CS120 — Software Development I

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1 Introduction

A program

```
public class Kilograms {
    public static void main(String[] args) {
        final double pounds = 20.0;
        System.out.print(pounds);
        System.out.print(" pounds is ");
        System.out.print(pounds / 2.2);
        System.out.println(" kilograms.");
    }
}
```

A program

```
public class Kilograms {
    public static void main(String[] args) {
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A program

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        System.out.println(" kilograms.");
    }
}
```
public class Kilograms {
    public static void main(String[] args) {
        final double pounds = 20.0;
        System.out.print(pounds);
        System.out.print(" pounds is ");
        System.out.print(pounds / 2.2);
        System.out.println(" kilograms.");
        return;
    }
}

**Parts of the program**

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.print(pounds / 2.2);
        System.out.println(" kilograms."); // End of this line
        return;
    }
}

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

/**
 * 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.print(pounds / 2.2);
        System.out.println(" kilograms."); // End of this line
        return;
    }
}

**Input as well as output**

import java.util.Scanner; // User input

/**
 * Converter from pounds to kilograms.
 */
public class Kilograms {
    public static void main (String [] args) {
        Scanner scanner = new Scanner(System.in);

        // Read a number of pounds, and convert it to kilograms
        System.out.print("How many pounds? ");
        final double pounds = scanner.nextDouble();
        final double kilograms = pounds / 2.2;

        // Print a message about the conversion
        System.out.print(pounds);
        System.out.print(" pounds is ");
        System.out.print(kilograms);
        System.out.println(" kilograms.");
        return;
    }
}

The other things that happens with a program

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 / 2.0);
        System.out.println(" kilograms.");
        return;
    }
}

Compiler says we have an error

Nothing!

The other things that happens with a program

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 / 0.0);
        System.out.println(" kilograms.");
        return;
    }
}

Runtime system says we have an error

A little bit of I/O and then nothing!
Errors are frustrating

Good news! There are really only six things you need to know here!

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

The less good news is that there’s a whole bunch of detail and skill associated with each of these.

Four ways Java will help you organize your work

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

The six things

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

In and out of the system
Where exactly is our program running?

• Should it matter?
• Abstract away from certain details
• There’s some source for input, and some destination for output
  – Give them a name, and describe operations on them
  – But don’t get hung up on the details of exactly what they are
  – Java calls them: System.in and System.out
  – Some operations on them are written as a suffix:
    System.out.print("Hello...");
    System.out.println("again");
  – For some operations we use a helper:
    Scanner scnr = new Scanner(System.in);
    // ... then later ...
    int quantity = scnr.nextInt();

2.1 Names and assignments

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 Tuesday:
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

It’s an update, not an equation

public static void main (String [] args) {
    Scanner scanner = new Scanner(System.in); // 0
    int total = 0; // 1

    System.out.print("Enter a number: "); // 2
    int num = scanner.nextInt(); // 3
    total = total + num; // 4

    System.out.print("Enter another number: "); // 5
    num = scanner.nextInt(); // 6
    total = total + num; // 7

    System.out.print("Just one more number: "); // 8
    num = scanner.nextInt(); // 9
    total = total + num; // 10

    System.out.println("Their sum is " + total); // 11
    return; // 12
}

• Step through with inputs 4,7 and 2
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

• 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

Clock time

```java
public static void main (String [] args) {
    final Scanner scanner = new Scanner(System.in); // 1
    System.out.print("How many seconds? "); // 2
    int given = scanner.nextInt(); // 3

    final int hours = given / (60 * 60); // 4
    given = given % (60 * 60); // 5
    final int minutes = given / 60; // 6
    final int seconds = given % 60; // 7

    System.out.printf("%d:%02d:%02d\n", // 8
        hours, minutes, seconds);
    return; // 9
}
```

• Try inputs: 3,923, 2,348 and 3,606.
Printing the clock time

What about the last statement of the clock time program?

System.out.printf("%d:%02d:%02d\n", hours, minutes, seconds);

- If you tried the program, you know it just prints the time

- Why is it different than this?

System.out.print(hours);
System.out.print(":");
System.out.print(minutes);
System.out.print(":");
System.out.println(seconds);

  - If we print the number 3, would we see 3 or 03?
    System.out.print(3);

- printf abbreviates print according to format
  - Everything in the first argument prints as normal, except for percent signs
  - The percent signs indicate how we should print things

Printing the clock time

- printf(control_string, value, value, ...);
  - Only the control string is (necessarily) printed

- %d means: take the next argument, print it as an integer (d for decimal)
  - %2d means: take two spaces for it
  - %02d means: fill up extra space with leading zeroes

- Other codes for strings, floating-point, etc.
  - We’ll come back to printf later

2.2 Leap years

Calculating a leap year

- How do we know if a year is a leap year?
  - Easy: if it’s divisible by four

- An algorithm using the Six Things

- In Java:
import java.util.Scanner;

public class LeapYear {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in); // 1
        System.out.print("What year? "); // 2
        final int year = scnr.nextInt(); // 3

        if (year % 4 == 0) { // 4
            System.out.println(year + " was a leap year!"); // 5
        } else { // 6
            System.out.println(year + " was not a leap year.");
        }

        return; // 7
    }
}

• Try 1986 and 1900

Really calculating a leap year

• There are exceptions to the divide-by-four rule
  – Years divisible by 100 are not leap years
  – Unless they are also divisible by 400

• So we need to make multiple decisions

import java.util.Scanner;

public class LeapYear {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in); // 1
        System.out.print("What year? "); // 2
        final int year = scnr.nextInt(); // 3

        if (year % 400 == 0) { // 4
            System.out.println(year + " was a leap year!"); // 5
        } else if (year % 100 == 0) { // 6
            System.out.println(year + " was not a leap year."); // 7
        } else if (year % 4 == 0) { // 8
            System.out.println(year + " was a leap year!"); // 9
        } else { // 10
            System.out.println(year + " was not a leap year.");
        }

        return; // 11
    }
}

10
• Try 1986 and 1900

Calculate, then output

import java.util.Scanner;

public class LeapYear {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in); // 1
        System.out.print("What year? "); // 2
        final int year = scnr.nextInt(); // 3

        final boolean isLeapYear; // 4
        if (year % 400 == 0) { // 5
            isLeapYear = true; // 6
        } else if (year % 100 == 0) { // 7
            isLeapYear = false; // 8
        } else if (year % 4 == 0) { // 9
            isLeapYear = true; // 10
        } else { // 11
            isLeapYear = false;
        }

        if (isLeapYear) { // 12
            System.out.println(year + " was a leap year!"); // 13
        } else { // 14
            System.out.println(year + " was not a leap year.");
        }

        return; // 15
    }
}

One more tweak

import java.util.Scanner;

public class LeapYear {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("What year? ");
        final int year = scnr.nextInt();

        final boolean isLeapYear;
        if (year % 400 == 0) {
            isLeapYear = true;
        } else if (year % 100 == 0) {
            isLeapYear = false;
        } else if (year % 4 == 0) {
            isLeapYear = true;
        } else {
            isLeapYear = false;
        }

        if (isLeapYear) {
            System.out.println(year + " was a leap year!");
        } else {
            System.out.println(year + " was not a leap year.");
        }

        return;
    }
}
isLeapYear = true;
} else if (year % 100 == 0) {
    isLeapYear = false;
} else if (year % 4 == 0) {
    isLeapYear = true;
} else {
    isLeapYear = false;
}

if (isLeapYear) {
    System.out.println(year + " was a leap year!");
} else {
    System.out.println(year + " was not a leap year.");
}

return;
}

A debugging trick

final boolean isLeapYear;
if (year % 400 == 0) {
    System.out.println("*** branch 1 ***"); // FIXME delete
    isLeapYear = true;
} else if (year % 100 == 0) {
    System.out.println("*** branch 2 ***"); // FIXME delete
    isLeapYear = false;
} else if (year % 4 == 0) {
    System.out.println("*** branch 3 ***"); // FIXME delete
    isLeapYear = true;
} else {
    System.out.println("*** branch 4 ***"); // FIXME delete
    isLeapYear = false;
}

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

About exceptions

• Later, we’ll look at code that generates or catches exceptions
• For now, you should just aware of them
  – You will see them as you debug your programs
  – Exercise: use (alter if you need) one of the programs from the book or from a lab exercise to make Eclipse throw an exception.
  – What does it look like?

2.3 The for-loop

A simple loop

```java
public class SimpleLoop {
    public static void main(String[] args) {
        for(int i=0; i<10; i++) { // 1
            final int squared = i*i; // 2
            System.out.println(i + " squared is " + squared); // 3
        }
    }
}
```

How the for-loop works

General loop structure:

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

• Steps Java takes:
  – int VARIABLE=START
  – Check CONTINUE_CONDITION, maybe stop running the loop
  – Run STATEMENT1 through STATEMENTn
  – Apply the CHANGE
  – Check CONTINUE_CONDITION, maybe stop running the loop
  – Run STATEMENT1 through STATEMENTn
  – Apply the CHANGE
  – Check CONTINUE_CONDITION, maybe stop running the loop
2.4 Factorials

What are factorials? A factorial is the product of all the integers from 1 up to some number.

- The factorial of 7 is $7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1$.
- Abbreviated $7!$.

