.

Exercise 5.5. Write a class `LeapYearChecker` with a static method `isLeapYear` which determines whether a year is a leap year. The rules and exceptions for determining whether a year is a leap year are:

- Most years are *not* leap years
- Unless the year is divisible by 4, in which case it *is* a leap year
- Unless the year is also divisible by 100, in which case it *is not* a leap year
- Unless the year is also divisible by 400, in which case it *is* a leap year

Your `isLeapYear` method should take a single argument of type `int` representing the year being tested, and should return its answer as a `boolean`, with `true` denoting a leap year.

Exercise 5.6. Write a class `IntervalIncludeChecker` with static method `containsPoint` which

- Takes three `double` values `x1`, `x2`, and `z`
  - The first two parameters `x1` and `x2` correspond to the start- and endpoints of one interval. We can assume that `x1` will be less than or equal to `x2`.  
  - The last parameter `z` is interpreted as a point on the same axis where the interval `[x1, x2]` lies.
- Returns an integer value to describe the position of `z` relative to the interval `[x1, x2]`:
  - The result should be *negative* if `z` is less than `x1`, that is, if the point lies to the left of the interval.
  - The result should be *positive* if `z` is greater than `x2`, that is, if the point lies to the right of the interval.
  - The result should be *zero* if `z` is both greater than or equal to `x1` and less than or equal to `x2`, that is, if the point in the interval.

In both this and the next exercise, assume that the interval is *closed*, that is, that the endpoints are included in the interval. So for example

- `IntervalIncludeChecker.containsPoint(0.0, 2.0, 9.0)` should return some positive number.
- `IntervalIncludeChecker.containsPoint(0.0, 2.0, 1.0)` and `IntervalIncludeChecker.containsPoint(0.0, 2.0, 2.0)` should both return zero.
- `IntervalIncludeChecker.containsPoint(0.0, 1.0, -1.0)` should return some negative number.
Exercise 5.7. Write a class `IntervalOverlapChecker` with static method `intervalsOverlap` which

- Takes four `double` values \( x_1, x_2, y_1, \) and \( y_2 \)

  - The first two parameters \( x_1 \) and \( x_2 \) correspond to the start- and endpoints of one interval. We can assume that \( x_1 \) will be less than or equal to \( x_2 \).
  
  - The latter two parameters \( y_1 \) and \( y_2 \) correspond to the start- and endpoints of a second interval. Again, we can assume that \( y_1 \) will be less than or equal to \( y_2 \).

- Returns `true` when the first and second intervals overlap.

As in the previous exercise, take both intervals to be closed, that is, that the endpoints are included in the intervals. So for example

- `IntervalOverlapChecker.intervalsOverlap(0.0, 2.0, 9.0, 11.0)` and `IntervalOverlapChecker.intervalsOverlap(9.0, 11.0, 0.0, 2.0)` should both return `false`.
  - `IntervalOverlapChecker.intervalsOverlap(0.0, 2.0, 1.0, 3.0)` and `IntervalOverlapChecker.intervalsOverlap(1.0, 3.0, 0.0, 2.0)` should both return `true`.
  - `IntervalOverlapChecker.intervalsOverlap(0.0, 1.0, 1.0, 2.0)` should return `true`.

6 Lecture 6 — Iteration

PITFALL: Keep things simple

Did your leap year method end this way?

```java
} else if (year % 4 == 0) {
    return true;
} else {
    return false;
}
```

This ending is correct — but it is more complicated than it needs to be

- When \( year \% 4 == 0 \) evaluates to `true`, the method returns `true`
  - When \( year \% 4 == 0 \) evaluates to `false`, the method returns `false`
  - Simplify by simply returning `year % 4 == 0` itself!

Because simpler methods are

- Easier to understand
- Easier to debug
- Easier to maintain

REVIEW: From the book

You’ve read about how Java allows us to describe the sixth Thing that a Computer Can Do: *iteration*

```java
for(int VARIABLE=START; CONTINUATION_CONDITION; CHANGE) {
    STATEMENT1;
    STATEMENT2;
```
Today we will look at some examples of using for-loops

How the for-loop works
General loop structure:

```java
for(int VARIABLE=START; CONTINUATION_CONDITION; CHANGE) {
    STATEMENT1;
    STATEMENT2;
    ...
    STATEMENTn;
}
```

• Steps Java takes:
  - `int VARIABLE=START`
  - Check `CONTINUATION_CONDITION`, maybe stop running the loop
  - Run `STATEMENT1` through `STATEMENTn`
  - Apply the `CHANGE`
  - Check `CONTINUATION_CONDITION`, maybe stop running the loop
  - Run `STATEMENT1` through `STATEMENTn`
  - Apply the `CHANGE`
  - Check `CONTINUATION_CONDITION`, maybe stop running the loop
  - Run `STATEMENT1` through `STATEMENTn`
  - Apply the `CHANGE`
  - Check `CONTINUATION_CONDITION`, maybe stop running the loop
  - Run `STATEMENT1` through `STATEMENTn`
  - Apply the `CHANGE`
  - ...and so on until the `CONTINUATION_CONDITION` is falsified

Exercise 6.1. In these exercises, do not use `Math` methods to calculate the square; just use multiplication.

1. Write a class `SimpleLoop` whose `main` method uses a loop to print the squares of the integers from 0 to 10.
2. Write a class `SimpleLoop2` whose `main` method uses a loop to print the squares of the integers from 10 to 30.
3. Write a class `SimpleLoop3` whose `main` method uses a loop to print the squares of the even integers from 10 to 30.
Exercise 6.2. Write a class `SentenceFixer` with a static method `printCapitalized` which

- Accepts a `String` parameter assumed to be a sentence,
- Returns nothing, and
- Prints that sentence making sure the first character is capitalized, and that subsequent characters are lower-case.

The standard methods `toUpperCase` and `toLowerCase` in class `java.lang.Character` will be helpful in converting characters to the correct case. As the usual first step, write a `main` method with examples and expected results. Step through your method by hand for the argument string `HELLO!` to be sure you understand how it works.

Exercise 6.3. The `factorial` function \( n! \) is defined informally as \( n! = n \cdot (n-1) \cdot \ldots \cdot 2 \cdot 1 \), and is defined formally by two rules:

- If \( n = 0 \), then \( n! = 1 \)
- If \( n > 0 \), then \( n! = n \cdot (n-1)! \)

Write a class `FactorialFinder` with a static method `factorial` which

- Accepts a single `int` parameter
- Returns a `long` result representing the factorial of the argument.

Since factorial is not defined on negative numbers, it does not matter what your method does for such input. As the usual first step, write a `main` method with examples and expected results.

Exercise 6.4. The `choose` function from probability is defined as

\[
\binom{n}{m} = \frac{n!}{m!(n-m)!}.
\]

Given the `factorial` method above, it is certainly possible to extend the `FactorialFinder` of Exercise 6.3 class with a method to implement choose directly:

```java
public static long nChooseM(final int n, final int m) {
    return factorial(n)/factorial(m)/factorial(n-m);
}
```

But this implementation is inefficient, and may cause overflow even when the final result actually can be represented as a `long`. Write a more efficient version of `nChooseM` which only performs the multiplications and divisions which are absolutely necessary. As usual, extend the `main` method with examples and expected results as a first step.

Exercise 6.5. The `Fibonacci` numbers are a sequence of integers indexed from 0 up, defined by:

- Fibonacci number 0 is 0.
- Fibonacci number 1 is 1.
- For any \( n > 1 \), Fibonacci number \( n \) is the sum of the two previous Fibonacci numbers (indexed \( n-1 \) and \( n-2 \)).

Write a class `FibonacciFinder` with a static method `fibonacci` which

- Accepts a single `int` parameter \( n \)
- Returns a `long` result representing Fibonacci number \( n \).

Since the series is not defined on negative numbers, it does not matter what your method does for such input. As the usual first step, write a `main` method with examples and expected results.
Lecture 7 — While loops and nested loops

LOOK BACK: Two looping patterns
We’ve seen two different patterns for how we use loops

Processing each element
- Some action for each value
- But we do not link different values together
- So far, this has been printing

Accumulating a new value
- No action for values by themselves
- But combine them (or something about them) together
- Factorial, Fibonacci
- Typified by an accumulator variable
  - Declared before the loop
  - Changed within the loop
  - Used after the loop

FROM THE READING: Another kind of loop
In the book, you read about another, simpler kind of loop

```
while (CONTINUATION_CONDITION) {
    STATEMENT1;
    STATEMENT2;
    // ...
    STATEMENTn;
}
```

- Steps Java takes:
  - Check CONTINUATION_CONDITION, maybe skip running the loop body at all
  - Run STATEMENT1 through STATEMENTn
  - Check CONTINUATION_CONDITION, maybe stop running the loop
  - Run STATEMENT1 through STATEMENTn
  - Check CONTINUATION_CONDITION, maybe stop running the loop
  - Run STATEMENT1 through STATEMENTn
  - … and so on until the CONTINUATION_CONDITION is falsified

- If there are variables to set up, or changes to make, we must implement them as separate statements before the loop or in the loop body
How to choose — _while_ or _for_?

