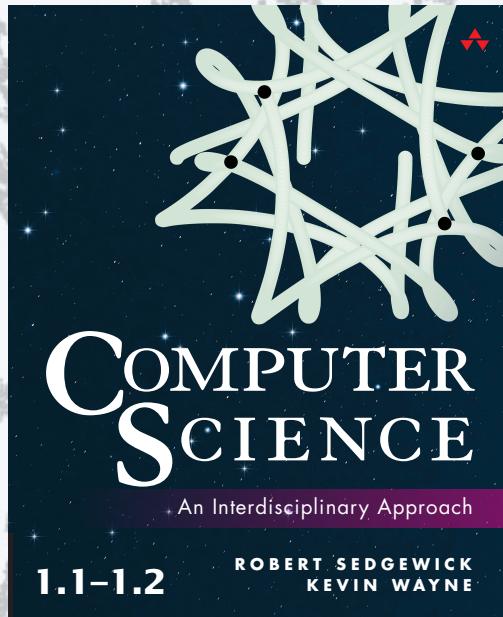




COMPUTER SCIENCE
SEGEWICK / WAYNE
PART I: PROGRAMMING IN JAVA



<http://introcs.cs.princeton.edu>

1. Basic Programming Concepts

1. Basic Programming Concepts

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

A human being should be able to
change a diaper,
plan an invasion,
butcher a hog,
conn 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.

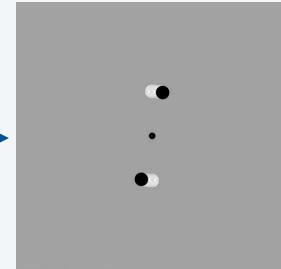
Robert A. Heinlein
Time Enough for Love (1973)

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 N heavenly bodies,
subject to Newton's laws of motion and gravity."



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



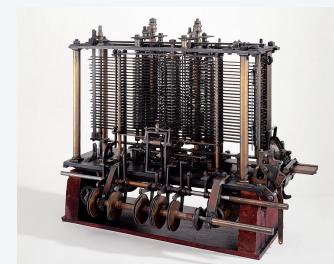
Programming enables you to make a computer do anything you want. ← well, *almost* anything (stay tuned)

first programmer →



Ada Lovelace

← first computer



Analytical Engine

Programming: telling a computer what to do

Programming

- Is *not* just for experts.
- Is a natural, satisfying and creative experience.
- Enables accomplishments not otherwise possible.
- The path to a new world of intellectual endeavor.



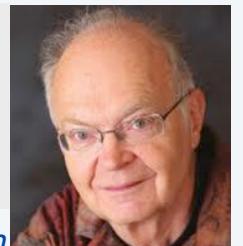
Telling a computer what to do

Challenges

- Need to learn what computers *can* do.
- Need to learn a programming *language*.

“Instead of imagining that our main task is to instruct a computer what to do, let us concentrate rather on explaining to human beings what we want a computer to do.”

– Don Knuth



Telling a computer what to do

Machine language

- Easy for computer.
- Error-prone for human.

```
10: 8A00  RA ← mem[00]
11: 8B01  RB ← mem[01]
12: 1CAB  RC ← RA + RB
13: 9C02  mem[02] ← RC
14: 0000  halt
```

Adding two numbers (see TOY lecture)

Natural language

- Easy for human.
- Error-prone for computer.



Actual newspaper headlines
—Rich Pattis

High-level language

- Some difficulty for both.
- An acceptable tradeoff.

```
for (int t = 0; t < 2000; t++)
{
    a[0] = a[11] ^ a[9];
    System.out.print(a[0]);
    for (int i = 11; i > 0; i--)
        a[i] = a[i-1];
}
```

Simulating an LFSR (see Prologue lecture)

But which high-level language?



Naive ideal: A single programming language for all purposes.

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.

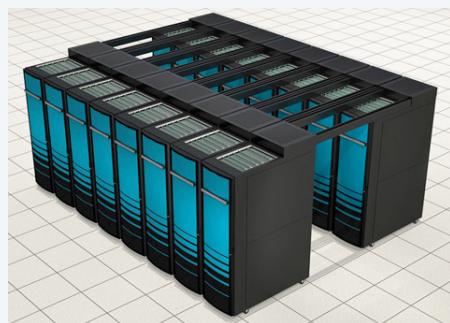


James Gosling

Java economy

- Mars rover.
- Cell phones.
- Blu-ray Disc.
- Web servers.
- Medical devices.
- Supercomputing.
- ...