How can we implement the factorial function?

```java
import java.util.Scanner;

public class Factorial {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("Factorial of: ");
        final int num = scnr.nextInt();
        // ...
    }
}
```

How can we implement the factorial function?

```java
import java.util.Scanner;

public class Factorial {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("Factorial of: ");
        final int num = scnr.nextInt();
    }
}
```
A factorial calculator

import java.util.Scanner;

public class Factorial {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in); // 1
        System.out.print("Factorial of: "); // 2
        final int num = scnr.nextInt(); // 3
        long product = 1; // 4

        for(int n=2; n<=num; n++) { // 5
            product = product * n; // 6
        }

        System.out.println("It’s: "+ product); // 7
        return; // 8
    }
}

• Try it with 4

A different factorial calculator

import java.util.Scanner;

public class Factorial {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("Factorial of: ");
        final int num = scnr.nextInt();
        long product = 1;

        for(int factor=num; factor>0; factor--) {
            product = product * factor;
        }
    }
}
System.out.println("It’s: " + product);

return;
}
)

• Try it with 4

The n-choose-m function
Factorial shows up in probability and statistics
For example:
• Let’s say we have a bag of $n$ distinct objects
• How many ways are there to choose $m$?
  • We write this as $\binom{n}{m}$.
  • It’s calculated as $\binom{n}{m} = \frac{n!}{m!(n-m)!}$

How it works
Five things: A B C D E
How can we choose 3?

• A B C
• A B D
• A B E
• A C D
• A C E
• A D E
• B C D
• B C E
• B D E
• C D E

• There are
  – Five ways to pick one thing out of five
  – Four ways to pick a second one from the remaining four
  – Three ways to pick a third one from the remaining three
That’s $5 \times 4 \times 3$

- But we don’t want to consider the order of these three things
  - Just ABC
  - Not ABC, ACB, BAC, BCA, CAB and CBA
  - There are $n!$ ways to order $n$ things

- So a first try would be $\binom{n}{m} = \frac{n(n-1)\ldots(n-m+1)}{m!}$
  - But the whole ellipses thing is informal and unsatisfying
- But note that we can multiply by $(n-m)!$ in both the numerator and denominator
  - That makes the top just $n!$
  - And the whole formula $\binom{n}{m} = \frac{n!}{m!(n-m)!}$

**How would we implement a choose calculator?**

**A simple choose calculator**

```java
final Scanner scnr = new Scanner(System.in); // 0
System.out.print("How many total objects? "); // 1
final int total = scnr.nextInt(); // 2
System.out.print("Choose many? "); // 3
final int choose = scnr.nextInt(); // 4

long totalFact = 1; // 5
for(int n=2; n<=total; n++) { // 6
    totalFact *= n; // 7
} // 8

long chooseFact = 1; // 9
for(int n=2; n<=choose; n++) { // 10
    chooseFact *= n; // 11
} // 12

long diffFact = 1; // 13
for(int n=2; n<=total-choose; n++) { // 14
    diffFact *= n; // 15
} // 16

final long ways = totalFact / chooseFact / diffFact; // 17
System.out.println(ways + " ways to choose"); // 18
return; // 19
```

- Try it with $4, 2$
Do less work!

- Note that when \( n > m \) we have
  \[
  n! = n \times (n - 1) \times \cdots \times (n - m + 1) \times (n - m)!
  \]

- So for \( \binom{n}{m} \), we have
  \[
  \binom{n}{m} = \frac{n!}{m!(n-m)!} = \frac{n \times (n - 1) \times \cdots \times (n - m + 1) \times (n - m)!}{m!(n-m)!} = \frac{n \times (n - 1) \times \cdots \times (n - m + 1)}{m!}
  \]

- Much easier to calculate!

A better choose calculator

```java
final Scanner scnr = new Scanner(System.in); // 0
System.out.print("How many total objects? "); // 1
final int total = scnr.nextInt(); // 2
System.out.print("Choose many? "); // 3
final int choose = scnr.nextInt(); // 4
long ways = 1; // 5
int totalFactor = total; // 6
for(int i=1; i<=choose; i++) { // 7
    ways = ways * totalFactor / i; // 8
    --totalFactor; // 9
}
System.out.println(ways + " ways to choose"); // 10
return; // 11
```

- Try it with 23, 4

2.5 How long is that number?

How to we find the length in digits of an integer?

- Use logarithms
- 1,000 = 10^3, so \( \log_{10} 1,000 = 3 \)
- 10,000 = 10^4, so \( \log_{10} 10,000 = 4 \)
- The number of digits is one more than the \( \log_{10} \)
- What about non-even powers of 10?
  - 1,000 < 3,162 < 10,000, so \( \log_{10} 1,000 < \log_{10} 3,162 < \log_{10} 10,000 \)
  - We need to round the logarithm down, then add 1
The Math class

- Java has many math functions in its standard library, including floor for rounding down, and log10
- Its full name is java.lang.Math
  - Classes in java.lang (unlike java.util) do not need an import
- Calculate the number of digits in an integer:

```java
final Scanner scnr = new Scanner(System.in);
System.out.print("Enter a natural number: ");
final int num = scnr.nextInt();
final long digitCount = 1+Math.round(Math.floor(Math.log10(num)));
System.out.println(num + " has " + digitCount + " digits");
return;
```

- Are we rounding twice?
- Why long?
  - * Use the Javadoc!
- Always address warnings!

2.6 Fibonacci numbers

What are the Fibonacci numbers

- The Fibonacci sequence starts with 1, then 1, then every subsequent number is the sum of the previous two.
  - 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, …

How would we design a Fibonacci calculator?

- OUTPUT a prompt
- INPUT num, to calculate the num-th Fibonacci number
- UPDATE (INITIALIZE)
  - The current Fibonacci number to 1
  - The previous Fibonacci number to 0
- ITERATE
  - Over values of n from 1 up, while n is less than num
  - ARITHMETIC add the current and previous Fibonacci numbers
  - UPDATE the previous and current Fibonacci numbers
- OUTPUT the current Fibonacci number
A Fibonacci calculator in Java

• OUTPUT a prompt
• INPUT num, to calculate the num-th Fibonacci number
• UPDATE (INITIALIZE)
  – Current to 1
  – Previous to 0
• ITERATE n from 1 up
  – While n < num
  – Add current and previous
  – UPDATE
• OUTPUT current

import java.util.Scanner;
public class Fibonacci {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("Which Fibonacci number? ");
        final int num = scnr.nextInt(); // 3
        long thisFib = 1; // Current Fib. num. // 4
        long prevFib = 0; // Previous Fib. num. // 5
        for(int n=1; n<num; n++) { // 6
            final long newFib = thisFib + prevFib; // 7
            prevFib = thisFib; // 8
            thisFib = newFib; // 9
        }
        System.out.println("It's: "+thisFib); // 10
        return; // 11
    }
}

2.7 Fix that sentence

Strings

• We’ve printed strings, but in fact they are values just like numbers and booleans

final String greeting = "hello";
final String name = "Jim";

• The built-in operator on strings is concatenation, written with the + sign

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

final String greetingAndSpaceAndName = greeting + " " + name;
Characters

- Strings are made of characters
- But characters and strings have completely different types!

```java
final char capitalA = 'A';
```

- Strings contains zero or more characters, but a character itself is exactly one character

```java
final String noXes = "";
final String oneX = "x";
final String threeXes = "xxx";
final char theX = 'x';
final char noCharX = ''; // Will cause an error!
final char twoCharsX = 'xx'; // Will cause an error!
```

- Strings to characters: use the `charAt` method

```java
final String alphabet = "abcdefghijklmnopqrstuvwxyz";
final char fifth = alphabet.charAt(4);
```

- Characters to strings: use the `String.valueOf` method

```java
final char letterE = 'e';
final String letterEagain = String.valueOf(letterE);
```

What does this program do?

```java
import java.util.Scanner;

public class FixCaps {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in); // 1
        System.out.print("Tell me your sentence: "); // 2
        final String sentence = scnr.nextLine(); // 3
        final char firstCharacter = sentence.charAt(0); // 4
        System.out.print(Character.toUpperCase(firstCharacter)); // 5
        for(int i=1; i<sentence.length(); i++) { // 6
            final char thisChar = sentence.charAt(i); // 7
            System.out.print(Character.toLowerCase(thisChar)); // 8
        }
        System.out.println(); // 9
        return; // 10
    }
}
```

- Try it with HELLO!
2.8 Another kind of selection

Characters and switch statements

System.out.print("Give me some letters! ");
final Scanner scnr = new Scanner(System.in);
final String letters = scnr.nextLine();
scnr.close();

final int len = letters.length();
int vowels = 0;
for(int i=0; i<len; i++) {
  final char letter = letters.charAt(i);
  switch (letter) {
    case 'a':
      vowels += 1;
      break;
    case 'e':
      vowels += 1;
      break;
    case 'i':
      vowels += 1;
      break;
    case 'o':
      vowels += 1;
      break;
    case 'u':
      vowels += 1;
      break;
  }
}
System.out.println("There were " + vowels + " vowels there.");

Many labels

System.out.print("Give me some letters! ");
final Scanner scnr = new Scanner(System.in);
final String letters = scnr.nextLine();
scnr.close();

final int len = letters.length();
int vowels = 0;
for(int i=0; i<len; i++) {
  final char letter = letters.charAt(i);
  switch (letter) {
    case 'a':
    case 'e':
      break;
    case 'i':
      break;
    case 'o':
      break;
    case 'u':
      break;
  }
case 'i':
  case 'o':
  case 'u':
    vowels += 1;
    break;
}
}
System.out.println("There were " + vowels + " vowels there.");

The default

System.out.println("Give me some letters! ");
final Scanner scnr = new Scanner(System.in);
final String letters = scnr.nextLine();
snr.close();

final int len = letters.length();
int vowels=0, nonvowels=0;
for(int i=0; i<len; i++) {
  final char letter = letters.charAt(i);
  switch (letter) {
  case 'a':
  case 'e':
  case 'i':
  case 'o':
  case 'u':
    vowels += 1;
    break;
  default:
    nonvowels += 1;
  }
}
System.out.println("There were 
  + vowels + " vowels and 
  + nonvowels + " non-vowels there.");

