1. Basic Programming Concepts

- Why programming?
- Program development
- Built-in data types
- Type conversion

### Built-in data types

A **data type** is a set of values and a set of operations on those values.

<table>
<thead>
<tr>
<th>Type</th>
<th>Set of Values</th>
<th>Examples of Values</th>
<th>Examples of Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>char</td>
<td>characters</td>
<td>'A' 'ø'</td>
<td>compare</td>
</tr>
<tr>
<td>String</td>
<td>sequences of characters</td>
<td>&quot;Hello World&quot; &quot;CS is fun&quot;</td>
<td>concatenate</td>
</tr>
<tr>
<td>int</td>
<td>integers</td>
<td>17 12345</td>
<td>add, subtract, multiply, divide</td>
</tr>
<tr>
<td>double</td>
<td>floating-point numbers</td>
<td>3.1415 6.022e23</td>
<td>add, subtract, multiply, divide</td>
</tr>
<tr>
<td>boolean</td>
<td>truth values</td>
<td>true false</td>
<td>and, or, not</td>
</tr>
</tbody>
</table>

Java’s built-in data types

### Pop quiz on data types

**Q.** What is a data type?
Pop quiz on data types

Q. What is a data type?

A. A set of values and a set of operations on those values.

---

Basic Definitions

A **variable** is a name that refers to a value.

A **literal** is a programming-language representation of a value.

A **declaration statement** associates a variable with a type.

An **assignment statement** associates a value with a variable.

---

Variables, literals, declarations, and assignments example: exchange values

```java
public class Exchange {
    public static void main(String[] args) {
        int a = 1234;
        int b = 99;
        int t = a;
        a = b;
        b = t;
    }
}
```

Q. What does this program do?

A. No way for us to confirm that it does the exchange! (Need output, stay tuned.)

---

Data type for computing with strings: String

**String data type**

<table>
<thead>
<tr>
<th>values</th>
<th>sequences of characters</th>
</tr>
</thead>
<tbody>
<tr>
<td>typical literals</td>
<td>“Hello”, “1”, “9”</td>
</tr>
<tr>
<td>operation</td>
<td>concatenate</td>
</tr>
<tr>
<td>operator</td>
<td>+</td>
</tr>
</tbody>
</table>

**Examples of String operations (concatenation)**

<table>
<thead>
<tr>
<th>expression</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Hi, ” + “Bob”</td>
<td>“Hi, Bob”</td>
</tr>
<tr>
<td>“1” + 2 + “1”</td>
<td>“121”</td>
</tr>
<tr>
<td>“1234” + “99”</td>
<td>“123499”</td>
</tr>
</tbody>
</table>

**Important note:** Character interpretation depends on context!

- **Ex 1:** plus signs
  - “1234” + “99” + “99”
  - Operator: +
- **Ex 2:** spaces
  - “1234 99 99”
  - Operators: +, 
- Typical use: Input and output.
Example of computing with strings: subdivisions of a ruler

```java
class Ruler {
    public static void main(String[] args) {
        String ruler1 = "1";
        String ruler2 = ruler1 + " 2 " + ruler1;
        String ruler3 = ruler2 + " 3 " + ruler2;
        String ruler4 = ruler3 + " 4 " + ruler3;
        System.out.println(ruler4);
    }
}
```

<table>
<thead>
<tr>
<th>ruler1</th>
<th>ruler2</th>
<th>ruler3</th>
<th>ruler4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 2 1</td>
<td>1 2 1</td>
<td>1 2 1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1 2 1</td>
<td>1 2 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 2 3 1</td>
<td>1 2 3 1</td>
</tr>
</tbody>
</table>

Input and output

is necessary for us to provide data to our programs and to learn the result of computations.

Humans prefer to work with strings.
Programs work more efficiently with numbers.

Output
- `System.out.println()` method prints the given string.
- Java automatically converts numbers to strings for output.