← millions of developers
billions of devices



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.

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



– Bjarne Stroustrup

Our approach

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

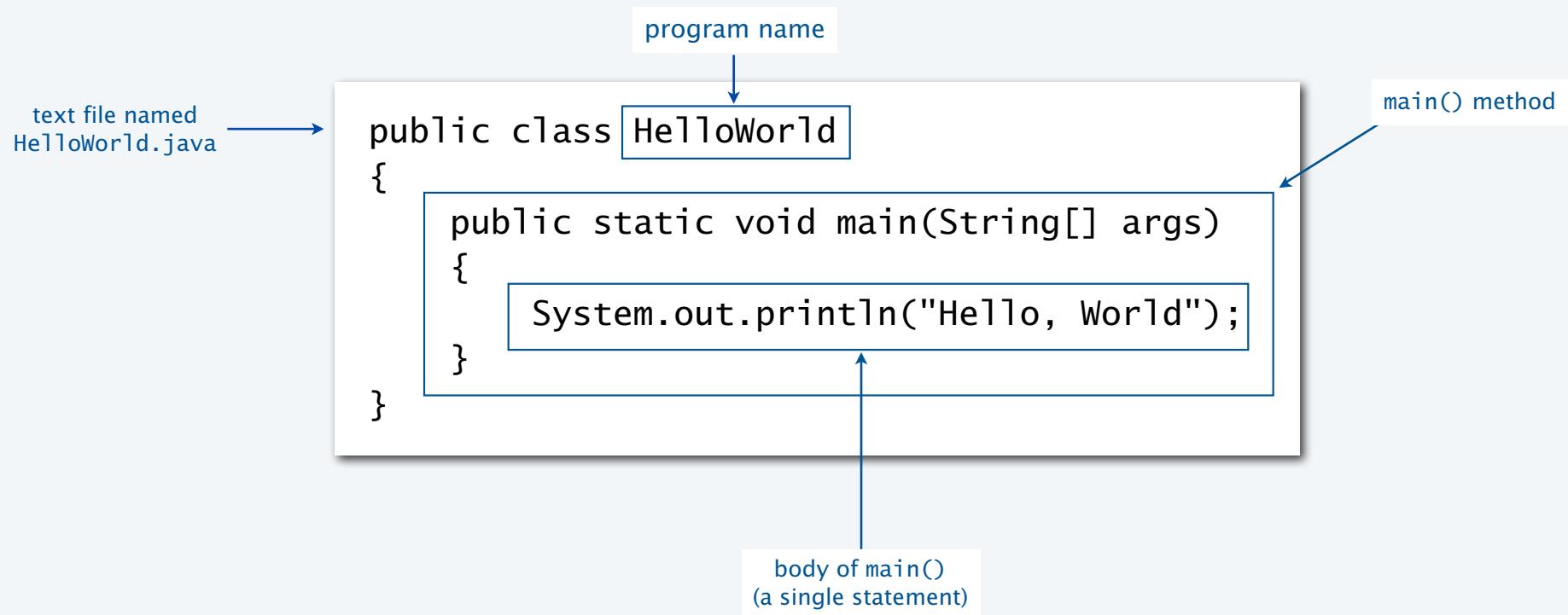
It's not about the language!