- _for_ loops are great when the loop ranges over _one_ variable, and there is _one_ change to that variable only between passes of the loop
- But otherwise it may be more natural to use a _while_ loop
  - If there are multiple loop variables
  - If there are many changes from pass to pass

**Exercise 7.1.** Write a class `VowelCounter` with static method `getVowelCount` whose one argument is a `String` and which returns the number of characters in the string which are vowels (a, e, i, o and u).

**Exercise 7.2.** The sequence $A_1$ is defined as follows:

$$A_1(n) = \begin{cases} 
  n^2 & \text{if } n \text{ is even} \\
  n + 1 & \text{if } n \text{ is odd}
\end{cases}$$

Write a class `AltSequence` with a static method `getSumTo` which takes an integer $n$, and returns the sum of the elements 0 through $n$ of sequence $A_1$. Use only a single loop, and test inside the loop whether a particular index is even or odd.

**Exercise 7.3.** Write a class `ChangeMaker` with a static method `getChange` which

- Takes a single `int` argument representing a number of cents
- Returns a string describing the way to represent that amount in the fewest number of common US coins. The string should be of the form "XX quarters, YY dimes, ZZ nickels, WW pennies". When (for example), YY is one, the string should use the singular dime instead of dimes.

**Exercise 7.4.** A character in a string is a _self-describing letter_ if its position in the string is the same as the letter’s position in the alphabet. For example, in the string "adc",

- The first and third characters a and c are self-describing letters, since a is the first letter in both the alphabet and in the string, and c is the third letter in both the alphabet and in the string.
- The second character d is not self-describing, since it is the fourth letter of the alphabet but the second character of the string

Write a class `SelfDescribers` with a static method `countSelfDescribing` which

- Takes a single `String` method
- Returns the number of self-describing letters in the string

As the usual first step, write a `main` method with examples and expected results.

**Nested loops**

We can _nest_ one loop inside of another

- The _inner_ loop runs several times each time the _outer_ loop body runs

**Exercise 7.5.** What do these loops do? Try to work out what it prints without running it before checking your prediction with Java.
1. for (int i=1; i<=6; i++) {
    for (int j=1; j<=i; j++) {
        System.out.print(i);
    }
    System.out.println();
}

2. for (int i=1; i<=6; i++) {
    for (int j=1; j<=(6-i); j++) {
        System.out.print("-");
    }
    for (int j=1; j<=i; j++) {
        System.out.print(i);
    }
    System.out.println();
}

What if we swap the two inner loops?

Exercise 7.6. Write a program to print this triangle:

```
0
01
012
0123
01234
012345
01234
0123
012
01
0
```

Find a solution which uses only a single outer and a single inner loop.

Exercise 7.7. Write a class `FramedSquare` with static method `printFramed` which

- Takes two arguments `frameSize` and `innerSize`
- Draws a square made of asterixes and periods, where
  - The asterixes form a frame on the outer edge of the square with thickness `frameSize`, and
  - The inside of the frame is filled in with a `innerSize`-by-`innerSize` square of periods.

So `printFramed(2, 7)` would print

```
**********
**********
*******...
*******...
*******...
*******...
**********
**********
```
Commenting on loops

Document your loop with a high-level comment on the purpose of the loop, but don’t just repeat what the code already says.

• Good

// Print a triangle of numbers, each row
// repeating the digit one greater than the
// row above.
for (int i=1; i<=6; i++) { // 1
    for (int j=1; j<=i; j++) { // 2
        System.out.print(i); // 3
    }
    System.out.println(); // 4
}

• Bad

// Loop i from 1 to 6, each time loop j from
// 1 to i, each time print i, and then in the
// outer loop start a new line.
for (int i=1; i<=6; i++) { // 1
    for (int j=1; j<=i; j++) { // 2
        System.out.print(i); // 3
    }
    System.out.println(); // 4
}

8 Lecture 8 — Array basics

Arrays

• So far we’ve studied
  – All of the Six Things a Program Can Do
  – One of the four ways Java helps us organize our work

• Now we move on to another way Java helps us organize our work

  1. Grouping sequences of operations together
  2. Grouping related data together
  3. Associating a group of data with operations relevant to that data
  4. Naming these groups and associations for easy and repeated use

• So far we’ve worked with scalars — single numbers or characters

• Now we’re going to look at data structures
  – (Many) items of the same type: an array
  – Items of (many) different type: classes and objects
Declaring and using arrays

Must declare an array variable just as we declare a numeric or string variable

- Append [] to a type to make it an array type
  - The size is not part of the type
  - int[]
  - String[]

- To write an array of values, put the values inside curly-braces, and separate them with commas
  - { 10, 20, 30, 40 }

- Refer to one element of an array by a numeric index
  - Write the number in square-brackets after the name of an array variable
    \texttt{int number = numbers[i];}
  - Index from 0
  - Indexing out of bounds will cause an error

- Get the length of an array with .length
  - Note that we do not use parentheses after length
  - It’s a property that we look up, not a method like \sin that calculates something

- Pass arrays to methods, and index array elements as if the array were declared locally
  \texttt{public static void arrayReceiver(double[] readings) { System.out.println(readings.length + \" \" + readings[0]); \}}

Exercise 8.1. Trace through the execution of this class (without running it first). What does it print?

\texttt{public class UseAnArray { public static void main(String[] argv) { int[] numbers = \{ 10, 20, 30, 40 \}; // 1 for(int i=0; i<numbers.length; i++) { // 2 final int number = numbers[i]; // 3 System.out.println(number); // 4 } } }}

Exercise 8.2. What is the largest Java array you can define? Is there a difference between the largest array that the Java compiler will allow you define, and the largest array that a running program on the system you happen to be using right now can allocate to a running program?

Exercise 8.3. What errors do you get when you:

- Try to read from an array slot which is beyond the upper limit of an array?
- Use round parentheses instead of square brackets when you declare an array?
- Use round parentheses instead of square brackets when you access an array element?

Which of these errors are compile-time errors, and which are run-time errors?
Exercise 8.4. Write a class `UseAStringArray` whose main method
• Declares a `String` array containing two values, "Hello" and "Goodbye", and then
• Loops through the array to print each of the values.

Exercise 8.5. Update your class `MonthNamer` from Exercise 4.4 to use an array within `getMonthName`.

Exercise 8.6. Write a class `ColumnMaker` with a static method `printInColumn` which
• Takes an array of integers as its single argument, and
• Prints the numbers right-aligned in a single column.

Use your `getCharacterLength` method from Exercise 2.8.

Exercise 8.7. Write a class `StatsFinder` with a static method `printSummaryStats` which takes an array of double values as its single argument, and calculates and prints messages detailing
• How many numbers there are.
• Their mean: the sum of the values divided by how many values there are.
• Their standard deviation: \( \sigma = \sqrt{\frac{\sum (\bar{x} - x_i)^2}{N-1}} \), where \( \bar{x} \) is the mean and \( N \) is the number of values.

Exercise 8.8. Extend method `printSummaryStats` of Exercise 8.7 to also print the median: the middlemost value contained in the array.

Exercise 8.9. Add another static method `getSummaryStats` to class `StatsFinder` from Exercise 8.7. Your `getSummaryStats` should, instead of just printing the various statistics, return a new `double[]` array where element 0 is the mean, element 1 is the standard deviation, and so on. As the usual first step, create several tests as the `main` method of `StatsFinder`. Be sure to examine the length of the array as well as each element. Rewrite `printSummaryStats` to remove duplicated code, so that it just calls `getSummaryStats` and prints its results in a comprehensible manner.

Exercise 8.10. Modify `StatsFinder` from Exercise 8.7 (or 8.8 or 8.9) to work with integers, and to additionally calculate:
• The maximum and minimum values of the array.
• The number of different values in the array, and how many times each one appears in the array.
• Their mode, the value which appears more often than any other.

Multiple arrays
We often use multiple arrays at the same time
• For operations which extract a result from both
• When elements at the same index are related

Exercise 8.11. The dot product is a common mathematical operation on pairs of numeric vectors (arrays) of the same size. Given two vectors \((x_i)_1^N\) and \((y_i)_1^N\), their dot product \(\vec{x} \cdot \vec{y} = \sum_i x_i y_i\). Write a class `DotProduct` with static method `getDotProduct` which
• Takes two arguments of type double[], and
• Returns the double dot product of the two arrays.