Command-line input
- Strings you type after the program name are available as `args[0]`, `args[1]`, ... at run time.
- Q. How do we give an integer as command-line input?
- A. Need to call system method `Integer.parseInt()` to convert the strings to integers.

Stay tuned for many more options for input and output, and more details on type conversion.

Input and output warmup: exchange values

```java
class Exchange {
    public static void main(String[] args) {
        int a = Integer.parseInt(args[0]);
        int b = Integer.parseInt(args[1]);
        int t = a;
        a = b;
        b = t;
        System.out.println(a);
        System.out.println(b);
    }
}
```

Q. What does this program do?
A. Reads two integers from the command line, then prints them out in the opposite order.

Data type for computing with integers: int

<table>
<thead>
<tr>
<th>int data type</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>integers between (-2^{31}) and (2^{31}-1)</td>
</tr>
<tr>
<td>operations</td>
<td>add</td>
</tr>
<tr>
<td>operator</td>
<td>+</td>
</tr>
</tbody>
</table>

Examples of int operations

<table>
<thead>
<tr>
<th>expression</th>
<th>value</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 + 3</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>5 - 3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5 * 3</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>5 / 3</td>
<td>1</td>
<td>drop fractional part</td>
</tr>
<tr>
<td>5 % 3</td>
<td>2</td>
<td>remainder</td>
</tr>
<tr>
<td>1 / 0</td>
<td></td>
<td>runtime error</td>
</tr>
</tbody>
</table>

Important note:
- Only \(2^{31}\) different int values.
- Not quite the same as integers.

Typical usage: Math calculations; specifying programs (stay tuned).
Example of computing with integers and strings, with type conversion

```java
public class IntOps {
    public static void main(String[] args) {
        int a = Integer.parseInt(args[0]);
        int b = Integer.parseInt(args[1]);
        int sum = a + b;
        int prod = a * b;
        int quot = a / b;
        int rem = a % b;
        System.out.println(a + " + " + b + " = " + sum);
        System.out.println(a + " * " + b + " = " + prod);
        System.out.println(a + " / " + b + " = " + quot);
        System.out.println(a + " % " + b + " = " + rem);
    }
}
```

Java automatically converts int values to String for concatenation.

Data type for computing with floating point numbers: double

<table>
<thead>
<tr>
<th>double data type</th>
<th>real numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>typical literals</td>
<td>3.14159, 2.0, 1.4142135623730951, 6.02e+23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>operations</th>
<th>add</th>
<th>subtract</th>
<th>multiply</th>
<th>divide</th>
<th>remainder</th>
</tr>
</thead>
<tbody>
<tr>
<td>operator</td>
<td>+</td>
<td>-</td>
<td>*</td>
<td>/</td>
<td>%</td>
</tr>
</tbody>
</table>

Examples of double operations

<table>
<thead>
<tr>
<th>expression</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.141 + .01</td>
<td>3.171</td>
</tr>
<tr>
<td>3.141 - .01</td>
<td>3.131</td>
</tr>
<tr>
<td>6.02e+23/2</td>
<td>3.01e+23</td>
</tr>
<tr>
<td>5.0 / 1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>10.0 % 3.141</td>
<td>0.577</td>
</tr>
<tr>
<td>Math.sqrt(2.0)</td>
<td>1.4142135623730951</td>
</tr>
</tbody>
</table>

Typical use: Scientific calculations.

Other built-in numeric types

<table>
<thead>
<tr>
<th>short data type</th>
<th>long data type</th>
</tr>
</thead>
<tbody>
<tr>
<td>values</td>
<td>values</td>
</tr>
<tr>
<td>integers between $-2^{15}$ and $2^{15}-1$</td>
<td>integers between $-2^{63}$ and $2^{63}-1$</td>
</tr>
<tr>
<td>operations</td>
<td>operations</td>
</tr>
<tr>
<td>[same as int]</td>
<td>[same as int]</td>
</tr>
</tbody>
</table>

Float data type

<table>
<thead>
<tr>
<th>values</th>
<th>real numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>operations</td>
<td>[same as double]</td>
</tr>
</tbody>
</table>

Why different numeric types?