A rich subset of the Java language vocabulary

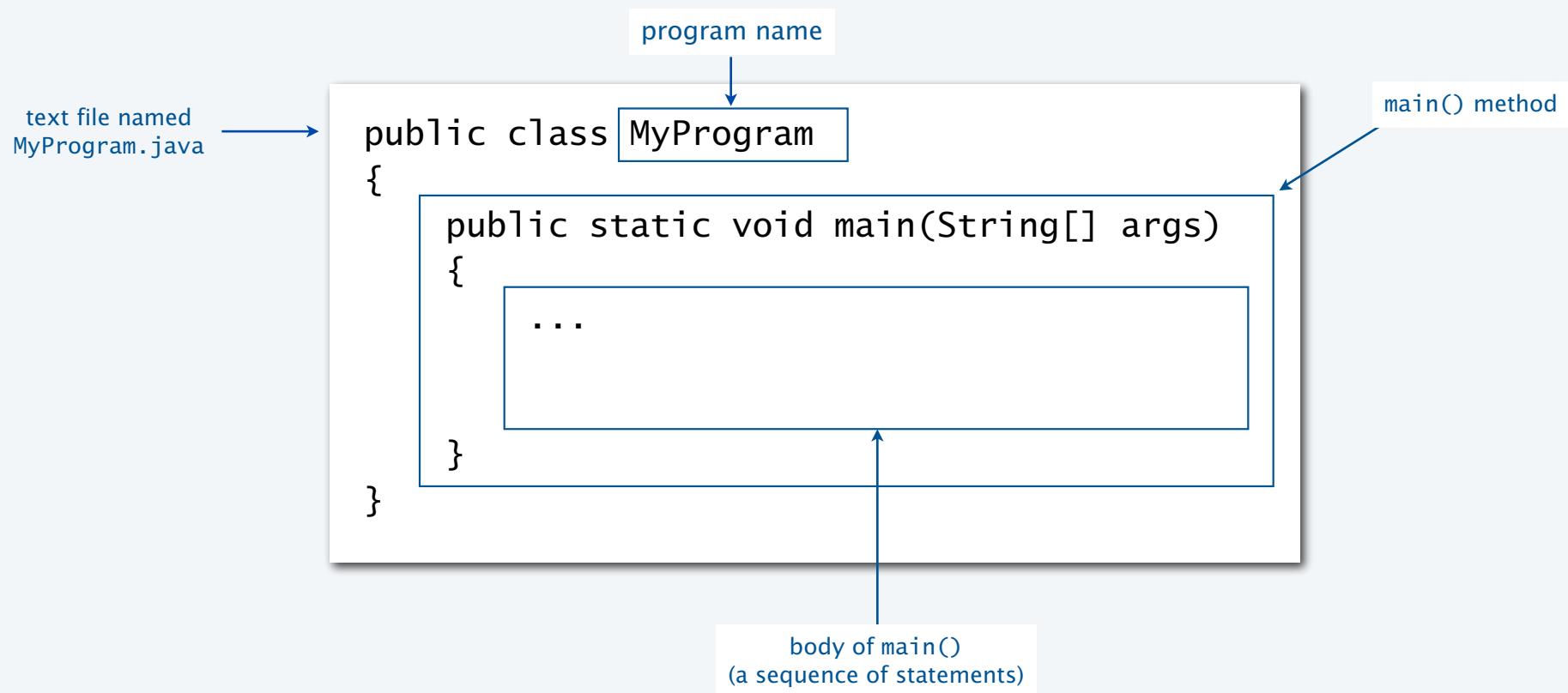
<i>built-in types</i>	<i>operations on numeric types</i>	<i>String operations</i>	<i>assignment</i>	<i>object oriented</i>	<i>Math methods</i>	
int	+	+	=		Math.sin()	
long	-	""			Math.cos()	
double	*	length()			Math.log()	
char	/	charAt()			Math.exp()	
String	%	compareTo()			Math.pow()	
boolean	++	matches()			Math.sqrt()	
	--				Math.min()	
<i>punctuation</i>	<i>comparisons</i>	<i>boolean operations</i>	<i>arrays</i>	<i>main()</i>	<i>Math.max()</i>	<i>System methods</i>
{	<	true	a[]		Math.abs()	System.print()
}	<=	false	length		Math.PI	System.println()
(>	!	new			System.printf()
)	>=	&&				
,	==					
;	!=					
						<i>our Std methods</i>
						StdIn.read*()
						StdOut.print*()
						StdDraw.*()
						StdAudio.*()
						StdRandom.*()

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

Anatomy of your first program



Anatomy of your next several programs



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.
```

```
% javac MyProgram.java  
MyProgram.java:3: invalid method declaration; return type required  
    public static main(String[] args)  
           ^
```

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”.

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

```
% javac MyProgram.java  
MyProgram.java:3: invalid method declaration; return type required  
    public static main(String[] args)  
           ^
```

A. Check HelloWorld. Aha! Forgot “void”.

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

Three versions of the same program.

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



```
*****
 * Compilation:  javac HelloWorld.java
 * Execution:    java HelloWorld
 *
 * Prints "Hello, World". By tradition, this is everyone's first program.
 *
 * % java HelloWorld
 * Hello, World
 *
*****
```

```
public class HelloWorld {

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



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

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

Note on program style

Different styles are appropriate in different contexts.