It does not matter what your program does if the arrays are not the same size. As the usual first step, write a main method with examples and expected results.

9 Lecture 9 — Changing arrays

We can update the contents as well
The square-bracket notation can be used on the left side of an assignment
• Updates the particular location of the array, rather than the array variable itself
• Example: names[3] = "Billy";

Exercise 9.1. Trace through the execution of this class (without running it first). What does it print?

```java
public class ChangeAnArray {
    public static void main(String[] argv) {
        int[] numbers = { 10, 20, 30, 40 };

        for(int i=0; i<numbers.length; i=i+1) {
            numbers[i] = numbers[i] * 2;
            System.out.println(numbers[i]);
        }
    }
}
```

Exercise 9.2. What errors do you get when you:
• Try to write to an array slot which is beyond the upper limit of an array?
• Assign a String to an array which you have declared to hold int values?

Which of these errors are compile-time errors, and which are run-time errors?

Allocating arrays without assigning to them
We can allocate space for the array without initializing its entries
• Use the new keyword, plus the array type
  – But to allocate space (as opposed to just giving the type), we must give a size
    – String[] names = new String[10];
• Fill in the elements one-by-one
• Arrays have initial values when we create them
  – For numeric types, zero
  – For boolean, false
  – For String, the special value null
Exercise 9.3. Trace through the execution of this class (without running it first). What does it print?

```java
public class UseAnArray {
    public static void main(String[] argv) {
        final int[] numbers = new int[4]; // 1
        number[0] = 1; // 2
        number[1] = 2; // 3
        number[2] = 3; // 4
        number[3] = 4; // 5
        for(int i=0; i<numbers.length; i=i+1) { // 6
            final int number = numbers[i]; // 7
            System.out.println(number); // 8
        }
    }
}
```

Exercise 9.4. Consider the following class:

```java
public class OddsEvens {
    public static void main(String[] args) {
        char[] characters = new char[50];
        // Your code goes here
        for(int i=0; i<characters.length; i=i+1) {
            System.out.println(i + " " + characters[i]);
        }
    }
}
```

In the indicated spot, add code which will initialize the array slots with an even-valued index (characters[0], characters[2], and so on) with 'E', and the array slots with an odd-valued index (characters[1], characters[3], and so on) with 'O'.

Exercise 9.5. Write a class `ArrayIntFinder` with a static method `getIndexOf` which

- Takes two arguments
  1. An array `numbers` of integers, and
  2. A single integer `target`
- Searches `numbers` for the index where `target` is found
- Returns either that index, or -1 if `target` was not found in `numbers`

When testing your code, be sure to try both cases where `target` is found in `numbers`, and cases where `target` is not found in `numbers`.

Exercise 9.6. Write a class `SortedArrayIntFinder` with a static method `getIndexOf` which whose arguments and result are just as in class `ArrayIntFinder` of Exercise 9.5 but where your method is allowed to assume that the array is sorted in order. Take advantage of the assumption of an ordered list by starting your search in the middle of the list, so that after every comparison your method can exclude half of the unsearched elements based on the target being greater or less than the middle element.

(For a hint, see p. 58)
Changing to a new array

```java
int[] numbers = { 1, 2, 3, 4 };
for(int i=0; i<numbers.length; i=i+1) {
    int number = numbers[i];
    System.out.println(number);
}

numbers = new int[] { 5, 6, 7 };
for(int i=0; i<numbers.length; i=i+1) {
    int number = numbers[i];
    System.out.println(number);
}
```

- The `new int[]` part is implied when we’re declaring the array variable.
- But we can’t change the length with something like

```java
numbers.length = 2;
```

### 10 Lecture 10 — Uses of arrays

#### Mutating scalar parameters

With scalar parameters, changes to the formal parameter do not escape the method

- Each method has its own workspace of storage locations for variables and local parameters
- No method call can change another method call’s storage locations

#### Exercise 10.1.

What do these programs do? Trace through the programs by hand before running them in Eclipse to confirm your hypotheses.

```java
public static void main(String[] args) {
    int y=30;
    f(y);
    System.out.println(y);
}
```

```java
public static void f(int x) {
    System.out.println(x);
    x=10;
    System.out.println(x);
}
```

```java
public static void main(String[] args) {
    int x=30;
    f(x);
    System.out.println(x);
}
```

```java
public static void f(int x) {
    System.out.println(x);
    x=10;
    System.out.println(x);
}
```
Passing arrays to methods

But the internals of arrays are not duplicated when we pass them to a method

- A call to `new` creates space separate from the *local* storage of parameters and variables
  - The *reference* is local, but the space itself is separate
  - Even if we write Line 2 as
    ```java
    int[] y = { 10, 20, 30 };
    ```
    The call to `new` is still implicit

Exercise 10.2. What do these programs do? Trace through each one by hand before running them in Eclipse to confirm your hypotheses.

```java
• public static void main(String[] args) {
    int[] y = new int[] { 10, 20, 30 };
    f(y);
    for(int i=0; i<y.length; i=i+1) {
        System.out.println(y[i]);
    }
}

public static void f(int[] x) {
    if (x.length > 1) {
        x[1] = -1;
    }
    return;
}

• public static void main(String[] args) {
    int[] y = new int[] { 10, 20, 30 };
    f(y);
    System.out.println("==========");
    for(int i=0; i<y.length; i=i+1) {
        System.out.println(y[i]);
    }
}

public static void f(int[] x) {
    x = new int[] { 1, 2, 3, 4, 5 };
    x[1] = -1;
    for(int i=0; i<x.length; i=i+1) {
        System.out.println(x[i]);
    }
    return;
}

• public static void main(String[] args) {
    int[] y = new int[] { 10, 20, 30 };
    f(y);
    System.out.println("==========");
    for(int i=0; i<y.length; i=i+1) {
        System.out.println(y[i]);
    }
}
```
public static void f(int[] x) {
    for(int i=0; i<x.length; i=i+1) {
        x[i] = i*100;
    }
    for(int i=0; i<x.length; i=i+1) {
        System.out.println(x[i]);
    }
    x = new int[] { 1, 2, 3, 4, 5 };
    if (x.length > 1) {
        x[1] = -1;
    }
    System.out.println("=\ldots=\ldots=");
    for(int i=0; i<x.length; i=i+1) {
        System.out.println(x[i]);
    }
    return;
}

Exercise 10.3. Write a class ScaleBy with method scaleByFactor which
  • Takes two arguments:
    1. An array numbers of double
    2. Another double value called factor
  • Multiplies every element of numbers by factor
  • Has no explicit return value
Include a main routine with several tests of scaleByFactor

Exercise 10.4. Write a class CapitalizeAllChars with method upcaseAll which
  • Takes two arguments:
    1. An array characters of char
  • Capitalizes every element of characters (use the library method Character.toUpperCase)
  • Has no explicit return value
Include a main routine with several tests of upcaseAll

Exercise 10.5. Write a class TwoGrouper with method sortIntoGroups which
  • Takes a single argument, an array of characters, which your method should assume contains only ‘R’ and ‘W’, and
  • Reorganizes the array so that all of the ‘R’ s come before all of the ‘W’ s.

Important restriction: your program may "visit" each element of the list only once. So for example, a program which simply goes through the array once to count the ‘R’ s, and which then makes a second pass to assign ‘R’ s and ‘W’ s, would not satisfy this restriction!
(For a hint, see p. [58])
Exercise 10.6. (Continues from Exercise 10.5) Write a class ThreeGrouper with method sortIntoGroups which

- Takes a single argument, an array of characters, which your method should assume contains only ‘R’, ‘W’ and ‘B’, and
- Reorganizes the array so that all of the ‘R’ s come before all of the ‘W’ s, all of the ‘W’ s come before all of the ‘B’ s.

Follow the same restriction as for Exercise 10.5: visit each node only once.

This problem was invented by Edsgar W. Dijkstra, who discovered many important computer science algorithms, and who originated in the Netherlands. The Dutch flag consists of three stripes, one red, one white, and one blue, and Dijkstra named this problem The Dutch National Flag problem.

Exercise 10.7. The Sieve of Eratosthenes is a classical technique for finding prime numbers. The idea of the Sieve is that we can write down the numbers which we are interested in testing for primality, from 2 up to the largest number of interest. We will either circle or scratch out each number in the sequence according to the following loop:

- While there is a number which is neither circled nor scratched out
  - Circle the smallest such number
  - Scratch out every multiple (for integer factors greater than 1) of the number we just circled

After running the loop, the prime numbers are exactly those which are circled. Write a class PrimesFinder with static method getPrimesMap which

- Takes one argument \( n \) of type int, and
- Returns a boolean array with \( n + 1 \) elements, so that slot \([i]\) is true exactly when \( i \) is prime.