Conditional expressions

System.out.println("There were 
  + vowels 
  + " vowel 
  + (vowels == 1 ? "" : "s") 
  + " and 
  + nonvowels 
  + " non-vowel" 
  + (nonvowels == 1 ? "" : "s")

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2.9 Another kind of loop

Fix that sentence again

```java
final Scanner scnr = new Scanner(System.in); // 1
System.out.print("Tell me your sentence: "); // 2
final String sentence = scnr.nextLine(); // 3
int i=0; // 4
while (i<sentence.length()) { // 5
    final char thisChar = sentence.charAt(i); // 6
    if (i == 0) { // 7
        System.out.print(Character.toUpperCase(thisChar)); // 8
    } else { // 9
        System.out.print(Character.toLowerCase(thisChar)); //
    }
    i++; // 10
}
System.out.println(); // 11
return; // 12
```

2.10 Multiple loops

What does this program do?

```java
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
}
```

Pitfalls with loop variables

- In a test

```java
for (int i=1; i<=6; i++) { // 1
    for (int j=1; i<=i; j++) { // 2
        System.out.print(i); // 3
    }
    System.out.println(); // 4
}
```

- In the post-loop effect
for (int i=1; i<=6; i++) { // 5
    for (int j=1; j<=i; i++) { // 6
        System.out.print(i); // 7
    }
    System.out.println(); // 8
}

Two inner loops

for (int i=1; i<=6; i++) { // 1
    for (int j=1; j<=(6-i); j++) { // 2
        System.out.print("-"); // 3
    }
    for (int j=1; j<=i; j++) { // 4
        System.out.print(i); // 5
    }
    System.out.println(); // 6
}

• What if we swap the two inner loops?

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
    }
Another triangle

For example, for 5:

0
01
012
0123
01234
012345
01234
0123
012
01
0

• How can we generate this triangle?

Another triangle

For example, for 5:

```java
final Scanner scnr = new Scanner(System.in);
System.out.print("Triangle size: ");
final int num = scnr.nextInt();
scnr.close();

for(int i=0; i<=num; i++) {
    for(int j=0; j<=i; j++) {
        System.out.print(j);
    }
    System.out.println();
}

for(int i=num-1; i>=0; i--) {
    for(int j=0; j<=i; j++) {
        System.out.print(j);
    }
    System.out.println();
}
```

• Can we do this with one loop?

BEAMERenv frame

What function will give the number of columns in these rows?

- Function graph

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 5</td>
</tr>
<tr>
<td>*</td>
</tr>
</tbody>
</table>
• Absolute value!
  – 5-l5-il

• In Java, it’s Math.abs

One loop

```java
public class SideTriangle {
    public static void main(String[] arg) {
        for(int i=0; i<=10; i++) {
            for(int j=0; j<=5-Math.abs(5-i); j++) {
                System.out.print(j);
            }
            System.out.println();
        }
    }
}
```

Another pattern

```
***********
***********
*******...
*******...
*******...
*******...
***********
***********
```

• How can we draw this pattern (in one pair of nested loops)?
  – Overall size of square
  – Size of border
Another pattern

```java
final Scanner scnr = new Scanner(System.in);
System.out.print("Overall size: ");
final int length = scnr.nextInt();
System.out.print("Border thickness: ");
final int border = scnr.nextInt();
final int upperBorder = length-border;
scnr.close();

for(int i=0; i<length; i++) {
    for(int j=0; j<length; j++) {
        if (i<border || i>=upperBorder
            || j<border || j>=upperBorder) {
            System.out.print("*");
        } else {
            System.out.print(".");
        }
    }
    System.out.println();
}
```

3 Methods

So what now?

- We’ve seen all of the Six Things a Program Can Do in action
- Now we move on to a way Java helps us organize
  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

3.1 Method basics

**Remember the Fibonacci calculator**

```java
import java.util.Scanner;

public class Fibonacci {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in); // 1
        System.out.print("Which Fibonacci number? "); // 2
        final int idx = scnr.nextInt(); // 3
        long thisFib = 1; // 4
```

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A Fibonacci calculator method
import java.util.Scanner;

public class Fibonacci {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in); // 1
        System.out.print("Which Fibonacci number? "); // 2
        final int idx = scnr.nextInt(); // 3
        final long fib = getFibonacci(idx); // 4
        System.out.println("It’s: "+fib); // 5
        return; // 6
    }

    public static long getFibonacci(int i) { // 7
        long thisFib = 1; // 8
        long prevFib = 0; // 9
        for(int n=1; n<i; n++) { // 10
            final long newFib = thisFib + prevFib; // 11
            prevFib = thisFib; // 12
            thisFib = newFib; // 13
        }
        return thisFib; // 14
    }
}

Elements of a method
- **A name** — getFibonacci
- **Parameters** — int i
  - Any number, zero or more
  - Where we define the method, we have *formal parameters*
public static long getFibonacci(int i) {
    // Where we use the method, we have actual parameters
    final long fib = getFibonacci(idx);
    // Argument is a synonym for parameter
    // A return type — long
    // A return value — return thisFib;
    // The return type can be void, in which case there’s no return value

    Why do we create a method
    // Break up the program into manageable units
    // Reuse code from program to program
    // For example, the various Math methods
    // Separate different aspects of the program
    // For example, separate user interaction from calculations

    Names are local
    // The way a name is used is local to methods
    // If we assign something else to a name, the effect does not travel outside of the method

    public static void main(String[] args) {
        int y = 40;
        f(y);
        System.out.println(y);
    }

    public static void f(int x) {
        x = 5; // Applies only to f’s variable x
        return;
    }

    3.2 A method for leap years

    Reaching way back — calculating a leap year

    import java.util.Scanner;

    public class LeapYear {
        public static void main(String[] args) {
            final Scanner scnr = new Scanner(System.in);
            System.out.print("What year? ");
        }
    }
final int year = scnr.nextInt();

if (year % 400 == 0) {
    System.out.println(year + " was a leap year!");
} else if (year % 100 == 0) {
    System.out.println(year + " was not a leap year.");
} else if (year % 4 == 0) {
    System.out.println(year + " was a leap year!");
} else {
    System.out.println(year + " was not a leap year.");
}

return;

• Note that we need the else statements to keep from printing multiple messages

A leap year method

public static boolean isLeapYear(int year) {
    if (year % 400 == 0) { return true; }
    if (year % 100 == 0) { return false; }
    if (year % 4 == 0) { return true; }
    return false;
}

public static void main(String[] args) {
    final Scanner scnr = new Scanner(System.in);
    System.out.print("What year? ");
    final int year = scnr.nextInt();

    final boolean isLeap = isLeapYear(year);
    if (isLeap) {
        System.out.println(year + " was a leap year!");
    } else {
        System.out.println(year + " was not a leap year.");
    }

    return;
}

• Since return alters the flow of control, we don’t need the else’s here

3.3 A choose method

The choose calculator

How would we write a method for the n-choose-m function?
public class Choose {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("How many total objects? ");
        final int total = scnr.nextInt();
        System.out.print("Choose how many? ");
        final int choose = scnr.nextInt();

        long ways = 1;
        int totalFactor = total;
        for(int i=1; i<=choose; i++) {
            ways = ways * totalFactor / i;
            --totalFactor;
        }

        System.out.println(ways + " ways to choose");
        return;
    }
}

A choose method

public class Choose {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("How many total objects? ");
        final int total = scnr.nextInt();
        System.out.print("Choose how many? ");
        final int choose = scnr.nextInt();
        System.out.println(nChooseM(total,choose) + " ways to choose");
        return;
    }
}

public static long nChooseM(int total, int choose) {
    long ways = 1;
    int totalFactor = total;
    for(int i=1; i<=choose; i++) {
        ways = ways * totalFactor / i;
        --totalFactor;
    }

    return ways;
}

Length methods

How would we write a method characterLength for the length of an integer in digits?

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public static int characterLength(long num) {
    return 1+Math.floor(Math.log10(num));
}

public static int characterLength(String str) {
    return str.length();
}

3.4 Factorial and Fibonacci methods

Reaching back again

import java.util.Scanner;

public class Factorial {
    public static void main(String[] args) {
        final Scanner scnr = new Scanner(System.in);
        System.out.print("Factorial of: ");
        final int num = scnr.nextInt();
        long product = 1;

        for(int n=2; n<=num; n++) {
            product *= n;
        }

        System.out.println("It’s: " + product);

        return;
    }
}

We make everything into a method now

public static long factorial(int num) {
    long product = 1;

    for(int n=2; n<=num; n++) {
        product *= n;
    }

    return product;
}

The recursive way

public static long factorial(int num) {
    if (num <= 1) {
        return 1;
    }

    return num * factorial(num-1);
}
A first idea for recursive Fibonacci

```java
public static long fib(int num) {
    if (num <= 0) {
        return 0;
    } else if (num == 1) {
        return 1;
    } else {
        return fib(num-1) + fib(num-2);
    }
}
```

Running the first idea

In the recursive implementation for computing the $n$th Fibonacci number with $n = 4$, how many recursive calls are made?

Calls we’d make

fib(5) calls first fib(3), then fib(4)

- fib(3) calls first fib(1), then fib(2)
  - fib(1) is a base case
  - fib(2) calls first fib(0), then fib(1)
    - fib(0) is a base case
    - fib(1) is a base case

- fib(4) calls first fib(2), then fib(3)
  - fib(2) calls first fib(0), then fib(1)
    - fib(0) is a base case
    - fib(1) is a base case
  - fib(3) calls first fib(1), then fib(2)
    - fib(1) is a base case
    - fib(2) calls first fib(0), then fib(1)
    - fib(0) is a base case
    - fib(1) is a base case

That’s 15 calls

- Lots of repeated work!
- Is recursion a bad approach for Fibonacci?
  - Or is this way of structuring recursion bad?
Fibonacci with a loop

public static long fib(final int num) {
    long fib=0;
    long next=1;

    for(int n=0; n<num; n++) {
        final long
        newNext=fib+next;
        fib = next;
        next = newNext;
    }

    return thisFib;
}

• The loop runs (about) num times, so we should be able to find a way that recurs num times
• Note how we use next and fib
  – Both calculated on each pass through the loop
  – Both preserved from one pass through the loop to the next
• How can we provide both from one recursive call to the next?
  – By passing both as parameters!