- Tradeoff between memory use and range for integers.
- Tradeoff between memory use and precision for real numbers.

Excerpts from Java’s Math Library

<table>
<thead>
<tr>
<th>public class Math</th>
</tr>
</thead>
<tbody>
<tr>
<td>double abs(double a)</td>
</tr>
<tr>
<td>double max(double a, double b)</td>
</tr>
<tr>
<td>double min(double a, double b)</td>
</tr>
<tr>
<td>double sin(double theta)</td>
</tr>
<tr>
<td>double cos(double theta)</td>
</tr>
<tr>
<td>double tan(double theta)</td>
</tr>
<tr>
<td>double exp(double a)</td>
</tr>
<tr>
<td>double log(double a)</td>
</tr>
<tr>
<td>double pow(double a, double b)</td>
</tr>
<tr>
<td>long round(double a)</td>
</tr>
<tr>
<td>double random()</td>
</tr>
<tr>
<td>double sqrt(double a)</td>
</tr>
<tr>
<td>double E</td>
</tr>
<tr>
<td>double PI</td>
</tr>
</tbody>
</table>
Example of computing with floating point numbers: quadratic equation

From algebra: the roots of $x^2 + bx + c$ are $\frac{-b \pm \sqrt{b^2 - 4c}}{2}$

```java
class Quadratic {
    public static void main(String[] args) {
        // Parse coefficients from command-line.
        double b = Double.parseDouble(args[0]);
        double c = Double.parseDouble(args[1]);
        // Calculate roots of $x^2 + bx + c$:
        double discriminant = b*b - 4.0*c;
        double root1 = (-b + Math.sqrt(discriminant)) / 2.0;
        double root2 = (-b - discriminant) / 2.0;
        // Print them out.
        System.out.println(root1);
        System.out.println(root2);
    }
}
```

Data type for computing with true and false: boolean

<table>
<thead>
<tr>
<th>boolean data type</th>
<th>true</th>
<th>false</th>
</tr>
</thead>
<tbody>
<tr>
<td>literals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>operations</td>
<td>and</td>
<td>or</td>
</tr>
<tr>
<td>operator</td>
<td>&amp;&amp;</td>
<td></td>
</tr>
</tbody>
</table>

Recall first lecture

Q. a XOR b?
A. (!a && b) || (a && !b)

Typical usage: Control logic and flow of a program (stay tuned).

Comparison operators

Fundamental operations that are defined for each primitive type allow us to compare values.

- **Operands**: two expressions of the same type.
- **Result**: a value of type boolean.

```
<table>
<thead>
<tr>
<th>operator</th>
<th>meaning</th>
<th>true</th>
<th>false</th>
</tr>
</thead>
<tbody>
<tr>
<td>==</td>
<td>equal</td>
<td>2 == 2</td>
<td>2 == 3</td>
</tr>
<tr>
<td>!=</td>
<td>not equal</td>
<td>3 != 2</td>
<td>2 != 2</td>
</tr>
<tr>
<td>&lt;</td>
<td>less than</td>
<td>2 &lt; 3</td>
<td>2 &lt; 2</td>
</tr>
<tr>
<td>&lt;=</td>
<td>less than or equal</td>
<td>2 &lt;= 2</td>
<td>3 &lt;= 2</td>
</tr>
<tr>
<td>&gt;</td>
<td>greater than</td>
<td>3 &gt; 2</td>
<td>2 &gt; 13</td>
</tr>
<tr>
<td>&gt;=</td>
<td>greater than or equal</td>
<td>3 &gt;= 2</td>
<td>2 &gt;= 3</td>
</tr>
</tbody>
</table>
```