Exercise 10.8. Extend class PrimesFinder of Exercise 10.7 with a static method printPrimes which takes a single int argument \( n \), and uses getPrimesMap to print the prime numbers less than or equal to \( n \).

Exercise 10.9. Extend class PrimesFinder of Exercise 10.7 with a static method primesTo which

- Takes a single int argument \( n \), and
- Returns an array of integers containing the prime numbers less than or equal to \( n \).

Methods can return new arrays

- The return type of a method can be an array type

  ```java
  public static int[] buildIntegerArray(...) {
  }
  ```

- The return value can be passed in from outside the array, or created within the array

  ```java
  public static int[] buildIntegerArray(int a, int b) {
  return new int[] { a, b }
  }
  ```

  ```java
  public static int[] pickEvenLength(int[] a, int[] b) {
  if (a.length % 2 == 0) {
  return a
  }
  if (b.length % 2 == 0) {
  ```
Exercise 10.10. Write a class ArraySplitter with a static method getUpperHalf which
   • Takes a single argument, an array of int values
   • Return an array which
     – Is half the length of the argument array
     – Contains the same values as the elements of the argument from the midway point to the highest index.
As usual, begin with a main method containing tests which verify the behavior of getUpperHalf.

Exercise 10.11. Write a class ArrayInterleaver with a static method interleaveArrays which
   • Takes two arguments, each an array of String values
   • Returns a new array
     – Whose length is the sum of the two argument arrays
     – And which contains the elements of the arrays, drawing in alternation from one array and then the other.
     If one argument array is longer than the other, then its additional elements should appear together at the end of the result.
So for arguments containing
   "A", "B", "C"
and
   "V", "W", "X", "Y", "Z"
the result should contain
As usual, begin with a main method containing tests which verify the behavior of interleaveArrays.

Exercise 10.12. Write a class BiggestElements with static method getBiggest which
   • Takes two arguments
     1. An array of integers numbers
     2. An additional integer howMany
   • If howMany is less than the length of numbers, then getBiggest should return a new array of length howMany containing the biggest values numbers.
     If howMany is greater than or equal to the length of numbers, then it should return numbers as-is.
As usual, begin with a main method containing tests which verify the behavior of getBiggest.
Exercise 10.13. Write a class `WordsTaker` with a static method `getWords` which

- Takes two arguments,
  1. A `String`, expected to consist of several space-separated words
  2. An `int`, representing how many of these words are of interest
- Returns an array of strings
  - The length of the array should be the same as the integer argument
  - The first (index 0) element of the result array should be the first space-separated word of the string argument, and so on

Assume for this exercise that there will always be enough words in the string for the integer argument. As the usual first step, create several tests of `getWords` for the main method of `WordsTaker`. Be sure to examine the length of the array as well as each element.

11 Lecture 11 — Sorting an array

What does this method do?

```java
public static void MYSTERY(int[] numbers) {
    int howMany = numbers.length;
    for(int a=1; a<howMany; a=a+1) {
        for(int b=howMany-1; a<=b; b=b-1) {
            if (numbers[b-1] > numbers[b]) {
                final int tmp = numbers[b-1];
                numbers[b-1] = numbers[b];
                numbers[b] = tmp;
            }
        }
    }
}
```

```java
public static void main(String[] args) {
    final int[] numbers = new int[] {10, 7, 3, 12, 18, 2, 8, 5, 20, 15};
    MYSTERY(numbers);
    for(int i=0; i<howMany; i=i+1) { System.out.print(numbers[i] + " "); } System.out.println();
}
```

The main method is straightforward

- We start by creating an array
  ```java
  final int[] numbers = new int[] {10, 7, 3, 12, 18, 2, 8, 5, 20, 15};
  ```
- We end by printing its contents
for(int i=0; i<howMany; i=i+1) {
    System.out.print(numbers[i] + " ");
}
System.out.println();

• MYSTERY seems to change the contents, so the numbers we print may not be the same as the numbers we first put into the array

But what about MYSTERY?

int howMany = numbers.length;       // 0
for(int a=1; a<howMany; a=a+1) {      // 1
    for(int b=howMany-1; a<=b; b=b-1) { // 2
        if (numbers[b-1] > numbers[b]) { // 3
            final int tmp = numbers[b-1]; // 4
            numbers[b-1] = numbers[b];    // 5
            numbers[b] = tmp;             // 6
        }
    }
}

• Look at just the if-statement at Line 3
  – If two consecutive elements (b-1 and b) have a larger value first, it will swap them.

• The inner loop starts at the end of the array, and does this possible swapping from right to left
  – So at the end of the inner loop, the lowest value from position a to the end of the array will be pushed into position a.

• The outer loop performs this pushing first to position 0, then to position 1, and so on up to the next-to-last position in the array.
  – So the smallest value ends up in position 0, the next smallest in position 1, and so on.
  – These loops sort the array.

Stepping through bubble sort

public static void bubbleSort(int[] numbers) {
    int howMany = numbers.length;
    for(int a=1; a<howMany; a=a+1) {      // 1
        for(int b=howMany-1; a<=b; b=b-1) { // 2
            if (numbers[b-1] > numbers[b]) { // 3
                final int tmp = numbers[b-1]; // 4
                numbers[b-1] = numbers[b];    // 5
                numbers[b] = tmp;             // 6
            }
        }
    }
}

• What happens on a call

    int[] fourNums = new int[] { 5, 20, 13, 2 }; bubbleSort(fourNums);
Exercise 11.1. What would happen in the case of applying bubble sort to this algorithm:

```java
int[] manyNums = new int[] {
    1, 2, 3, 4, 5, 6, 7, 8, 9, 10,
    11, 12, 13, 14, 15, 16, 17, 18, 19, 20,
    21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 0
};
bubbleSort(manyNums);
```

What happens the second time we run the body of the outer loop? The third? The thirtieth? How can we improve `bubbleSort` based on this observation?

What does bubble sort cost?

- How many times will we execute the comparison between elements (and possibly swap them) for an array of length \( n \)?
- The first time through the inner loop, it’s \( n - 1 \) times; then \( n - 2 \), and so on down to 1.
- So in total, it’s \( \sum_{i=1}^{n-1} i = \frac{n^2 - n}{2} \).
  - The constant factor \( \frac{1}{2} \) isn’t an interesting detail — for input of size \( n \), the number of steps is on the order of \( n^2 \).
  - Even subtracting \( n \) does not have a big impact, once \( n \) starts to get big.
  - The \( n^2 \) growth is what’s interesting to us — the growth is proportionate to \( n^2 \).
- Bubble sort is fine for smaller arrays, but for larger arrays gets too slow.
  - The best sorting algorithms run in \( O(n \log n) \) time — we’ll look at one of these later this semester if time allows.

Exercise 11.2. Bubble sort is not the only possible sorting algorithm. Selection sort implements the following idea:

- First, go through every element of the list, and find the index of the smallest value. If that value is not at slot 0, swap it with the value at slot 0.
- Next, go through every element of the list except the first, and find the index of the smallest value among them. If that value is not at slot 1, swap it with the value at slot 1.
- And so on, for each slot in the list.

Write a class `SelectionSorter` with a method `sort` which

- Takes a list of integers as its input,
- Performs a selection sort on the list, and
- Returns nothing.

As the usual first step, create several tests of `sort` for the main method of `SelectionSorter`.
Exercise 11.3. For each of the following arrays, how many swaps will selection sort make for each? How many will bubble sort make?

- \( \{1,2,3,4,5,6,7,8,9,10\} \)
- \( \{10,9,8,7,6,5,4,3,2,1\} \)
- \( \{20,40,60,80,100,120,140,160,0\} \)
- \( \{160,0,20,40,60,80,100,120,140\} \)
- \( \{120,140,160,180,200,20,40,60,80,100\} \)
- \( \{200,180,160,140,120,100,80,60,40,20\} \)

12 Lecture 12 — Multidimensional arrays

Two-dimensional arrays

- So far we've used arrays with a single index — called one-dimensional.
- But we can have any number of indices in a matrix:

```java
final String[][] phrases = {
    { "Hello", "Let's eat", "See you later" },
    { "Bonjour", "Bon appetit", "Au revoir" },
    { "Guten Tag", "Mahlzeit", "Tschau" }
};
```

- When we traverse this matrix, we can use the known length of each inner array

Uneven arrays

- Two dimensional arrays do not have to be rectangular
- Each row can span a different number of columns

```java
final String[][] wordsWeKnow = {
    { "hello", "let", "us", "eat",
      "goodbye", "see", "you", "later" },
    { "bonjour", "bon", "appetit", "au", "revoir" },
    { "guten", "tag", "mahlzeit", "tschau" }
};
```

- Some true expressions:

```java
wordsWeKnow.length == 3
wordsWeKnow[0].length == 8
wordsWeKnow[1].length == 5
wordsWeKnow[2].length == 4
```

- Must check the length of each inner array when traversing
Exercise 12.1. Write a class `WordMatrix` with a static method `printWordMatrix` which
- Takes a two-dimension array of strings, that is a `String[][]`, as its single argument,
- Prints the words so that each columns of words are aligned, and
- Otherwise returns no value.