Recursion with accumulating parameters

• Instead of calculating the result in a method body after the return of a recursive call,
• Calculate the result in the arguments of the call

static long fibHelper(int n, long fib, long next) {
    if (n<1) {
        return fib;
    } else {
        return fibHelper(n-1, next, fib+next);
    }
}

public static long fib(int n) {
    return fibHelper(n, 0, 1);
}
3.5 Factorial and Fibonacci methods

Recursion with accumulating parameters

- Instead of calculating the result in a method body after the return of a recursive call,
- Calculate the result in the arguments of the call

```
static long fibHelper(int n, long fib, long next) {
    if (n<1) {
        return fib;
    } else {
        return fibHelper(n-1, next, fib+next);
    }
}
```

```
public static long fib(int n) {
    return fibHelper(n, 0, 1);
}
```

3.6 Methods and your work

Projects going forward

- Will specify methods you should write
- Be sure that you match the method name, and the number and types of arguments
- Use the main method to show how you’ve been testing the other methods as you develop
  - Not necessarily just the required methods
  - If you decompose the problem further, test those methods too
  - I’ll look at the quality of your tests when assessing

Documenting methods

- The code in these slides do not often have comments
  - There’s usually no room for them
  - And our discussion of the code serves the same purpose
- But it’s important to document code
  - And it counts for part of your grade
- Let’s document bubbleSort as an example

```
public static void bubbleSort(int[] array) {
    final int len = array.length;
    for(int a=1; a<len; a++) {
        for(int b=len-1; a<=b; --b) {
```
if (array[b-1] > array[b]) {
    final int tmp = array[b-1];
    array[b-1] = array[b];
    array[b] = tmp;
}
}

Inline comments for the details of the algorithm

- The beginning of a loop is almost always interesting enough to warrant a comment

  // "a" moves from the left of the array forward; we push the a\textsuperscript{th} smallest element of the array to the (a-1)\textsuperscript{st} place
  for(int a=1; a<howMany; a++) {
      - We're explaining why we're looping and what \textit{a} represents
        * Not necessary to point out that \textit{a} loops from 1 to an upper bound; we explain instead that we're moving across the array
      - We're also explaining the purpose of this loop

- Similarly for the inner loop

  // To push an element leftwards, we start from the right side, // and move leftward doing comparisons. \textit{b} is the position we // will compare next.
  for(int b=howMany-1; a<=b; --b) {

Inline comments for the details of the algorithm

- Decisions like \texttt{if} statements and \texttt{switch} blocks are also usually interesting enough to document

- Again, explain the significance of the decision; don't just rephrase Java into tedious English

  // Check if two elements are out of order, and if so, swap // them.
  if (array[b-1] > array[b]) {
      - Here, it makes sense to explain the body of the \texttt{if} as well
      - Sometimes, the body of the \texttt{if} will be complicated enough to warrant several inline comments along the way
Javadoc comments for the method itself

/**
 * Sorts an array of integers.
 * @param array The array to be sorted.
 *
 * This routine works only on integer arrays, not String arrays.
 */
public static void bubbleSort(int[] array) {

    • A Javadoc comment always starts /**, and the standard style is to have the vertical line of single
      asterixes
    • The first lines should be a short *verb clause* summarizes very briefly what the method does
    • Then document the parameters with @param and the return value (if there’s one) with @returns
    • Next give a fuller description of the operation, limits, efficiency, etc. of the method
    • Eclipse will generate the Javadoc of your code
    • For examples, see the standard Java API

Testing methods

• Structuring code with methods can make testing your programs easier

• To now:
  – Every different test of a program required manually running it, changing the parameters each
    time
  – Hard to remember the whole suite of different values, hard to keep track of the "right" answer
    for each case

• But now:
  – The interesting code can be in named methods
  – We can use the main method to test the other methods

4 Arrays

4.1 Array basics

So what now?

• We’ve seen all of the Six Things a Program Can Do in action

• Now we move on to the four ways Java helps us organize our work

  1. Grouping sequences of operations together
  2. Grouping *related data* together

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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 seen mostly *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 arrays

```java
public class UseAnArray {
    public static void main(String[] argv) {
        int[] numbers = { 1, 2, 3, 4 };  // 1

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

- Index from 0
- 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

### We can update the contents as well

```java
public class ChangeAnArray {
    public static void main(String[] argv) {
        int[] numbers = { 1, 2, 3, 4 };

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

### A notation for reading through the contents

```java
public class UseArrayElements {
    public static void main(String[] argv) {
        int[] numbers = { 1, 2, 3, 4 };
        for(final int number : numbers) {
            System.out.println(number);
        }
    }
}
```
• But this only works for reading the array elements.
• We couldn’t change them this way.

Changing to a new array

```java
int[] numbers = { 1, 2, 3, 4 };  
for(final int number : numbers) {
    System.out.println(number);
}

numbers = new int[] { 5, 6, 7 };  
for(final int number : numbers) {
    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;
```

Arrays of any type

```java
public class UseStringArray {
    public static void main(String[] argv) {
        String[] names = { "Hello", "Goodbye" };  
        for(final String name : names) {
            System.out.println(name);
        }
    }
}
```

What does final mean?

Declaring an array variable final rules out our example of resetting the array variable:

```java
public class BadUseOfArrays {
    public static void main(String[] argv) {
        final int[] numbers = { 1, 2, 3, 4 };  
        for(final int number : numbers) {
            System.out.println(number);
        }

        // This line gives an error
        numbers = new int[] { 5, 6, 7 };
    }
}
```
But we can still change the contents

public class ChangeFinalArray {
    public static void main(String[] argv) {
        final int[] numbers = { 1, 2, 3, 4 }; // 1

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

• final applies only to the binding to the name itself, not to operations we might perform via the name.

4.2 Combining two arrays: the dot product

Combining two arrays: the dot product

• It’s a math thing, an operation on vectors

• $\vec{u} \cdot \vec{v} = \sum_i u_i v_i$
  – For two vectors of equal length, multiply corresponding elements, and return the sum

• Example: [1,2,3] · [10,1000,100000]

How can we implement the dot product?

public class DotProduct {
    public static void main(String[] args) {
        final int[] array1 = { 2, 4, 6 }; // 1
        final int[] array2 = { 100, 1000, 10000 }; // 2
Dot product

public class DotProduct {
    public static void main(String[] args) {
        final int[] array1 = { 2, 4, 6 }; // 1
        final int[] array2 = { 100, 1000, 10000 }; // 2

        int total = 0; // 3
        for(int i=0; i<array1.length; ++i) { // 4
            total += array1[i] * array2[i]; // 5
        }

        System.out.println("Dot product is: " + total); // 6
        return; // 7
    }
}

• Tracing execution

4.3 Sorting an array

What does this program do?

final Scanner scnr = new Scanner(System.in); // 1
System.out.print("How many numbers? "); // 2
final int howMany = scnr.nextInt(); // 3

final int[] numbers = new int[howMany]; // 4
for(int i=0; i<howMany; i++) { // 5
    System.out.print("Number " + 1+i + ": "); // 6
    numbers[i] = scnr.nextInt(); // 7
}

for(int a=1; a<howMany; a++) { // 8
    for(int b=howMany-1; a<=b; --b) { // 9
        if (numbers[b-1] > numbers[b]) { // 10
            final int tmp = numbers[b-1]; // 11
            numbers[b-1] = numbers[b]; // 12
            numbers[b] = tmp; // 13
        }
    }
}

for(int i=0; i<howMany; i++) { System.out.print(numbers[i] + " "); } // 14

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The first part is more straightforward

```java
final Scanner scnr = new Scanner(System.in); // 1
System.out.print("How many numbers? "); // 2
final int howMany = scnr.nextInt(); // 3

final int[] numbers = new int[howMany]; // 4
for(int i=0; i<howMany; i++) { // 5
    System.out.print("Number " + 1+i + ": "); // 6
    numbers[i] = scnr.nextInt(); // 7
}
```

And the last part just prints the array:

```java
for(int i=0; i<howMany; i++) { System.out.print(numbers[i] + " "); } // 14
System.out.println(); // 15
```

But what about these loops?

```
for(int a=1; a<howMany; a++) { // 8
    for(int b=howMany-1; a<=b; --b) { // 9
        if (numbers[b-1] > numbers[b]) { // 10
            final int tmp = numbers[b-1]; // 11
            numbers[b-1] = numbers[b]; // 12
            numbers[b] = tmp; // 13
        }
    }
}
```

- Look at just the if-statement at Line 10
  - 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

```java
final Scanner scnr = new Scanner(System.in); // 1
System.out.print("How many numbers? "); // 2
final int howMany = scnr.nextInt(); // 3

final int[] numbers = new int[howMany]; // 4
for(int i=0; i<howMany; i++) { // 5
    System.out.print("Number " + 1+i + ": "); // 6
    numbers[i] = scnr.nextInt(); // 7
}

for(int a=1; a<howMany; a++) { // 8
    for(int b=howMany-1; a<=b; --b) { // 9
        if (numbers[b-1] > numbers[b]) { // 10
            final int tmp = numbers[b-1]; // 11
            numbers[b-1] = numbers[b]; // 12
            numbers[b] = tmp; // 13
        }
    }
}

for(int i=0; i<howMany; i++) { System.out.print(numbers[i] + " "); } // 14
System.out.println(); // 15
return;
```

- 4 numbers: 5, 20, 13, 2

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.
  - We write this as $O(n^2)$ — on the order of $n^2$.
- 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.
4.4 The Sieve of Eratosthenes

How do we work out if numbers are prime?