- Integrated development environment
- Booksite
- 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.

or your boss!

The screenshot shows a web browser window with the URL <http://www.cs.princeton.edu/introcs/11hello>HelloWorld.java.html>. The page title is "HelloWorld.java". The content is a Java program:

```
/*
 * Compilation: javac HelloWorld.java
 * Execution: java HelloWorld
 *
 * Prints "Hello, World". By tradition, this is everyone's first program.
 *
 * % java HelloWorld
 * Hello, World
 *
 * ***** These 17 lines of text
 * they serve to remind
 * us what to type to co
 * the purpose of the pr
 * of the program and th
 * lines in our programs
 *
 */
public class HelloWorld {
    public static void main(String[] args) {
        System.out.print("Hello, World");
        System.out.println();
    }
}
```

Copyright © 2007, Robert Sedgewick
Last updated: Wed Jul 18 09:15:45 E

Program 1.1.1 Hello, World

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

This code is a Java program that accomplishes a simple task. It is traditionally a beginner's first program. The box below shows what happens when you compile and execute the program. The terminal application gives a command prompt (% in this book) and executes the commands that you type (javac and then java in the example below). The result in this case is that the program prints a message in the terminal window (the third line).

```
% javac HelloWorld.java
% java HelloWorld
Hello, World
```

PROGRAM 1.1.1 IS AN EXAMPLE OF A COMPLETE Java program. Its name is `HelloWorld`, which means that its code resides in a file named `HelloWorld.java` (by convention in Java). The program's sole action is to print a message back to the terminal window. For continuity, we will use some standard Java terms to describe the program, but we will not define them until later in the book. PROGRAM 1.1.1 consists of a single class named `HelloWorld` that has a single method named `main()`. This method uses two other methods named `System.out.print()` and `System.out.println()` to do the job. (When referring to a method in the text, we use `()` after the name to distinguish it from other kinds of names.) Until SECTION 2.1, where we learn about classes that define multiple methods, all of our classes will have this same structure. For the time being, you can think of “class” as meaning “program.”

The first line of a method specifies its name and other information; the rest is a sequence of statements enclosed in braces and each followed by a semicolon. For the time being, you can think of “programming” as meaning “specifying a class



COMPUTER SCIENCE

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PART I: PROGRAMMING IN JAVA

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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

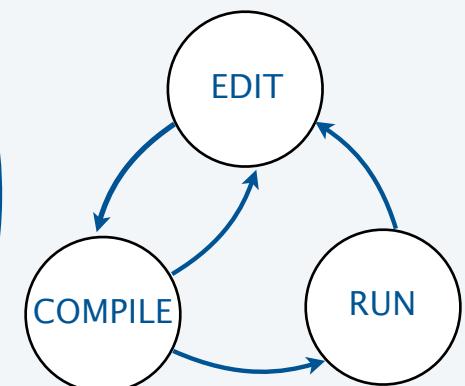
- Create it by typing on your computer's keyboard.
- Result: a text file such as `HelloWorld.java`.

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.
not a legal Java program

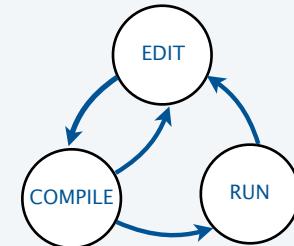
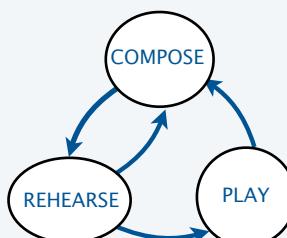
3. RUN your program

- Use the Java runtime.
- Result: your program's output.
- Mistake? Go back to 1. to fix, recompile, and run.
a legal Java program that does the wrong thing



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: Software for editing, compiling and running programs.

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.