Examples

- **non-negative discriminant?** ( $b^2 - 4.0a^2$ ) >= 0.0
- **beginning of a century?** ( year % 100 ) == 0
- **legal month?** ( month >= 1 ) && ( month <= 12 )

Example of computing with booleans: leap year test

Q. Is a given year a leap year?
A. Yes if either (i) divisible by 400 or (ii) divisible by 4 but not 100.

```java
class LeapYear {
    public static void main(String[] args) {
        // Parse year from command-line.
        int year = Integer.parseInt(args[0]);
        boolean isLeapYear;
        // divisible by 4 but not 100
        isLeapYear = (year % 4 == 0) && (year % 100 != 0);
        // or divisible by 400
        isLeapYear = isLeapYear || (year % 400 == 0);
        System.out.println(isLeapYear);
    }
}
```

Typical double values are approximations so beware of == comparisons.
1. Basic Programming Concepts

- Why programming?
- Program development
- Built-in data types
- Type conversion

Type checking

Types of variables involved in data-type operations always must match the definitions.

The Java compiler is your friend: it checks for type errors in your code.

```java
public class BadCode
{
    public static void main(String[] args)
    {
        String s = "123" + 2;
    }
}
```

When appropriate, we often convert a value from one type to another to make types match.

Type conversion with built-in types

Type conversion is an essential aspect of programming.

**Automatic**
- Convert number to string for "s".
- Make numeric types match if no loss of precision.

<table>
<thead>
<tr>
<th>expression</th>
<th>type</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;s&quot;: &quot;99&quot;</td>
<td>String</td>
<td>&quot;99&quot;</td>
</tr>
<tr>
<td>11 * 0.25</td>
<td>double</td>
<td>2.75</td>
</tr>
</tbody>
</table>

**Explicitly defined** for function call.

```java
Integer.parseInt("123")  // int 123
Math.round(2.71828)       // long 3
```

**Cast** for values that belong to multiple types.
- Ex: small integers can be short, int or long.
- Ex: double values can be truncated to int values.

```java
(int) 2.71828              // int 2
(int) Math.round(2.71828)  // int 3
11 * (int) 0.25            // int 0
```

Pay attention to the type of your data. Type conversion can give counterintuitive results but gets easier to understand with practice.
Pop quiz on type conversion

Q. Give the type and value of each of the following expressions.

a. \((7 / 2) \times 2.0\)

b. \((7 / 2.0) \times 2\)

c. "2" + 2

d. 2.0 + "2"

6.0, a double (7/2 is 3, an int)

7.0, a double

22, a String

2.02, a String

An instructive story about type conversion

Why different numeric types?
• Tradeoff between memory use and range for integers.
• Tradeoff between memory use and precision for floating-point.

A conversion may be impossible.
• Example: (short) 70000.
• Short values must be between \(-2^{15}\) and \(2^{15} - 1 = 32767\).

What to do with an impossible conversion?
• Approach 1: Avoid doing it in the first place.
• Approach 2 (Java): Live with a well-defined result.
• Approach 3: Crash.
Summary

A data type is a set of values and a set of operations on those values.

Commonly-used built-in data types in Java

- **String**, for computing with sequence of characters, for input and output.
- **int**, for computing with integers, for math calculations in programs.
- **double**, for computing with floating point numbers, typically for science and math apps.
- **boolean**, for computing with true and false, for decision making in programs.

In Java you must:

- Declare the types of your variables.
- Convert from one type to another when necessary.
- Identify and resolve type errors in order to compile your code.
- Pay attention to the type of your data.

The Java compiler is your friend: it will help you identify and fix type errors in your code.
A human being should be able to
change a diaper,
plan an invasion,
butcher a hog,
conmon a ship,
design a building,
write a sonnet,
balance accounts,
build a wall,
set a bone,
comfort the dying,
take orders,
give orders,
cooperate,
act alone,
solve equations,
analyze a new problem,
pitch manure,
program a computer,
cook a tasty meal,
fight efficiently, and
die gallantly.

Specialization is for insects.