- Write out the numbers we’re interested in testing for primality

```
  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
 31 32 33 34 35 36 37 38 39 40
 41 42 43 44 45 46 47 48 49 50
 51 52 53 54 55 56 57 58 59 60
 61 62 63 64 65 66 67 68 69 70
 71 72 73 74 75 76 77 78 79 80
 81 82 83 84 85 86 87 88 89 90
 91 92 93 94 95 96 97 98 99 100
```

How do we work out if numbers are prime?

- Write out the numbers we’re interested in testing for primality
- 1 is not a prime, so scratch it out

```
+  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
 31 32 33 34 35 36 37 38 39 40
 41 42 43 44 45 46 47 48 49 50
 51 52 53 54 55 56 57 58 59 60
 61 62 63 64 65 66 67 68 69 70
 71 72 73 74 75 76 77 78 79 80
 81 82 83 84 85 86 87 88 89 90
 91 92 93 94 95 96 97 98 99 100
```

How do we work out if numbers are prime?

- Write out the numbers we’re interested in testing for primality
- 1 is not a prime, so scratch it out
- Look at the lowest unmarked number — mark it as prime

```
+  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
 31 32 33 34 35 36 37 38 39 40
 41 42 43 44 45 46 47 48 49 50
 51 52 53 54 55 56 57 58 59 60
 61 62 63 64 65 66 67 68 69 70
 71 72 73 74 75 76 77 78 79 80
 81 82 83 84 85 86 87 88 89 90
 91 92 93 94 95 96 97 98 99 100
```
How do we work out if numbers are prime?

- Write out the numbers we’re interested in testing for primality
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- 1 is not a prime, so scratch it out
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- But strike out its multiples — they’re definitely not prime
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• But strike out its multiples — they’re definitely not prime
• And so on with the new lowest unmarked number, and so on, and so on, and so on
• So let’s code that up

The Sieve

```java
System.out.print("Find the primes up through what number? ");
final Scanner scnr = new Scanner(System.in);
final int upThrough = scnr.nextInt();
scnr.close();

final boolean[] isPrime = new boolean[1+upThrough];

isPrime[0] = false;
isPrime[1] = false;
for(int i=2; i<=upThrough; ++i) {
    isPrime[i] = true;
}
```

The Sieve
System.out.print("Find the primes up through what number? ");
final Scanner scnr = new Scanner(System.in);
final int upThrough = scnr.nextInt();
scnr.close();

final boolean[] isPrime = new boolean[1+upThrough];

isPrime[0] = false;
isPrime[1] = false;
for(int i=2; i<=upThrough; ++i) {
    isPrime[i] = true;
}

for(int low=0; low<=upThrough; ++low) {
    if (isPrime[low]) {
        System.out.println(low + " is prime.");
    }
}

The Sieve

System.out.print("Find the primes up through what number? ");
final Scanner scnr = new Scanner(System.in);
final int upThrough = scnr.nextInt();
scnr.close();

final boolean[] isPrime = new boolean[1+upThrough];

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for(int i=2; i<=upThrough; ++i) {
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}

for(int low=0; low<=upThrough; ++low) {
    if (isPrime[low]) {
        System.out.println(low + " is prime.");
    }
}

The Sieve
for(int low=0; low<=upThrough; ++low) {
    if (isPrime[low]) {
        System.out.println(low + " is prime.");
        for(int nonPrime=low+low; nonPrime<=upThrough; nonPrime += low) {
            isPrime[nonPrime] = false;
        }
    }
}

4.5 Two-dimensional 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
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

4.6 Lining up columns of information

Remember the wordsWeKnow matrix

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

- We discussed, but did not implement, having the columns line up
- A starting point, for this implementation

```java
for(int i=0; i<wordsWeKnow.length; i++) {
    for(int j=0; j<wordsWeKnow[i].length; j++) {
        System.out.print(wordsWeKnow[i][j] + " ");
    }
    System.out.println();
}
```

What do we need to think about?

What’s involved with lining up the columns?

- Every column the same width, or each column padded separately?
  - We’ll do both, first every column the same
• Need to look at the width of *every* word before we know the width of any column

• Since some rows have more columns than others, we need to look at all of the rows to know how many columns there are

• Must add the right amount of spaces to pad each string

**Every column the same width**

```java
// Find the width

// For each row and column

// Add padding for this string

// Print this string

int width=0;
for(final String[] row : wordsWeKnow) {
    for(final String word : row) {
        final int thisWidth = word.length();
        if (thisWidth > width) {
            width = thisWidth;
        }
    }
}
```

**Every column the same width**

```java
// For each row and column

// Add padding for this string
```
// Print this string

)

Every column the same width

int width=0;
for(final String[] row : wordsWeKnow) {
  for(final String word : row) {
    final int thisWidth = word.length();
    if (thisWidth>width) {
      width=thisWidth;
    }
  }
}

for(final String[] row : wordsWeKnow) {
  for(final String word : row) {
    // Add padding for this string

    // Print this string

)}

Every column the same width

int width=0;
for(final String[] row : wordsWeKnow) {
  for(final String word : row) {
    final int thisWidth = word.length();
    if (thisWidth>width) {
      width=thisWidth;
    }
  }
}

for(final String[] row : wordsWeKnow) {
  for(final String word : row) {
    final int pad = width - word.length();
    for(int i=0; i<pad; i++) {
      System.out.print(" ");
    }
  }
}

53
int width=0;
for(final String[] row : wordsWeKnow) {
    for(final String word : row) {
        final int thisWidth = word.length();
        if (thisWidth>width) {
            width=thisWidth;
        }
    }
}
for(final String[] row : wordsWeKnow) {
    for(final String word : row) {
        final int pad = width - word.length();
        for(int i=0; i<pad; i++) {
            System.out.print(" ");
        }
        System.out.print(word);
        System.out.print(" ");
    }
    System.out.println();
}

Every column the minimum width

• What’s our algorithm here?
// Check this column’s width, and maybe
// update the maximum

} // For each row and column entry {

// Print the padding for this column

// Print this entry

} // For each row and column entry {
System.out.println();
}

Every column the minimum width

int cols = 0;
// For each row {

    // Check the width of this row, and maybe update
    // the columns count

} // For each row {

// Allocate space for the widths array
// For each row and column entry {

    // Check this column’s width, and maybe
    // update the maximum

} // For each row and column entry {

// For each row and column entry {
// Print the padding for this column

// Print this entry

} System.out.println();

}

Every column the minimum width

int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;

    // Check the width of this row, and maybe update // the columns count
    }

    // Allocate space for the widths array
    // For each row and column entry {

        // Check this column’s width, and maybe // update the maximum
        }

    // For each row and column entry {

        // Print the padding for this column

        // Print this entry

    ) System.out.println();

} Every column the minimum width

int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;
    if (thisWidth > cols) {
        cols = thisWidth;
    }
}

// Allocate space for the widths array
// For each row and column entry {

    // Check this column’s width, and maybe
    // update the maximum

} // For each row and column entry {

    // Print the padding for this column

    // Print this entry

} System.out.println();
}

Every column the minimum width

int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;
    if (thisWidth > cols) {
        cols = thisWidth;
    }
}

int[] widths = new int[cols];
// For each row and column entry {
Every column the minimum width

```java
int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;
    if (thisWidth > cols) {
        cols = thisWidth;
    }
}

int[] widths = new int[cols];
for (int row=0; row<wordsWeKnow.length; row++) {
    final String[] rowArray = wordsWeKnow[row];
    for (int col=0; col<rowArray.length; col++) {
        final int thisWidth = rowArray[col].length();
        // Check this column’s width, and maybe
        // update the maximum
    }
}
```

// For each row and column entry {

    // Print the padding for this column

    // Print this entry

    }
// Print this entry

) System.out.println();
)

Every column the minimum width

int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;
    if (thisWidth > cols) {
        cols = thisWidth;
    }
}

int[] widths = new int[cols];
for (int row=0; row<wordsWeKnow.length; row++) {
    final String[] rowArray = wordsWeKnow[row];
    for (int col=0; col<rowArray.length; col++) {
        final int thisWidth = rowArray[col].length();

        // Check this column’s width

    }
}

// For each row and column entry {

    // Print the padding for this column

    // Print this entry

} System.out.println();
)

Every column the minimum width

int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;
    if (thisWidth > cols) {
        cols = thisWidth;


int[] widths = new int[cols];
for (int row=0; row<wordsWeKnow.length; row++) {
    final String[] rowArray = wordsWeKnow[row];
    for (int col=0; col<rowArray.length; col++) {
        final int thisWidth = rowArray[col].length();
        if (widths[col] < thisWidth) {
            widths[col] = thisWidth;
        }
    }
}

// For each row and column entry {

    // Print the padding for this column

    // Print this entry

} System.out.println();
}

Every column the minimum width

int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;
    if (thisWidth > cols) {
        cols = thisWidth;
    }
}

int[] widths = new int[cols];
for (int row=0; row<wordsWeKnow.length; row++) {
    final String[] rowArray = wordsWeKnow[row];
    for (int col=0; col<rowArray.length; col++) {
        final int thisWidth = rowArray[col].length();
        if (widths[col] < thisWidth) {
            widths[col] = thisWidth;
        }
    }
}
for (int row=0; row<wordsWeKnow.length; row++) {
    final String[] rowArray = wordsWeKnow[row];
    for (int col=0; col<rowArray.length; col++) {
        final String word = rowArray[col];

        // Print the padding for this column
        // Print this entry
    }
    System.out.println();
}