Exercise 12.2. A magic square is an $n$-by-$n$ array of integers where
- The values 1 through $n^2$ each occur exactly once in the array
- The values of each row sum to $n$
- The values of each column sum to $n$
- The values of each diagonal sum to $n$

Write a class `MagicSquareChecker` with a method `isMagicSquare` which
- Takes a single argument, an array of arrays of integers
- Returns true exactly when
  - The array is a square — the top-level array-of-arrays and each contained array all have the same length, and
  - The array forms a magic square

As usual, first write a `main` method with ample tests of `isMagicSquare`.

Exercise 12.3. Consider the square below:

```
R A D A R
A D A R A
D A R A D
A R A D A
R A D A R
```

There are many different paths we could follow starting from a square in this array, where the letters in the path spell `RADAR`. Some examples:

```
R A D A R
A D A R A
D A R A D
A R A D A
R A D A R
```

Write a class `RadarFinder` with method `getRadarCount` which
- Takes an array of arrays of `char`, and
- Returns the number of paths through neighboring squares which spell `RADAR`

Decide for yourself (and document) how you will treat non-square arrays, and diagonal paths. As usual, first write a `main` method with ample tests of `getRadarCount`.

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13 Lab — Recursion

For the lab between Midterm 2 and the next lecture, we will work a few exercises on an interesting side topic.

Exercise 13.1. Write a class `RecursiveFactorial` with a static method `factorial` which implements a recursive version of the factorial function (see Exercise 6.3) which does not use a loop, but instead uses recursion.

Exercise 13.2. Write a class `RecursiveFibonacci` with a static method `fib` which implements a recursive version of Fibonacci number calculation (see Exercise 6.5) which does not use a loop, but instead uses recursion. Make sure your method does not take excessively long on large values.

14 Lecture 13 — Classes and objects

Classes and objects
A class is a description — a sort of thing

• String is one class we’ve seen already

An object is one instance of a class

• "Hello" and "Goodbye" are two different String objects
  – Special syntax for creating a String object

• Ordinarily we create a new object of a class using `new`
  – For example, from the book:
    ```java
    Scanner scn = new Scanner(System.in);
    ```

Fields
With an array, we access the elements by number

• With an object, we access the fields by name

• Declarations look like the local variables of a method
  – But they are not part of any method

```java
public class ThreeThings {
    int myNumber;
    String myName;
    boolean myStatus;
}
```

Creating one object of a class

```java
public class ThreeThings {
    int myNumber;
    String myName;
    boolean myStatus;
}
```
ThreeThings is like String — there can be many different String objects, and there can be many different ThreeThings objects

Here is a way to make a ThreeThings object

```java
ThreeThings myThree = new ThreeThings();
myThree.myNumber = 20;
myThree.myName = "Threepio";
myThree.myStatus = true;
System.out.println(myThree.myName);
```

Classes are not just for fields

- You have already written many static methods
  - Call them in the same way as a mathematical function
  - Pass them arguments
  - Can get a value back from them
- You have also used a different kind of method
  - The length method on strings
  - Called in the context of one particular string value
- We can write our own object methods which read and write the fields of an object

Getters and setters

In Java, the typical style is to use accessor and mutator methods instead of reading or writing fields directly

- So we would prefer ThreeThings like this:

```java
public class ThreeThings {
    private int myNumber;
    private String myName;
    private boolean myStatus;

    public int getMyNumber() { return myNumber; }
    public String getMyName() { return myName; }
    public boolean getMyStatus() { return myStatus; }

    public void setMyNumber(int n) { myNumber=n; }
    public void setMyName(String n) { myName=n; }
    public void setMyStatus(boolean s) { myStatus=s; }
}
```

- private is the opposite of public — it means that the field can only be directly read or written from inside the class
  - Other classes do not have access
- So our old example becomes

```java
ThreeThings myThree = new ThreeThings();
myThree.setMyNumber(20);
myThree.setMyName("Threepio");
myThree.setMyStatus(true);
System.out.println(myThree.getMyName());
```
Constructor

A constructor is a special method called when we create an object

• And at no other time!

Constructors can

• Set up an object’s fields
• Use parameters to make the initial field values

So we could add a constructor to ThreeThings

```java
public class ThreeThings {
    private int myNumber;
    private String myName;
    private boolean myStatus;

    public ThreeThings(int num, String name, boolean stat) {
        myNumber = num;
        myName = name;
        myStatus = stat;
    }

    // ...
}
```

Exercise 14.1. Create a class Student to store the following information about a student:

• Their name
• Their ID
• Their current classes
• The number of credits earned

Include a constructor which receives these values, and accessor methods for each.

• Store their name in two fields firstNames and lastName
• Store their ID as an int
• Store their current classes as an array of strings
• Store the number of credits earned as an int

Exercise 14.2. Create a class Vehicle with the following private field:

• A single String field makeModel for the make/model
• An int field fuelCap for the capacity of the fuel tank
• An double field mpg for the miles-per-gallon efficiency

Define a constructor which receives and assigns the field values in the above order, and accessor methods for each.

Exercise 14.3. Add a method getRange to class Vehicle of Exercise 14.2 which calculates from the the fuelCap and mpg fields the maximum distance which the vehicle could drive on a single tank. As the usual first step, add tests of getRange to a main method.
Exercise 14.4. Write a class QuizScores to hold information about a student’s quiz scores in a class (obviously not this class, since we do not have quizzes). Your class should have the following constructor and methods:

- The constructor should take an array of integers, holding the quiz scores.
- Methods getHighest and getLowest should return the highest and lowest scores received. They take no arguments, and return an int.
- Method getAverage should return a double value, the average score received.

Exercise 14.5. Extend class QuizScores from Exercise 14.4 with two additional methods,

- Method countGreaterThan takes an integer and returns the number of quiz scores which are greater than the argument.
- Method getAverageDroppingLowest should return a double value, the average score excluding the lowest.

As the usual first step, add tests of these methods to a main method.

Exercise 14.6. Pick a board or paper game, and write a class whose objects represent the state of play of that game, and whose method provide information in a form which is convenient for applying the rules of that game. What information should your class store as fields?

Exercise 14.7. Write a class CharChecker whose constructor takes a single string (which we will refer to as base), and with the following methods:

- An accessor getBase for base
- A method countMatches which take a single string str, and which returns the number of characters of str which are also in base.

For example, the statements

CharChecker cc = new CharChecker("abc");
System.out.println(cc.countMatches("abracadabra"));

should print 8.

As the usual first step, add tests of these methods to a main method. Do not use any methods of String except charAt and length to solve this problem.

Exercises 14.8 through 14.11 will remind you of Exercises 8.7 through 8.10. Review your StateFinder implementations before starting these exercises, and expect to deploy some of the same algorithms here.

Exercise 14.8. Write a class DataSet to perform statistical analysis of a set of numbers.

- It should have a constructor which takes a single argument, an array of double values.
- Method mean should take no arguments, and should return the mean of the values from the array.
- Its field for storing data should be private.

As the usual first step, add tests of its method to a main method.
Exercise 14.9. Consider your class `DataSet` from Exercise 14.8. What happens if we run

```java
int[] numbers = new int[] { 5.0, 6.0, 7.0 };
DataSet ds = new DataSet(numbers);
numbers[1] = 12.0;
System.out.println(ds.mean());
```

With the usual setup for fields

```
private double[] numbers;
```

```
public DataSet(double[] numbers) {
    this.numbers = numbers;
}
```

The `mean` would return `8.0`, not `6.0` — the array itself is shared — we have allocated only one of them, and passed around references to it. Update the `DataSet` constructor to make sure that the storage we use for the numbers in a `DataSet` instance is separated from the array passed to the constructor. (See p. 58 for a hint if you need.)

Exercise 14.10. Extend class `DataSet` of the previous exercises to give the data sets a name.

- Add an additional constructor that takes both the `String` name and a `double` array.
- Provide accessor and mutator methods `getName` and `setName`.
- But keep the original constructor as well! For a `DataSet` instance created without a name, the `getName` accessor should return the string "(unnamed)".

Exercise 14.11. Add a method `stdDev` to `DataSet` from Exercise 15.5 which takes no arguments and returns the standard deviation of the data. (See Exercise 8.7 for a formula for standard deviation.) Since we use the mean for calculating the standard deviation, `stdDev` will need to call `mean`.