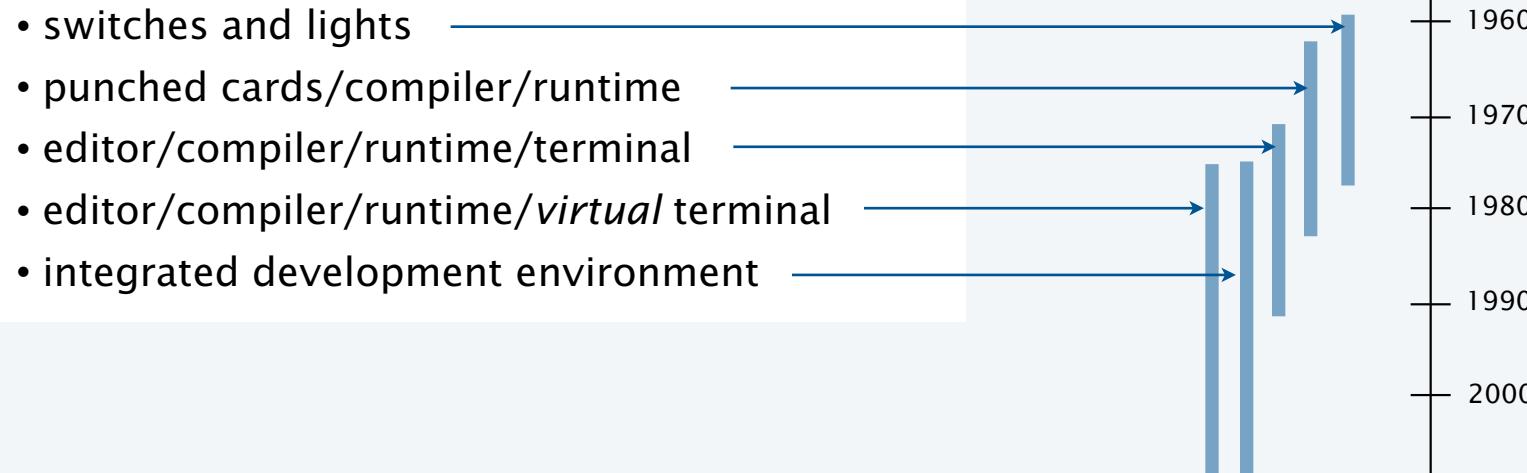
Bottom line: Variety of useful tools.

Program development environments: a very short history

Historical context is important in computer science.