Every column the minimum width

int cols = 0;
for (int row=0; row<wordsWeKnow.length; row++) {
    final int thisWidth = wordsWeKnow[row].length;
    if (thisWidth > cols) {
        cols = thisWidth;
    }
}

int[] widths = new int[cols];
for (int row=0; row<wordsWeKnow.length; row++) {
    final String[] rowArray = wordsWeKnow[row];
    for (int col=0; col<rowArray.length; col++) {
        final int thisWidth = rowArray[col].length();
        if (widths[col] < thisWidth) {
            widths[col] = thisWidth;
        }
    }
}

for (int row=0; row<wordsWeKnow.length; row++) {
    final String[] rowArray = wordsWeKnow[row];
    for (int col=0; col<rowArray.length; col++) {
        final String word = rowArray[col];
        final int pad = widths[col] - word.length();
        for (int i=0; i<pad; i++) {
            System.out.print(" ");
        }
        System.out.print(word);
        System.out.print(" ");
    }
    System.out.println();
}
Pulling words out of a line

// Read in a line of text.
final Scanner scanner = new Scanner(System.in);
System.out.print("Enter a line of text: ");
final String sourceLine = scanner.nextLine();
final int sourceLength = sourceLine.length();

// Read how many words we should take from the line.
System.out.print("Extract how many words? ");
final int wordCount = scanner.nextInt();

// Prepare an array to hold the words.
final String[] words = new String[wordCount];
// We’ll scan through the line looking for spaces.
int position = 0;
// The word we’ll fill in next.
int nextWord = 0;

while (position<sourceLength && nextWord<wordCount) {
    // Skip over any spaces.
    while (position<sourceLength && sourceLine.charAt(position) == ' ') {
        ++position;
    }
    final int wordStart = position;

    // Now skip over non-spaces.
    while (position<sourceLength && sourceLine.charAt(position) != ' ') {
        ++position;
    }
    final int wordEnd = position;

    // Copy that word into the array.
    words[nextWord] = sourceLine.substring(wordStart, wordEnd);
    ++nextWord;
}

• What happens on a "normal" run?
• What happens when we ask for too many words?
Using the words

```java
final Scanner scanner = new Scanner(System.in);
System.out.print("Enter a line of text: ");
final String sourceLine = scanner.nextLine();
final int sourceLength = sourceLine.length();

System.out.print("Extract how many words? ");
final int wordCount = scanner.nextInt();

final String[] words = new String[wordCount];
int position = 0;
int nextWord = 0;

while (position<sourceLength
    && nextWord<wordCount) {

    while (position<sourceLength
        && sourceLine.charAt(position)==' ')
        ++position;
    final int wordStart = position;

    while (position<sourceLength
        && sourceLine.charAt(position)!=' ')
        ++position;
    final int wordEnd = position;

    words[nextWord] = sourceLine
        .substring(wordStart, wordEnd);
    ++nextWord;
}
```

Printing the array

First try

```java
final int found = words.length;
System.out.println("Found " + found + " words");
for(int i=0; i<found; i++) {
    System.out.println(i + ". " + words[i]);
}
```

• But what if there were fewer words in the line than the user asked us to pull?

A good change

```java
final int found = nextWord;
```
4.8 Some random stuff
Let's pick some numbers

```java
import java.util.Random;

public class RandomDistrib {
    public static void main(String[] args) {
        // Get a source of random numbers
        final Random src = new Random();
        final int MAX_PICK = 100;

        // Pick 10,001 random integers, each between 0 and 99 (inclusive)
        final int[] someInts = new int[10001];
        for(int i=0; i<someInts.length; i++) {
            someInts[i] = src.nextInt(MAX_PICK);
        }

        • So what can we do with 10,001 random numbers?

        We can find their average
        double total=0.0;
        for(int i=0; i<someInts.length; i++) {
            total += someInts[i];
        }
        final double average = total/someInts.length;
        System.out.println("Average of the numbers is "+average);

        We count how many there are of each
        final int[] census = new int[MAX_PICK];
        for(int i=0; i<MAX_PICK; i++) {
            census[i] = 0;
        }
        for(int i=0; i<someInts.length; i++) {
            census[someInts[i]] += 1;
        }

        We can find their median
        int finderTotal=0;
        int finderIndex=0;
        while (finderTotal<5000) {
            finderTotal += census[finderIndex];
            finderIndex += 1;
        }
        System.out.println("Median value is "+finderIndex);
```
We can find their mode

```java
int mode=0;
int modeFreq = census[mode];
for(int i=1; i<MAX_PICK; i++) {
    final int thisFreq = census[i];
    if (thisFreq>modeFreq) {
        mode=i;
        modeFreq=thisFreq;
    }
}
System.out.println("Mode is " + mode + " (" + modeFreq + " occurrences)");
```

We can find their standard deviation

Formula:  \( \sigma = \sqrt{\frac{\sum_{i=0}^{N-1} (\bar{x} - x_i)^2}{N-1}} \)

```java
int sumOfSq=0;
for(int i=0; i<someInts.length; i++) {
    final double diff = someInts[i] - average;
    sumOfSq += diff*diff;
}
final double stdDev = Math.sqrt(sumOfSq/10000);
```

4.9 Methods and arrays

Passing arrays to methods

- Recall: the way a name is used is local to methods
  - If we assign something else to a name, the effect does not travel outside of the method
- But the internals of arrays are not duplicated for function calls

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

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

Recall bubble sort

```java
public static void main(String[] args) {
    final Scanner scnr = new Scanner(System.in); // 1
    System.out.print("How many numbers? "); // 2
    final int howMany = scnr.nextInt(); // 3

    final int[] numbers = new int[howMany]; // 4
    for(int i=0; i<howMany; i++) { // 5
        System.out.print("Number "+ 1+i + ":"); // 6
        numbers[i] = scnr.nextInt(); // 7
    }

    for(int a=1; a<howMany; a++) { // 8
        for(int b=howMany-1; a<=b; --b) { // 9
            if (numbers[b-1] > numbers[b]) { // 10
                final int tmp = numbers[b-1]; // 11
                numbers[b-1] = numbers[b]; // 12
                numbers[b] = tmp; // 13
            }
        }
    }

    for(int i=0; i<howMany; i++) { System.out.print(numbers[i] + " "); } // 14
    System.out.println(); // 15

    return;
}
```

Bubble sort as a method

```java
public static void main(String[] args) {
    final Scanner scnr = new Scanner(System.in); // 1
    System.out.print("How many numbers? "); // 2
    final int howMany = scnr.nextInt(); // 3

    final int[] numbers = new int[howMany]; // 4
    for(int i=0; i<howMany; i++) { // 5
        System.out.print("Number "+ 1+i + ":"); // 6
        numbers[i] = scnr.nextInt(); // 7
```
bubbleSort(numbers); // 8

for(int i=0; i<howMany; i++) { System.out.print(numbers[i] + " "); } // 9
System.out.println(); // 10

return; // 11

public static void bubbleSort(int[] array) {
    final int len = array.length; // 12
    for(int a=1; a<len; a++) { // 13
        for(int b=len-1; a<=b; --b) { // 14
            if (array[b-1] > array[b]) { // 15
                final int tmp = array[b-1]; // 16
                array[b-1] = array[b]; // 17
                array[b] = tmp; // 18
            }
        }
    }
    return;
}

The dot product program

public class DotProduct {
    public static void main(String[] args) {
        final int[] array1 = { 2, 4, 6 }; // 12
        final int[] array2 = { 100, 1000, 10000 }; // 13

        int total = 0;
        for(int i=0; i<array1.length; ++i) {
            total += array1[i] * array2[i]; // 16
        }

        System.out.println("Dot product is: " + total);
        return;
    }
}

The dot product method

public class DotProduct {
    public static void main(String[] args) {
        final int[] array1 = { 2, 4, 6 }; // 12
        final int[] array2 = { 100, 1000, 10000 }; // 13


public static int dotProduct(int[] array1, int[] array2) {
    int total = 0;
    for (int i = 0; i < array1.length; ++i) {
        total += array1[i] * array2[i];
    }
    return total;
}

public static int findMatch(int[] numbers, int target) {
    return findMatch(numbers, target, 0, numbers.length);
}

public static int findMatch(int[] numbers, int target, int lowIdx, int upperBnd) {
    // Midpoint of low and high values
    final int midPoint = (upperBnd + lowIdx) / 2; // 1

    // The value we find at the midpoint
    final int foundVal = numbers[midPoint]; // 2

    if (target == foundVal) { // 3
        // Base case 1: item found at midPoint position
        return midPoint; // 4
    } else if (upperBnd - lowIdx == 1) { // 5
        // Base case 2: match not found
        return -1; // 6
    } else if (target < foundVal) { // 7
        // Recursive case: the target is less than midPoint, so it’s
        // in the lower half
        return findMatch(numbers, target, lowIdx, midPoint); // 8
    } else { // 8
        // Recursive case: the target is greater than midPoint, so it’s
        // in the upper half
        return findMatch(numbers, target, midPoint + 1, upperBnd); // 9
    }
}

- Search for 20 in {5,20,53,61,67,78,85,90}
• Search for 25 in \( \{10, 20, 30\} \)

5 Classes and objects

5.1 Class and object basics

The six things and the four ways

• 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

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

• We’ve seen arrays and methods

• One last Java structure: our own classes

Classes and objects

A class is a sort of thing; an object is one instance of a class

• String and Scanner are two classes we’ve seen already

• "Hello" and "Goodbye" are two different String objects

  – There’s a special syntax for creating a String

• Ordinarily we create a new object of a class using new

    final Scanner scn = new Scanner();

Defining a class

Name

• Normally the name of a class is the same as the name of the file where it is defined

Fields - storage for simple values

• The state of each object of the class
Methods - code to be executed

- We’ve already written static methods
  - Separate from objects of the class
- Object methods are linked to the context of one object
  - Like how charAt refers to the characters of a particular string

A class for student records
The university needs certain information about every student

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

Creating fields
We can turn that information into field declarations

- Their name
  - String firstName, lastName;
- Their ID
  - int id;
- Their current classes
  - String[] currentClasses;
- The number of credits earned
  - int creditsEarned;

Starting a student record class

```java
public class Student {
    private String firstName, lastName;
    private int id;
    private String[] currentClasses;
    private int creditsEarned;

    // If a field should never be changed, we can tag it as final
    public class Student {
        private String firstName, lastName;
        private final int id;
        private String[] currentClasses;
        private int creditsEarned;
```
What operations might we need to perform on student records?