15 Lecture 14 — Mutation

Objects can change over time

- Fields can be updated, just like local variables
- `Mutator` methods change one field
  - Mutator and accessor method are companion simple methods

Distinguishing immutable and mutable fields

- Fields which never change can receive the keyword `final`
- We can (and should) use `final` with local method variables as well

Exercise 15.1. Extend class `Student` of Exercise 14.1 with the assumption that a student ID will never change.

Exercise 15.2. Extend class `Student` of Exercise 15.1 with methods to update a student record:

- Update the name
- Report passed classes
- Enroll in new classes
Exercise 15.3. Revise class `Vehicle` of Exercise 14.3 with an additional private fields:

- An `int` field `mileage` for the number of miles recorded by the vehicle

Modify the constructor to initialize this field as well, and add both an accessor and a mutator method to set the field. As the usual first step, add tests of using the setter to a `main` method.

Exercise 15.4. Revisit your game board design from Exercise 14.6. Add methods which update the state in response to a player move, and write tests for the effects which are not simple (such as displacing an opponent’s piece).

Exercise 15.5. Extend the class `DataSet` of Exercise 14.8 with two methods:

- `addData`, which takes an array `additionalData` of double values. These values should be added to the values already in the `DataSet`, and should cause `mean` to return an updated, new value based on all of the data.
- `clearData`, which resets the data storage to contain no numbers.

Exercise 15.6. Consider your class `DataSet` from Exercise 14.5 (without the `stdDev` method of Exercise 14.11). We have made `mean` a method, but when the data do not change, the mean will not change either. Update the class and methods so that we recalculate the mean value only when we need to, and just save the value when the data is unchanged. (See p. 21 for a hint if you need.)

Exercise 15.7. There are two ways to add caching of derived values to a version of `DataSet` with more than one derived value. Consider the version of `DataSet` from Exercise 14.11 with both `mean` and `stdDev`: extend this class to add two pairs of fields, one for `mean` and one for `stdDev`, in the manner of Exercise 15.6.

Exercise 15.8. Another way to add caching of derived values is to use a `single` boolean flag to indicate new data, but still multiple `double` fields for the cached values, plus a `private` helper method `updateCached` which recomputes all of the cached values. Extend `DataSet` of Exercise 14.11 to implement this idea, making sure that `mean` and `stdDev` call it only when there is new data.

Exercise 15.9. In `DataSet`, we considered data where the individual points have no particular identity — they were just numbers. Sometimes, individual data points have an identity beyond just their value, and each comes with its own label. For examples, the times of racers may be labeled with the racer’s name, or rainfall totals may be labelled with the location of measurement.

Write a class `TopThree` to keep track of the three highest labelled data values. There should be six simple accessor methods for the stored data:

- Methods `getValue1` and `getLabel1` return the highest data value, and its label
- Methods `getValue2` and `getLabel2` return the second-highest data value, and its label
- Methods `getValue3` and `getLabel3` return the third-highest data value, and its label

There should be one mutator method `reviewDatum` which

- Takes two arguments, a `double` value and a `String` label
- Returns no value
- Might update some of the top three values, if the value is higher than the ones reviewed previously

The constructor for `TopThree` should take the initial top three values and labels

```java
public TopThree(double bestValue, String bestLabel,
                 double secondValue, String secondLabel,
                 double thirdValue, String thirdLabel)
```

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Exercise 15.10. Modify class TopThree of Exercise 15.9 so that the constructor does not assume that the three value/label pairs are already in order, but instead works out for itself which label has the highest value.

Be mindful about mutability
Pay attention to whether fields are mutable

• When understanding others’ software
  – To understand how the class is used
  – To understand what you can do with it

• Which Java classes have you seen...
  – That are completely immutable
  – That can change over time

• Often, immutable classes are easier to understand
  – And less error-prone

Notes on writing classes

• Stay organized! Write your class contents in order:
  – Fields first
  – Then the constructor
  – Then accessors
  – Then mutators
  – Then any other object methods
  – Then static methods
  – Use the navigator windows in Eclipse

• Label fields private
  – Except for global constants like pi, this is a nearly-universal style in Java
  – Label fields and variables final whenever they do not change

• Two kinds of documentation:
  – Use the Javadoc comments
    * Produce the same kind of HTML pages that we’ve looked at for String, Math, etc.
    * Start with /**, end with */
    * Describe the inputs and outputs of each method, and its overall purpose
    * Use the Javadoc tool to generate reference pages
  – Algorithm descriptions
    * Part of the code only, not the Javadoc pages
    * Start with //
    * Describe how the statements of the method achieve the method’s overall goals
16 Lecture 15 — Objects as results

Methods can create and return objects

Just as methods can create and return arrays, methods can create and return objects

```java
public class SmallClass {
    private final String label;

    // ... constructors, accessors ...

    public SmallClass addSublabel(String sublabel) {
        return new SmallClass(label + "." + sublabel);
    }
}
```

Exercise 16.1. Write a class `Complex` to model complex numbers

- The constructor should take two `double` values, for the real and imaginary parts
- Numbers are constants, so the fields should be `final`
- Provide accessors `getReal` and `getImaginary`
- Provide method `magnitude`, returning a `double`
- Provide method `conjugate`, which needs no arguments, and returns another `Complex`
- Provide methods `add`, `subtract`, `multiply` and `divide`, each taking a single `Complex` argument and returning a `Complex` result

The formulas for these operations are on p. 59.

Exercise 16.2. Update your board game idea from Exercises 14.6 and 15.4 so that the board representations are immutable, and the methods in response to a player move return a new object representing a board in the new state.

Exercise 16.3. In Exercise 15.5 we added a method `addData` which changed the underlying data, so that `mean` would normally return a different value. For this exercise we will again extend the `DataSet` Exercise 14.8 to add data, but in a way that does not change the underlying data set:

- Add a method `addData` which takes an array of `double` values, and returns a new `DataSet`. The resulting instance should contain all of the values of the original instance, plus all values from the argument array. The original instance should not be changed in any way.
- Add a method `removeData` which takes an array of `double` values, and which also returns a new `DataSet`. The resulting instance should contain all of the values of the original instance except the values from the argument array. Again, the original instance should not be changed in any way.

As usual, begin by adding tests of the new methods to `main`.

Exercises 16.4 and 16.5 refer to class `Rectangle`:

```java
public class Rectangle {
    private final double width, height, leftX, upperY;

    /**
     * Construct the representation of a rectangle on the plane.
     * @param width The width along the x-axis of this rectangle
     * @param height The width along the y-axis of this rectangle
     */
```
public Rectangle(final double width, final double height,
    final double leftX, final double upperY) {
    this.width = width;
    this.height = height;
    this.leftX = leftX;
    this.upperY = upperY;
}

public double getWidth() { return width; } 
public double getHeight() { return height; } 
public double getLeftX() { return leftX; } 
public double getUpperY() { return upperY; } 

Exercise 16.4. Add a method overlaps to class Rectangle which

• Takes one argument, which is also a Rectangle, and
• Return true when the two rectangles overlap in the plane with an area greater than 0, or false otherwise.

As usual, write a main method for Rectangle which verifies that overlaps is implemented correctly.

Exercise 16.5. Add a static method centeredAt to class Rectangle which

• Takes four double arguments,
  1. A width
  2. A height
  3. An x-coordinate
  4. A y-coordinate, and
• Returns a Rectangle whose center is at the given point.

Extend the main method for Rectangle to verify that centeredAt is implemented correctly.

17 Lecture 16 — Interfaces

Interfaces describe methods, but do not implement them

• Traditional use of methods:
  – Only declare methods, but give no method bodies
    * Exceptions in more recent Java systems, but we do not consider these now
  – No fields
  – No constructors
• Classes can declare themselves to implement an interface (or multiple interfaces) but must provide full implementations of the methods
An interface for doing something

A small interface example:

```java
public interface DoIt {
    public void doSomething(int i, double x);
    public int doSomethingElse(String s);
}
```

And a class which implements that interface:

```java
public class PrintingNumbersMeasuringStrings implements DoIt {
    public void doSomething(int i, double x) {
        System.out.println(i*i+x);
    }
    public int doSomethingElse(String s) {
        return s.length();
    }
}
```

Two ways to do something

```java
public interface DoIt {
    public void doSomething(int i, double x);
    public int doSomethingElse(String s);
}
```

One way

```java
public class PrintMeasure1 implements DoIt {
    public void doSomething(int i, double x) {
        System.out.println(i*i+x);
    }
    public int doSomethingElse(String s) {
        return s.length();
    }
}
```

Another way

```java
public class PrintMeasure2 implements DoIt {
    public void doSomething(int i, double x) {
        System.out.println(2*i*i+x);
    }
    public int doSomethingElse(String s) {
        return s.length()/2;
    }
}
```
Implementing two interfaces

Another simple interface:

```java
public interface DoMoreover {
    public long doAThirdThing(double x);
}
```

A class can declare that it implements both interfaces

```java
public class VeryAble implements DoIt, DoMoreover {
    public void doSomething(int i, double x) {
        System.out.println(i*i+x);
    }
    public int doSomethingElse(String s) {
        return s.length();
    }
    public long doAThirdThing(double x) {
        return Math.round(x*x);
    }
}
```

Why use interfaces?