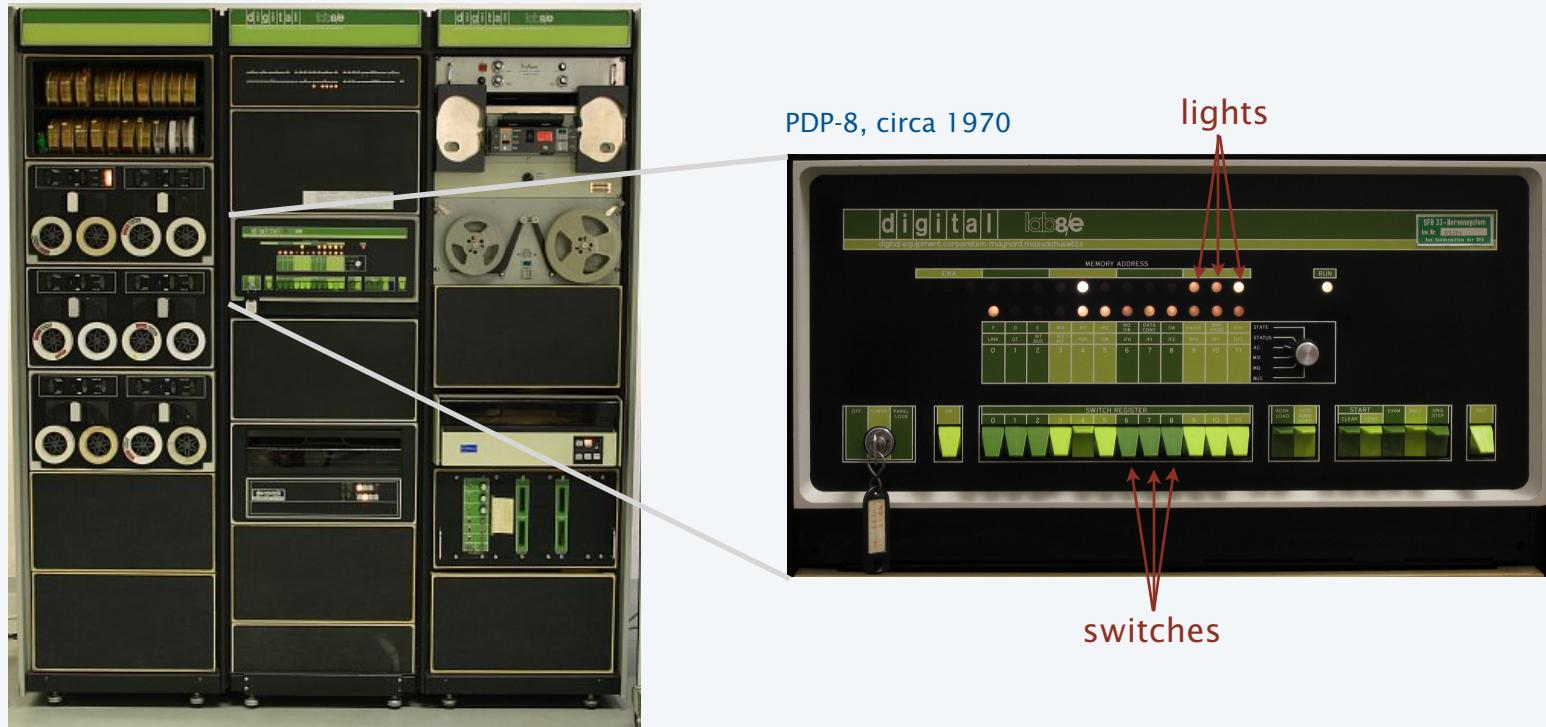
- We regularly use old software.
- We regularly emulate old hardware.
- We depend upon old concepts and designs.