- Get the name, or id, or current classes, etc.
- Update the name
- Report passed classes
- Enroll in new classes

These all become different methods

**Accessor or "get" methods**
Some methods give us information

```java
public String getFirstNames() {
    return firstNames;
}
public String getLastName() {
    return lastName;
}
public int getId() {
    return id;
}
```

and so on

- Accessors often take no arguments
- Accessors return a value

**Mutator methods**
Some methods change the state of the object

The simplest mutators are *setters*, which just update a field

```java
public void setFirstNames(final String newNames) {
    firstNames = newNames;
}
public void setLastName(final String newLastName) {
    lastName = newLastName;
}
```

Other mutators can have more complicated changes

```java
public void awardCreditHours(final int credits) {
    creditsEarned = creditsEarned + credits;
}
```

- Mutators usually take arguments
- Mutators usually are `void`
Starting it all up

There is one more bit of code associated with a class — the constructor

- Constructors set up a new object
- Always run right away for a new instance of the class, and then never again
- Constructors have the same name as their class
- May also have parameters, and have a body of statements like a method
- Unlike a method, they do not have an explicit return type
- And they do not actually return anything — they just set up the space which new allocates
- Like filling in the pages of a book

Constructing a student record

```java
public Student(String fnames, String lname, int iden) {
    firstNames = fnames;
    lastName = lname;
    id = iden;
    currentClasses = new String[0];
    creditsEarned = 0;
}
```

- Fields can be set from a parameter, or to a constant
- Fields marked final must be set when the object is set up

The whole thing

```java
public class Student {
    private String firstNames, lastName;
    private final int id;
    private String[] currentClasses;
    private int creditsEarned;

    public Student(String fnames, String lname, int iden) {
        firstNames = fnames;
        lastName = lname;
        id = iden;
        currentClasses = new String[0];
        creditsEarned = 0;
    }

    public String getFirstNames() {
        return firstNames;
    }
    public String getLastName() {
```
return lastName;
}
public int getId() {
    return id;
}

public void setFirstNames(final String newNames) {
    firstNames = newNames;
}
public void setLastName(final String newLastName) {
    lastName = newLastName;
}

public void awardCreditHours(final int credits) {
    creditsEarned = creditsEarned + credits;
}

• Stay organized! We write
  – Fields first
  – Then the constructor
  – Then accessors
  – Then mutators

• We label fields private
  – We’ll see what that means, and what alternatives there are, later

• Two kinds of documentation:
  – 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
  – 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

5.2 A class with one single field

A small class

public class SmallClass {
    private final String label;

    public SmallClass(final String label) {

this.label = label;
}

public String getLabel() {
    return label;
}

public boolean longerLabelThan(final SmallClass thatLabel) {
    if (this.label.length() > thatLabel.label.length()) {
        return true;
    } else {
        return false;
    }
}

A main routine for SmallClass

class Main {
    public static void main(String[] args) {
        final SmallClass sc1 = new SmallClass("alpha"), sc2 = new SmallClass("beta"), sc3 = new SmallClass("gamma");

        System.out.println("sc1 label: "+sc1.label);
        System.out.println("sc3 > sc2: "+sc3.longerLabelThan(sc2));
    }
}

5.3 Complex numbers

Complex number basics

Imaginary numbers are the square roots of negative numbers

\[ i = \sqrt{-1} \]

Complex numbers are the sum of a real component and an imaginary component

- 1+2i, 3.4-132.65i, etc.
- Imaginary component may have coefficient 0 — so all real numbers also complex
- Real component may have value 0 — so all imaginary numbers also complex

Java does not have complex numbers built in

- But we can model them as a class of our own
Designing a class of complex numbers

- What fields do we need in our complex number class?
  - One for the real component, one for the imaginary component
  - Store each as a double

- What methods on complex numbers do we need?
  - Getters for each component
  - Arithmetic: addition, subtraction, multiplication, division
    * There’s also exponentiation, trig functions, etc., although the formulas are rather complex
  - Other operations: magnitude, conjugate
  - A test for zero is a common method for this sort of class

- What sort of constructor do we need?
  - Takes real and imaginary components, stores them in the object fields

The basics

- All classes start by declaring them by name
- Then we declare the fields and their types
  - We’ll use a different object for each complex number, so the fields can be final
- The constructor just sets up the fields

```
public class Complex {

    private final double real, imaginary;

    Complex(final double real,
            final double imaginary) {
        this.real = real;
        this.imaginary = imaginary;
    }

    // Accessors
    public double getReal() {
        return real;
    }
    public double getImaginary() {
        return imaginary;
    }
}
```
Addition and subtraction

• We add complex numbers componentwise:
  – Add the real part to the real part
  – Add the complex part to the complex part

• In Java, object methods are in the context of one object
  – But addition is a binary operator
  – So the method takes a second argument
  – The result is a separate object

• Subtraction is just like addition

```java
public Complex add(final Complex that) {
    final double realResult = real + that.real;
    final double imaginaryResult = imaginary + that.imaginary;
    return new Complex(realResult, imaginaryResult);
}

public Complex subtract(final Complex that) {
    final double realResult = real - that.real;
    final double imaginaryResult = imaginary - that.imaginary;
    return new Complex(realResult, imaginaryResult);
}
```

Multiplication

Multiplying two sums: FOIL

• \((a+bi)(c+di) = ac+adi+bci-bd\)

• Since \(i^2=-1\), instead of \(bdi^2\) we have \(-bd\)

• Simplifying, the product is \((ac-bd)+(ad+bc)i\)

```java
public Complex multiply(final Complex that) {
    final double resultReal =
        real * that.real
        - imaginary * that.imaginary;
    final double resultImaginary =
        real * that.imaginary;
    return new Complex(resultReal, resultImaginary);
}
```
Conjugate

Conjugate is a simple idea that will help us when we implement division

• \( a + bi = a - bi \)

• The conjugate has the nice property that a number multiplied by its conjugate is always a real number

• Conjugate is a unary operation, so it does not take an additional argument

Another useful operation is simpler multiplication by a real coefficient

• \( a(b+ci) = ab + aci \)

Division

With conjugate and multiplication, division is straightforward

• We need to simplify \( \frac{a+bi}{c+di} \) to the form \( x+yi \)

• First multiply the quotient top-and-bottom by the conjugate of \( c+di \):

\[
\frac{a + bi}{c + di} = \frac{(a + bi)(c + di)}{(c + di)(c + di)}
\]

• Since \( (c + di)(c + di) \) is real, we can express the quotient in terms of the operations we have already implemented

```java
public Complex divide(final Complex c) {
    final Complex conj = c.conjugate();
    final double denom = c.multiply(conj).getReal();
    return this.multiply(conj)
        .scale(1/denom);
}
```
Magnitude
If we interpret complex numbers as points on a plane, magnitude represents the distance from the origin

```java
public double magnitude() {
    return Math.sqrt(real*real + imaginary*imaginary);
}
```

5.4 Data sets

Representing a data set — first steps

```java
public class Data {
    public double[] data;

    public double mean() {
        double total = 0.0;
        for(int i=0; i<data.length; i++) {
            total += data[i];
        }
        return total/data.length;
    }
}
```

Better: keep data internal to the class

```java
public class Data {
    private double[] data;

    public double mean() {
        double total = 0.0;
        for(int i=0; i<data.length; i++) {
            total += data[i];
        }
        return total/data.length;
    }
}
```

- Can be accessed only by methods of the same class
- So the only way to access the object is via its methods

Constructors to set up the object

```java
public class Data {
    private double[] data;

    public Data(double[] sourceData) {
        data = new double[sourceData.length];
    }
}
for(int i=0; i<sourceData.length; i++) {
    data[i] = sourceData[i];
}

public double mean() {
    double total = 0.0;
    for(int i=0; i<data.length; i++) {
        total += data[i];
    }
    return total/data.length;
}

Adding to the data set

public class Data {
    private double[] data;

    public void addData(double[] additionalData) {
        final int l = data.length;
        double[] newData = new double[l + additionalData.length];
        for(int i=0; i<l; ++i) {
            newData[i] = data[i];
        }
        for(int i=0; i<additionalData.length; ++i) {
            newData[l+i] = additionalData[i];
        }
        data = newData;
    }

    // ...

    Clearing the data set

    public class Data {
        private double[] data;

        public void clearData() {
            data = new double[0];
        }

    Then we can have multiple data sets

    Data data1 = new Data(array1);
    Data data2 = new Data(someOtherArray);
    Data data3 = new Data(thirdArray);
Multiple constructors

```java
public class Data {
    private String name;
    private double[] data;

    public Data(double[] sourceData) {
        this("(unnamed)", sourceData);
    }

    public Data(String dataSetName, double[] sourceData) {
        name = dataSetName;
        data = new double[sourceData.length];
        for(int i=0; i<sourceData.length; i++) {
            data[i] = sourceData[i];
        }
    }

    // ...
    • In this situation, calling this as if it were a function means we want to use a different constructor
    • We can do this only in a constructor
      – Moreover, we can do this only as the first step in a constructor