Robert A. Heinlein
Time Enough for Love (1975)

You need to know how to program
in order to be able to tell a computer what you want it to do.

Naive ideal: Natural language instructions.

*Please simulate the motion of the heavenly bodies, subject to Newton’s laws of motion and gravity.

Prepackaged solutions (apps) are great when what they do is what you want.

Programming enables you to make a computer do anything you want.

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Programming enables you to make a computer do anything you want.
Our Choice: Java

Java features
- Widely used.
- Widely available.
- Continuously under development since early 1990s.
- Embraces full set of modern abstractions.
- Variety of automatic checks for mistakes in programs.

Java economy
- Mars rover.
- Cell phones.
- Blu-ray Disc.
- Web servers.
- Medical devices.
- Supercomputing.
- ... millions of developers billions of devices

A rich subset of the Java language vocabulary

<table>
<thead>
<tr>
<th>built-in types</th>
<th>operations on numeric types</th>
<th>String operations</th>
<th>assignment</th>
<th>object oriented</th>
<th>Math methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>int</td>
<td>+</td>
<td>==</td>
<td>=</td>
<td>static class</td>
<td>Math.sin()</td>
</tr>
<tr>
<td>long</td>
<td>+</td>
<td>compareTo()</td>
<td>else</td>
<td>public</td>
<td>Math.cos()</td>
</tr>
<tr>
<td>double</td>
<td>/</td>
<td>length()</td>
<td>for</td>
<td>private</td>
<td>Math.log()</td>
</tr>
<tr>
<td>char</td>
<td>%</td>
<td>charAt()</td>
<td>new</td>
<td>Math.exp()</td>
<td>Math.exp10()</td>
</tr>
<tr>
<td>String</td>
<td>++</td>
<td>matches()</td>
<td>final</td>
<td>Math.pow()</td>
<td>Math.sqrt()</td>
</tr>
<tr>
<td>boolean</td>
<td>--</td>
<td>true</td>
<td>toString()</td>
<td>Math.signum()</td>
<td>Math.abs()</td>
</tr>
</tbody>
</table>

punctuation

<p>| { |</p>
<table>
<thead>
<tr>
<th>}</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
</tr>
<tr>
<td>&lt;=</td>
</tr>
<tr>
<td>(</td>
</tr>
<tr>
<td>)</td>
</tr>
<tr>
<td>&gt;</td>
</tr>
<tr>
<td>&gt;=</td>
</tr>
<tr>
<td>,</td>
</tr>
<tr>
<td>;</td>
</tr>
</tbody>
</table>

Your programs will primarily consist of these plus identifiers (names) that you make up.

Our Choice: Java

Java features
- Widely used.
- Widely available.
- Continuously under development since early 1990s.
- Embraces full set of modern abstractions.
- Variety of automatic checks for mistakes in programs.

Facts of life
- No language is perfect.
- You need to start with some language.

Our approach
- Use a minimal subset of Java.
- Develop general programming skills that are applicable to many languages.

It’s not about the language!

“There are only two kinds of programming languages: those people always [gripe] about and those nobody uses.”

Bjarne Stroustrup

Anatomy of your first program

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

program name

main() method

body of main() (a single statement)
Anatomy of your next several programs

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

Program name

Main method

Body of main() (a sequence of statements)

```
public class HelloWorld {
    public static void main(String[] args) {
        System.out.println("Hello, World");
    }
}
```

Pop quiz on "your first program"

Q. Use common sense to cope with the following error messages.

```
% javac MyProgram.java
% java MyProgram
Main method not public.
```

A. Must have forgotten "public".

```
% javac MyProgram.java
MyProgram.java:1: invalid method declaration; return type required
public static main(String[] args)
```

A. Check HelloWorld. Aha! Forgot "void".

```
public class HelloWorld { public static void main(String[] args) { System.out.println("Hello, World"); }
```

Three versions of the same program.