- More than one class can provide the same interface

```java
public class AlsoAble implements DoIt, DoMoreover {
    public void doSomething(int i, double x) {
        System.out.println("i is "+i);
        System.out.println("x is "+x);
    }
    public int doSomethingElse(String s) { return 3; }
    public long doAThirdThing(double x) {
        return Math.round(x)+2;
    }
}
```

- Method can give an interface as an argument type

  - *Any* class implementing the interface is accepted
  - *Only* interface methods may be used on that argument

```java
public void workWith(DoIt d) {
    d.doSomething(1, 3.4);
    d.doSomething(20, 0.004);
    d.doSomethingElse("Hello");
}
```

Exercise 17.1. There is another common way to represent complex numbers. We can imagine the complex numbers as points on a plane, with the real component for the x-axis, and the imaginary component as the y-axis. But we can also represent points on the plane by two other numbers: their distance from the origin, and the measure of the angle formed by a line from the point to the origin, and the positive part of the x-axis.

So for example, the point (1,1) is at a distance of $\sqrt{2}$ from the origin. It forms a 45°-angle with the positive part of the x-axis, but we use radian measure instead of degrees, so we would measure the angle as $\frac{\pi}{4}$. In terms of complex numbers, we write: $1 + i = \sqrt{2} e^{\pi i/4}$.
Refactor the class Complex of Exercise 16.1 to have the name CartesianComplex, and instead define Complex to be this interface:

```java
public interface Complex {
    public double getReal();
    public double getImaginary();
    public boolean isZero();
    public double getMagnitude();
    public double getAngle();
    public Complex add(Complex that);
    public Complex subtract(Complex that);
    public Complex multiply(Complex that);
    public Complex dividedBy(Complex that);
}
```

Then create a class PolarCartesian which also implements Complex. Be sure you use accessor methods to access the components of a number passed as an argument to the various operations — this way it makes sense to add two numbers which happen to have different representations.

As the usual first step, write tests making sure that both CartesianComplex and PolarComplex are correct.

18 Lecture 17 — Inheritance

18.1 A class for representing people

Revisiting how we represent people

```java
public class Person {
    private final String firstNames;
    private final String lastName;
    public Person(final String firstNames,
                   final String lastName) {
        this.firstNames = firstNames;
        this.lastName = lastName;
    }
    public String getFirstNames() { return firstNames; }
    public String getLastName() { return lastName; }
    public String fullName() {
        return firstNames + " " + lastName;
    }
}
```

What if some of the people we are representing are students?

- We’d also want to store the classes they’re taking
- But this would be true only of students, so not everyone should have this information
- One way of modeling this is through a subclass

```java
public class Student extends Person {
    private final int[] courseIds;
    public Student(final String firstNames,
                   final String lastName,
                   final int[] courseIds) {
```
super(firstNames, lastName);
this.courseIds = courseIds;
}
public int[] getCourseIds() { return courseIds; }
}

**Instantiating classes and subclasses**

```java
final Person person
    = new Person("Jean-Luc", "Godard");
• Has methods `getFirstNames` and `getLastName`
• If we have some method
  ```java
  public void getInLine(Person p) {
    // ...
  }
  ```
  then we can pass `person` to it

final Student student
    = new Student(
          "Jean-Luc", "Godard",
          new int[] { 1250678, 1250678, 1250678 });
• Has methods `getFirstNames`, `getLastName` and `getCourseIds`
• We can also pass `student` to `getInLine`
  – Every Student is also a Person
  – But not every Person is a Student

**The `super` statement**

What is this magic?

```java
public Student(final String firstNames,
               final String lastName,
               final int[] courseIds) {
    super(firstNames, lastName);
    // ...
}
```  

Remember: every Student is also a Person

• The constructor for Person carries the instructions for setting up each instance of Person
• So to set up a Student, we must first set up the Person aspects of it
• The call to `super` here refers to the constructor of the superclass
  – Right number and type of arguments
  – Must be the first step of the subclass constructor
What about the fields?

```java
public class Person {
    private final String firstNames;
    public String getFirstNames() {
        return firstNames;
    }
    // etc.

    • Person and Student each have private fields
    • Could we add something like this method to Student?

        public String statusLine() {
            return firstNames + " "
                + lastName + " in "
                + courseIds.length
                + " classes";
        }

public class Student
    extends Person {
    private final int[] courseIds;
    public int[] getCourseIds() {
        return courseIds;
    }
    // etc.

    • We cannot!
      – When a field is parked private, it is accessible only in the class where it is defined
      – But getLastName() is public, so the methods are accessible even if the field isn’t
      – We can also label protected instead of public or private — accessible in subclasses

So subclasses can add functionality…

public class Student extends Person {
    private final int[] courseIds;
    public Student(final String firstNames,
                    final String lastName,
                    final int[] courseIds) {
        super(firstNames, lastName);
        this.courseIds = courseIds;
    }
    public int[] getCourseIds() { return courseIds; }
}

…and subclasses can also change parent methods

public class Person {
    // ...
    public String getEmailAddr() {
        return firstNames
            .substring(0,1)
• Every person has a gmail address, just assume it’s a boring one made from the name

• But students have a school address

public class Student
extends Person {

    @Override public String
    getEmailAddr() {
        return getLastName()
            .substring(0,4)
            + getFirstNames()
            .substring(0,3)
            + "597@uwlax.edu";
    }
}

• The definition of getEmailAddress in Student overrides the definition in Person

Using these methods

Assume we have a method in a third class

public class Driver {

    public void printFancyEmail(Person p) {
        System.out.print(p.getFirstNames());
        System.out.print(p.getLastName());
        System.out.print(" <");
        System.out.print(p.getEmailAddr());
        System.out.println(" >");
    }
}

• What will this method print for an instance of Person? Of Student?

Subclasses can also change parent methods

• The method

    public void printFancyEmail(Person p) {
        System.out.print(p.getFirstNames());
        System.out.print(p.getLastName());
        System.out.print(" <");
        System.out.print(p.getEmailAddr());
        System.out.println(" >");
    }

• Called with Person instance
final Person bill = new Person("William", "Shatner");
printFancyEmail(bill);

- Prints
    William Shatner <WShatner@gmail.com>

Subclasses can also change parent methods

- The method

    public void printFancyEmail(Person p) {
        System.out.print(p.getFirstNames());
        System.out.print(" ");
        System.out.print(p.getLastName());
        System.out.print(" <");
        System.out.print(p.getEmailAddr());
        System.out.println(" >");
    }

- Called with Student instance

    final Person noamy = new Student("Noam", "Chomsky", new int[] {
        1250678,1261800,1350786
    });
    printFancyEmail(noamy);

    - Prints
        Noam Chomsky <chomnoa597@uw.lax.edu>
        - Because the version of getEmailAddr depends on the type of the object itself, not the type of the variable’s declaration

Relevant methods are set by object creation

final Person bill = new Person("William", "Shatner");
final Person
    noamy = new Student("Noam", "Chomsky", new int[] {
        1250678,1261800,1350786
    });

- It doesn’t matter that the objects are assigned after creation to variable declared to be Person
- What matters is that they are created as a Person and Student
    - These types, at creation time, determine the methods which will run
- The determination stays even if we put the actual instances in a context which "forgets" the specific type
- When we pass noamy to printFancyEmail:
    - Inside printFancyEmail we can’t make assumptions that the argument might be a Student
    - Java can only assume it is a Person
    - But it is the object itself that knows how to run getEmailAddr
- This effect is known as polymorphism
- "Many forms"
- We have already seen polymorphism in action, with interfaces
- In fact two things in Java are called polymorphic; this one is method polymorphism, also called dynamic dispatch
  * We will explore parametric polymorphism in Week 14

Exercise 18.1. Write a class Square which extends class Rectangle of Exercises 16.4-16.5. Square should have a single constructor which takes three double arguments: the first for the length of a side of the triangle, and the other for the x- and y-coordinates of the upper-left corner of the square.

Extend the main method for Rectangle to verify that your constructor for Square is implemented correctly.