Creating and returning a new instance

```java
public class Data {
    private String name;
    private double[] data;

    public Data withAdditionalData(double[] additionalData) {
        final int l = data.length;
        double[] newData = new double[l + additionalData.length];
        for(int i=0; i<l; ++i) {
            newData[i] = data[i];
        }
        for(int i=0; i<additionalData.length; ++i) {
            newData[l+i] = additionalData[i];
        }
        return new Data(name, newData);
    }

    // ...
    • Very useful if we consider our class data to be immutable
      – So methods create and return new classes instead of changing existing ones.
    • Many Java library classes use this approach
```
An object can refer to itself

Every Java object can refer to itself

- The local variable \texttt{this} is always defined in object methods
- It refers to the object itself
- Its type is the class in which the method lives
- Can be used
  - For clarity
  - When parameter names, etc. shadow field names
  - To pass the object as an argument to another method
  - We’ll see several examples of using \texttt{this} in the next several classes

Choosing names

Remember how we defined the constructor

```java
public class Data {
    private String name;
    private double[] data;

    public Data(String dataSetName, double[] sourceData) {
        name = dataSetName;
        data = new double[sourceData.length];
        for(int i=0; i<sourceData.length; i++) {
            data[i] = sourceData[i];
        }
    }

    // ...
}
```

Consistent use of this

Many would argue that it is better style to \textit{shadow} field names with constructor argument names

- To make the purpose of the parameters clear
- To avoid needing odd or inconsistent alternate names just to avoid shadowing

```java
public class Data {
    private String name;
    private double[] data;

    public Data(String name, double[] data) {
        this.name = name;
        this.data = new double[data.length];
        for(int i=0; i<data.length; i++) {
            this.data[i] = data[i];
        }
    }
```
This and that

Sometimes you'll see that as a parameter name

- It's not special like this — it's just a local name like x or i or nameString
- Handy especially for small methods where the purpose is otherwise very clear

```java
public class Data {
    private String name;
    private double data[];

    public boolean hasLargerDataSet(Data that) {
        return this.data.length > that.data.length;
    }

    // ...
}
```

Caching values when we compute them

```java
private double theSavedMean;
private boolean haveMeanSaved = false;
public double getMean() {
    if (!haveMeanSaved) {
        double total=0.0;
        for(int i=0; i<data.length; ++i) {
            total += data[i];
        }
        theSavedMean = total / data.length;
        haveMeanSaved = true;
    }
    return theSavedMean;
}
```

But when we change the data, we must clear the cache

```java
public void addData(double additionalData[]) {
    final int l = data.length;
    double newData[] = new double[l + additionalData.length];
    for(int i=0; i<l; ++i) {
        newData[i] = data[i];
    }
    for(int i=0; i<additionalData.length; ++i) {
        newData[l+i] = additionalData[i];
    }
}
```
data = newData;
haveMeanSaved = false;
}

What if we cache other things too?

- Standard deviation, higher moments, median, etc.
- We still could compute each value separately
- Or cache all of them at the same time

```java
private boolean cacheUpdated = false;
private void ensureCached() {
  if (!cacheUpdated) {
    final int count = data.length;
    double total=0.0, sqTotal=0.0;
    for(int i=0; i<count; ++i) {
      double point = data[i];
      total += point;
      sqTotal += point*point;
    }
    theSavedMean = total/count;
    theSavedStdDev = Math.sqrt(count*sqTotal - total*total)/count;
    cacheUpdated = true;
  }
}
```

Consolidate clearing

- If we compute each value separately, then we have several different is-cached flags
- It is prudent to consolidate clearing them under one method

```java
private void clearCached() {
  haveMeanSaved = false;
  haveStdDevSaved = false;
  // ...
}
```

- Every time we mutate the values, all the flags must be reset

5.5 The ArrayList class

Java provides built-in representations of many data structures

- Today we’ll look at class ArrayList
Based on arrays

- So accessing an element by its index is fast
- But inserting an element into the middle of a list can be slower

- The class keeps track of the size of the array and the size of the list
  - So the number of the elements in the list may differ from the size of the underlying array
  - When the array needs to grow, the ArrayList allocates new space without the programmer needing to know

- No direct access to the underlying array
  - Instead, ArrayList defines an application programmer interface (API) of different operations

To use

As with an array, name the type of list elements

- When we use ArrayList as a type, we mention the type of the elements of the list
- ArrayList<Integer>, ArrayList<Character>, ArrayList<BigInteger>, etc.
- The type of elements we try to add to a list must match the declared type
- Elements we extract from the list will match the given type

Some ArrayList<E> constructors and methods

- ArrayList() — Constructor for a new empty list
- ArrayList(int init) — Constructor for a new empty list, where we tell Java that it should have capacity for at least init entries
- size() — Returns the number of elements now in the list
- isEmpty() — Returns true if the list contains no elements
- contains(Object o) — Returns true if o is now in the list
- clear() — Empties the list
- add(E element) — Append the element to the end of the list
- get(int index) — Returns the given element of the list
- remove(int index) — Removes the given element from the list
- set(int index, E element) — Sets the element at the given position of the list
  - It’s an error if there’s no such element of the list
import java.util.ArrayList;

public class UseArrayList {
    public static void main(String[] argv) {
        final ArrayList<Integer> numbers = new ArrayList<Integer>();
        numbers.add(1);
        numbers.add(2);
        numbers.add(3);
        numbers.add(4);

        for(int i=0; i<numbers.size(); i++) {
            final int number = numbers.get(i);
            System.out.println(number);
        }
    }
}

public class ChangeAnArrayList {
    public static void main(String[] argv) {
        final ArrayList<Integer> numbers = new ArrayList<Integer>();
        numbers.add(1);
        numbers.add(2);
        numbers.add(3);
        numbers.add(4);

        for(int i=0; i<numbers.size(); i++) {
            numbers.set(i, 2*numbers.get(i));
            System.out.println(numbers.get(i));
        }
    }
}

public class IterateArrayList {
    public static void main(String[] argv) {
        final ArrayList<Integer> numbers = new ArrayList<Integer>();
        numbers.add(1);
        numbers.add(2);
        numbers.add(3);
        numbers.add(4);

        for(int i=0; i<numbers.size(); i++) {
            System.out.println(numbers.get(i));
        }
    }
}

A small example

Changing the ArrayList

Iterating through the ArrayList
for(final int number: numbers) {
    System.out.println(number);
}

5.6 Permuting the letters of a word

Permuting the letters of a word
For a string tab, the shufflings of its letters are

- tab
- tba
- atb
- abt
- bta
- bat

It’s a recursive algorithm

- We figure out a way to describe a partly-completed shuffling
- The recursive algorithm figures out the possible next steps for the partly-completed shuffling, and tries them one at a time
- The recursion ends when the shuffling is completed

How to shuffle

- A partial shuffle has
  - The prefix of the shuffle we’re working on
  - The characters which remain to be shuffled

- Given a partial shuffle, what are the next steps?
  - Each characters remaining to be shuffled could be appended to the prefix

- When there are no more characters to be shuffled, the prefix will in fact be a complete shuffle
The state of a shuffler
Each shuffler has the prefix and the characters still to be shuffled

```java
public class WordShuffler {
    private final String prefix;
    private final ArrayList<Character> unshuffled;

    public WordShuffler(String prefix,
                         ArrayList<Character> unshuffled) {
        this.prefix = prefix;
        this.unshuffled = unshuffled;
    }
}
```

Setting up a shuffler
When we start shuffling a string, we must set up what the constructor needs

```java
public static WordShuffler getShuffler(String string) {
    final ArrayList<Character> unshuffled = new ArrayList<Character>(string.length());
    for(final char c : string.toCharArray()) {
        unshuffled.add(c);
    }
    return new WordShuffler("", unshuffled);
}
```

Shuffling action

```java
public void shuffle() {
    if (unshuffled.isEmpty()) {
        System.out.println(prefix);
    } else {
        for(final Character c : unshuffled) {
            final String
                nextPrefix = prefix + String.valueOf(c);
            final ArrayList<Character> nextUnshuffled =
                new ArrayList<Character>(unshuffled);
            nextUnshuffled.remove(c);
            final WordShuffler nextShuffler =
                new WordShuffler(nextPrefix, nextUnshuffled);
            nextShuffler.shuffle();
        }
    }
}
```

A main routine

```java
public static void main(String[] args) {
    final Scanner scanner = new Scanner(System.in);
    ```
System.out.print("Word to scramble: ");
final String word = scanner.next();
final WordShuffler shuffler = getShuffler(word);
shuffler.shuffle();
}

Shuffling "tab"

private final String prefix;
private final ArrayList<Character> unshuffled;

public static WordShuffler getShuffler(String string) {
    final ArrayList<Character>
    unshuffled = new ArrayList<Character>(string.length());
    for (final char c : string.toCharArray()) {
        unshuffled.add(c);
    }
    return new WordShuffler("", unshuffled);
}

public void shuffle() {
    if (unshuffled.isEmpty()) {
        System.out.println(prefix);
    } else {
        for (final Character c : unshuffled) {
            final String
            nextPrefix = prefix + String.valueOf(c);
            final ArrayList<Character> nextUnshuffled =
            new ArrayList<Character>(unshuffled);
            nextUnshuffled.remove(c);
            final WordShuffler nextShuffler =
            new WordShuffler(nextPrefix, nextUnshuffled);
            nextShuffler.shuffle();
        }
    }
}

public static void main(String[] args) {
    final Scanner scanner = new Scanner(System.in);
    System.out.print("Word to scramble: ");
    final String word = scanner.next();
    final WordShuffler shuffler = getShuffler(word);
    shuffler.shuffle();
}

• What happens when we shuffle tab?