Lesson: Fonts, color, comments, and extra space are not relevant in Java language.
1. Basic Programming Concepts

- Why programming?
- Program development
- Built-in data types
- Type conversion

Program development in Java

is a three-step process, *with feedback*

1. **EDIT** your program
   - Create it by typing on your computer’s keyboard.
   - Result: a text file such as HelloWorld.java.

2. **COMPILE** it to create an executable file
   - Use the Java compiler
   - Result: a Java bytecode file such as HelloWorld.class
   - Mistake? Go back to 1. to fix and recompile.

3. **RUN** your program
   - Use the Java runtime.
   - Result: your program’s output.
   - Mistake? Go back to 1. to fix, recompile, and run.

Image sources

http://commons.wikimedia.org/wiki/File:KnuthAltenheim.jpg
http://commons.wikimedia.org/wiki/File:Ada развиваем.jpg
http://commons.wikimedia.org/wiki/File:Sjarno-stroustrup.jpg

Note on program style

Different styles are appropriate in different contexts.
- Integrated development environment
- Book
- Your code

Enforcing consistent style can
- Stifle creativity.
- Confuse style with language.

Emphasizing consistent style can
- Make it easier to spot errors.
- Make it easier for others to read and use code.
- Enable development environment to provide visual cues.

Bottom line for you: Listen to the person assigning your grade.
Software for program development

Any creative process involves cyclic refinement/development.

A significant difference with programs: We can use our computers to facilitate the process.

Program development environment: We can use our computers to facilitate the process.

Two time-tested options: (Stay tuned for details).

Virtual terminals
- Same for many languages and systems.
- Effective even for beginners.
Bottom line: Extremely simple and concise.

Integrated development environment
- Often language- or system-specific.
- Can be helpful to beginners.
Bottom line: Variety of useful tools.

Program development environments: a very short history

Historical context is important in computer science.
- We regularly use old software.
- We regularly emulate old hardware.
- We depend upon old concepts and designs.

Widely-used methods for program development
- switches and lights
- punched cards/compiler/runtime
- editor/compiler/runtime/terminal
- editor/compiler/runtime/virtual terminal
- integrated development environment

Program development with switches and lights

Circa 1970: Use switches to input binary program code and data, lights to read output.

Stay tuned for details [lectures on the "TOY machine"].

Program development with punched cards and line printers

Mid 1970s: Use punched cards to input program code and data, line printer for output.

Ask your parents about the "computer center" for details.
Program development with timesharing terminals

Late 1970s: Use terminal for editing program, reading output, and controlling computer.

Timesharing allowed many users to share the same computer.

Program development with personal computers (one approach)

1980s to present day: Use multiple virtual terminals to interact with computer.
- Edit your program using any text editor in a virtual terminal.
- Compile it by typing `javac HelloWorld.java` in another virtual terminal.
- Run it by typing `java HelloWorld`

Program development with personal computers (another approach)

1980s to present day: Use a customized application for program development tasks.
- Edit your program using the built-in text editor.
- Compile it by clicking the “compile” button.
- Run it by clicking the “run” button or using the pseudo-command line.

Software for program development: tradeoffs

Virtual terminals

Pros
- Approach works with any language.
- Useful beyond programming.
- Used by professionals.
- Has withstood the test of time.

Cons
- Good enough for long programs?
- Dealing with independent applications.
- Working at too low a level?

This course: Used in lectures/book.

IDE

Pros
- Easy-to-use language-specific tools.
- System-independent (in principle).
- Used by professionals.
- Can be helpful to beginners.

Cons
- Overkill for short programs?
- Big application to learn and maintain.
- Often language- or system-specific.

Recommended for assignments.
Lessons from short history

Every computer has a program development environment that allows us to:
- **EDIT** programs.
- **COMPILE** them to create an executable file.
- **RUN** them and examine the output.

Two approaches that have served for decades and are still effective:
- multiple virtual terminals.

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1. Basic Programming Concepts