18.2 Class Object

Everything is an Object

- Even if you don't declare it, every class we define extends Object
- It is the ultimate Java superclass
- Methods declared on Object are available for every object of every class. These methods include:
  toString() — produce a representation of the object as a String
    * By default, include the class name and the address of the object
    * Overrides of this method should include the @Override annotation
  equals(Object o) — test if this is equal to another object
    * By default, tests whether the two are exactly the same instance
      * So it looks at the pointers and the location in memory, not the contents
    * For most classes, this is not what we want "equals" to mean, so this method is commonly overridden
      * In String, for example, equals is overridden to check the length and then the corresponding characters

Exercise 18.2. The class Card models playing cards

```java
public class Card {
    private final String suit;
    private final int rank;

    public Card(final String suit, final int rank) {
        this.suit=suit;
        this.rank=rank;
    }

    public String getSuit() { return suit; }
    public int getRank() { return rank; }
}
```

Add an equals method to this class which overrides Object.equals, and which returns true when the two Card instances have both the same rank and the same suit. Remember to think about the appropriate comparison techniques for each field, and add tests of the correct operation of equals to your main method.
Exercise 18.3. Add a `toString` method to class `Card` which overrides `Object.toString`, and which

- Returns an output string of the form `RANK of SUIT`. So for example the statements

  ```java
card c = new Card("hearts", 5);
System.out.println(c);
```

  should print `5 of hearts`

- Prints rank 1 as `ace`, rank 11 as `jack`, rank 12 as `queen`, and rank 13 as `king`. So for example the statements

  ```java
card c = new Card("spades", 12);
System.out.println(c);
```

  should print `queen of spades`. Add tests to ensure that `toString` returns correct results to your `main` method.

Exercise 18.4. Add a method `equals` to class `Complex` of Exercise 16.1 which overrides `Object.equals`, and which equates two instances of `Complex` exactly when they have both the same real component, and the same complex component. Add tests to your `main` method to ensure that `equals` returns correct results.

Exercise 18.5. Add a `toString` method to class `Complex` of Exercise 16.1 which overrides `Object.toString`, and which

- Returns the single-character `0` for any instance in which both components are zero
- Returns the string representation of the real component only when the complex component is zero
- Returns the string representation of the imaginary component followed by `i` when the real component is zero
- Returns a string of the form `X+Yi` otherwise

Add tests to your `main` method to ensure that `toString` returns correct results.

Exercise 18.6. Add `toString` methods to classes `CartesianComplex` and `PolarComplex` of Exercise 17.1 which override `Object.toString`, and which both return a string in the same format as described in Exercise 18.5. Add tests to your `main` methods to ensure that `toString` returns correct results.

Exercise 18.7. Add `equals` methods to classes `CartesianComplex` and `PolarComplex` of Exercise 17.1 which override `Object.equals`, and which test for standard equality of complex numbers for any representation implementing interface `Complex`. So for example, the statements

```java
complex cm2i = new CartesianComplex(-2,0),
    pm2i = new PolarComplex(2,Math.pi);
System.out.println(cm2i.equals(pm2i));
```

should print `true`. Add tests to your `main` methods to ensure that `equals` returns correct results.

Exercise 18.8. Write classes which implement a media library:

- Class `Media` includes immutable private fields and public accessors for the title, primary artist, and playing time
- Classes `Video` and `Audio` both extend `Media`
  - Class `Video` includes immutable private fields and public accessors for the director, studio and actors
  - Class `Audio` includes immutable private fields and public accessors for the music company/label
- Classes `DVD`, `FromNetflix`, `CD`, and `Cassette` extend the above classes with further information specific to each format
Exercise 18.2 — card checking

Add an equals method to class Card:

```java
class Card {
    private final String suit;
    private final int rank;

    public Card(final String suit, final int rank) {
        this.suit = suit;
        this.rank = rank;
    }

    public String getSuit() {
        return suit;
    }
    public int getRank() {
        return rank;
    }
}
```

• It’s easy to imagine a method on Card that tests whether two cards are the same

```java
public boolean isEqualTo(final Card that) {
    return this.getSuit().equals(that.getSuit())
    && this.getRank() == that.getRank();
}
```

• But there’s one problem
  – isEqualTo takes a Card as its argument
  – But equals can take any Object — equals(Object o)
  – To test semantic equality of Card objects, we need the getSuit() and getDigits() methods
  – But that field doesn’t exist on Objects, so Java would reject this code:

```java
@Override public boolean equals(final Object that) {
    return this.getSuit() == that.getSuit()
    && this.getRank() == that.getRank();
}
```

19 Lectures on user interfaces

Listening to the outside world

This semester we focused on information moving around within a program
• From method to method
• Into and out of arrays and objects

We have also printed information — but otherwise our classes have mostly not interacted with the outside world
• Early, we looked at a few examples of reading information from the keyboard

We now consider building user interfaces

• Keyboard input is a simple way to get plain text input from the user
• Graphic user interfaces (GUIs) which allow us to both receive and present information in more sophisticated ways
Graphic user interfaces

- Different from a text-based program
  - Design and layout of a graphic window
  - Buttons can usually be pressed in any order
  - Different criteria for exiting

- The central structure of GUI programming is the event loop
  - The main activity is to loop "forever," each time waiting for a new event
    - One button click
    - One keypress
    - One system notification
    - One timer that we’d set going off
    - One background task that we’d started completing
  - Then dispatch the event, and loop again
    - Exiting is something we do explicitly, as a reaction to a particular sort of event
  - More programming if you do it from scratch
    - But Java libraries take care of much of the details

- Even more important to separate different parts of the program
  - In main for text programs, good to separate user interaction from the guts of the program
  - In GUI programs, we’ll see separation of
    - Domain-specific classes — the back end
    - GUI elements (which sometimes need to know about program specific stuff) — the front end
    - Deciding how to react to mouse and keyboard events

Anatomy of a program with a GUI

- The window itself, and the window components that go into it
  - A JFrame
  - A helper for arranging the components within the window
  - An object of some subclass of Layout, often a GridBagLayout, plus helper objects describing different constraints and choices
  - A separate object for each component
  - The different kinds of component have different classes: JLabel, JTextField, JTextArea, JButton, JTable etc., etc.
  - Add scroll bars via JScrollPane, or menus

- Additional objects implement interfaces to react to user actions
  - Today, we will skip these details — we will assemble windows, but they will not yet react to the mouse and keyboard
  - An ActionListener, which receives ActionEvents

- Use fields in the window’s class to hold objects particular to the domain
  - Example: Eclipse is a GUI which works with your files, a compiler, and a JVM
    - So the Eclipse window would know about project options, where the compiler lives on your system, information about the program, etc.

- The main routine is short, may do nothing more than activate the primary window

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20 Closing lecture: The road ahead

Roadmap

20.1 The roadmap in depth

On the roadmap: programming skills, from basic to solid

On the roadmap: software engineering
On the roadmap: hardware and systems

CS120 → CS220 → CS340

CS270 — Assembler and Computer Org. → CS370 — Architecture → CS441 — Operating System Concepts

CS471 — Data Communication

CS470 — Parallel and Distributed Systems

CS431 — Robotics

Embedded Systems Emphasis

CS272 — Microcontrollers I

CS372 — Micro. II

CS472 — Internet of Things

On the roadmap: theory and numerical techniques

CS120 → CS220 → CS340

CS225 — Discrete Computational Structures

CS421 — Programming Language Concepts

CS442 — Compilers

CS453 — Theory of Computation

CS351 — Simulation

CS353 — Algorithms

CS419 — Optimization

CS419 — Machine learning
On the roadmap: large applications

On the roadmap: web technologies

21 Hints on selected exercises

Exercise 2.8 Use the logarithm function for base 10.

Exercise 10.5 Use two different int variables as two different pointers into the list — one from the start, looking for Ws; the other from the end, looking for Rs. Use a while loop instead of a for loop to decide whether there are more swaps to be made.

Exercise 9.6 • Identify lo and hi indices
  • Structure your searching loop to continue as long as lo<hi.
  • When target is less than what you find at the midpoint between lo and hi, update hi to exclude the indices where you now now that target could not possibly be; and similarly for when target is greater than the middle element.

Exercise 14.9 Allocate a new array for the DataSet object, and then copy the numbers into it.

Exercise 15.6 Add a pair of private fields:
  • A boolean field newData which set to true whenever there is new data.
• A double field mean which is sometimes set to the mean value.

The method mean should check whether there is new data: if not, then it can used the stored value; if so, it should first update both of these two fields.

Exercise 16.1

• Magnitude: $|x + iy| = \sqrt{x^2 + y^2}$

• $(x + iy) + (z + iw) = (x + z) + i(y + w)$

• $(x + iy) - (z + iw) = (x - z) + i(y - w)$

• $(a + bi) \cdot (c + di) = ac + adi + bci - bdi = (ac - bd) + i(ad + bc)$

• Conjugate: $\overline{a + ib} = a - ib$

• $\frac{a + bi}{c + di} = \frac{(a + bi)(c + di)}{(c + di)(c + di)}$. Note that the product of a number with its conjugate is a real number.