Widely-used methods for program development



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.



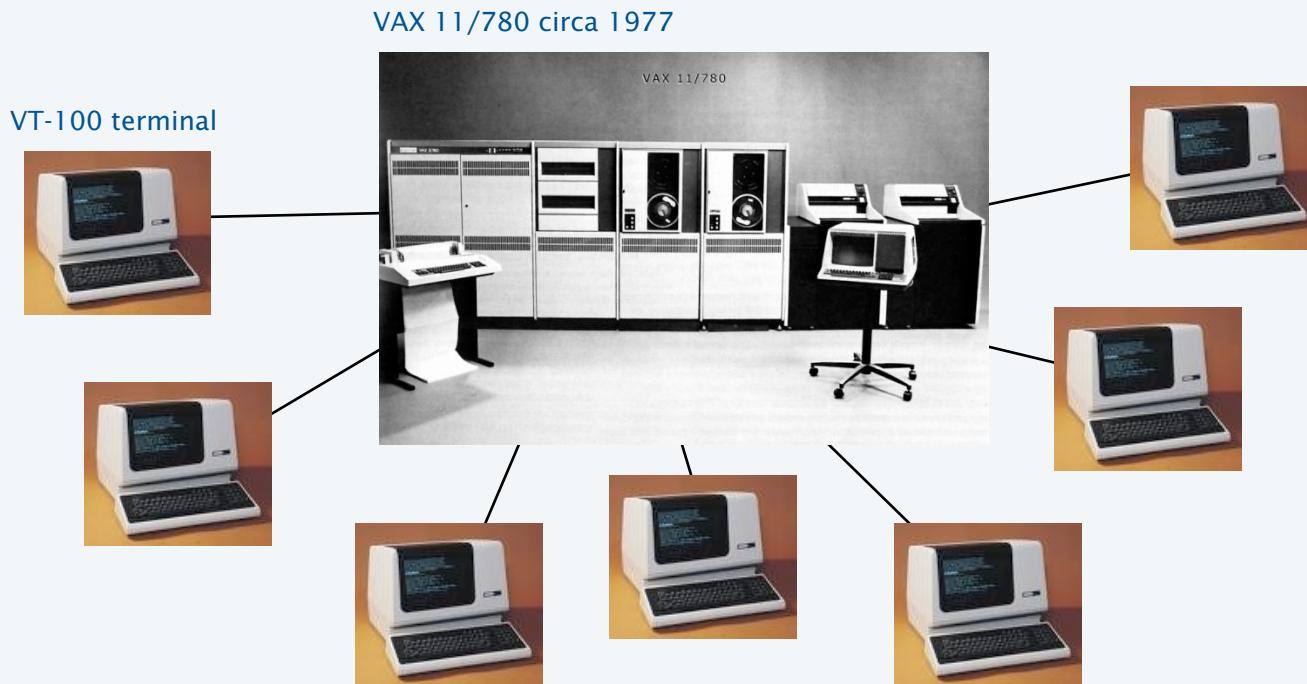
IBM System 360, circa 1975



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.

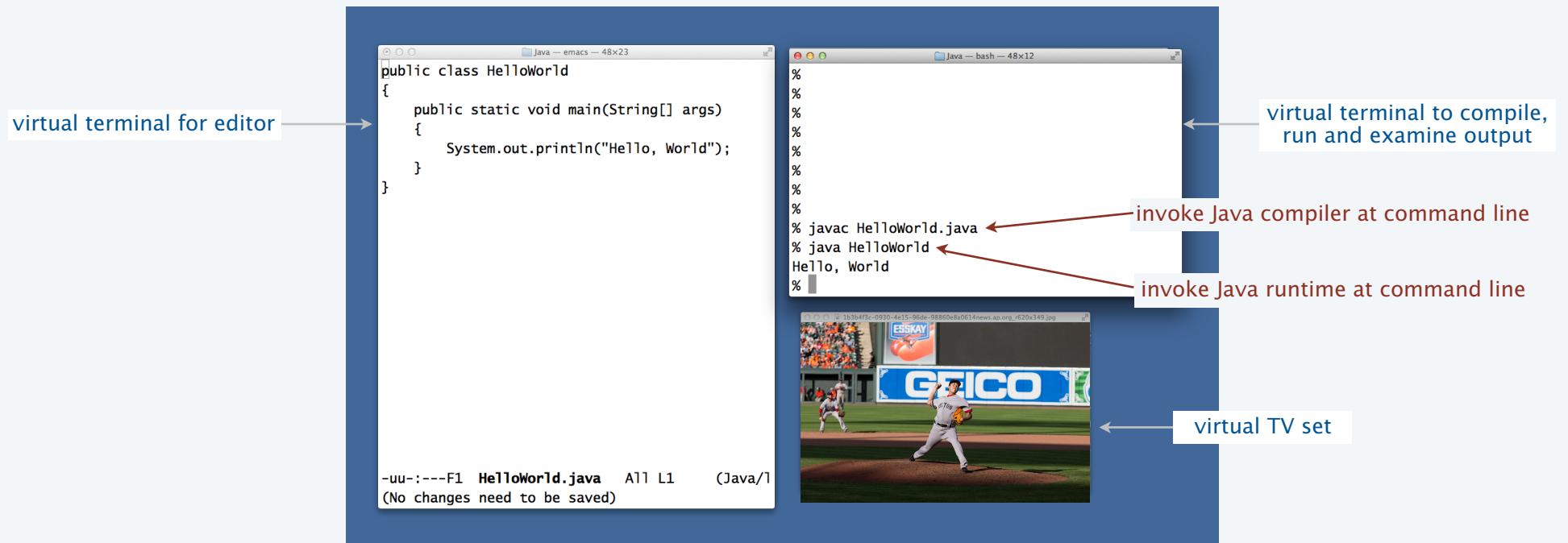


Timesharing allowed many users to share the same computer.

Program development with personal computers (one approach)

1980s to present day: Use multiple *virtual terminals* to interact with computer.

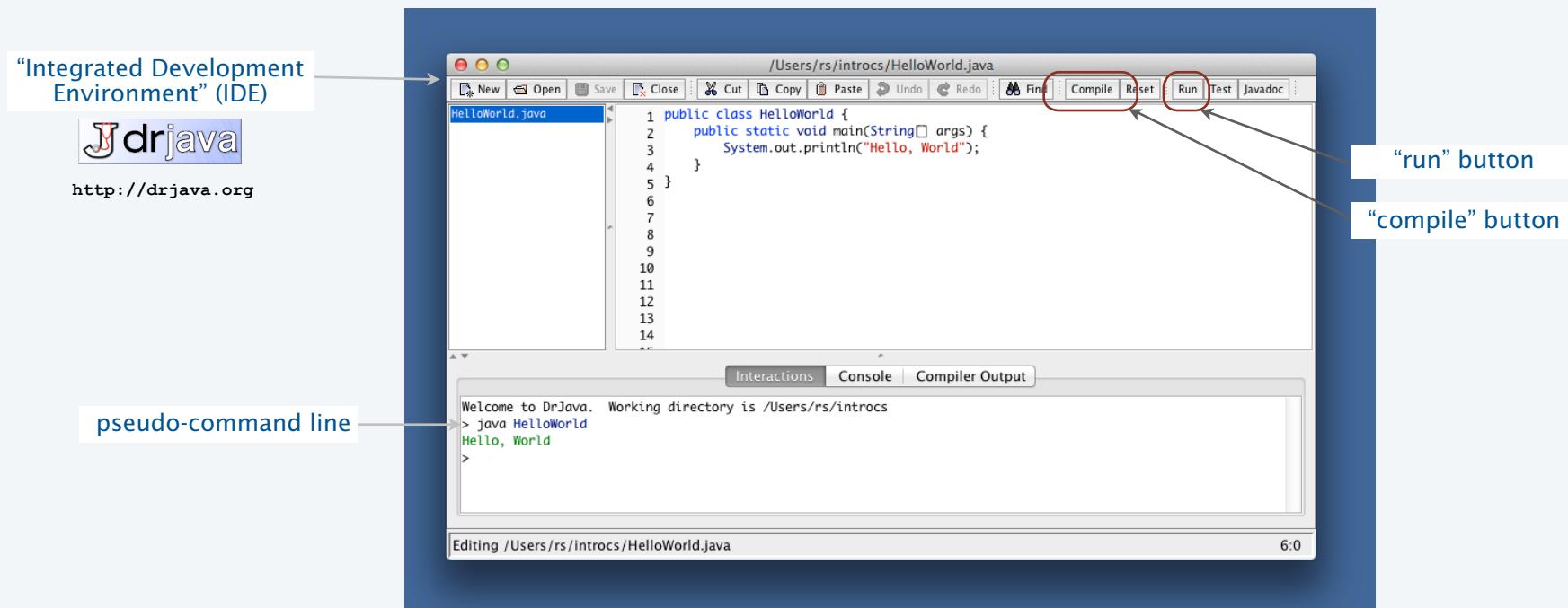
- **Edit** your program using any text editor in a virtual terminal.
- **Compile** it by typing `javac HelloWorld.java` in another virtual terminal.
- **Run** it by typing `java HelloWorld`



Program development with personal computers (another approach)

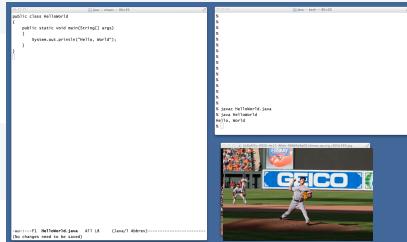
1980s to present day: Use a *customized application* for program development tasks.

- 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

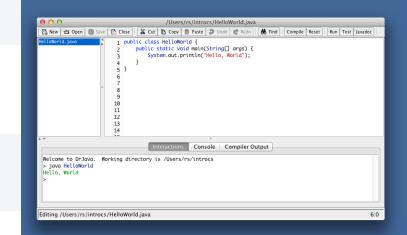
- Approach works with any language.
- Useful beyond programming.
- Used by professionals.
- Has withstood the test of time.

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.

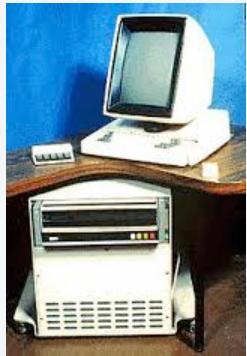
Lessons from short history

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.



Xerox Alto 1978



Apple Macintosh 1984



IBM PC 1990s



Macbook Air 2014



Wintel ultrabooks 2010s



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PART I: PROGRAMMING IN JAVA

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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.

<i>type</i>	<i>set of values</i>	<i>examples of values</i>	<i>examples of operations</i>
char	characters	'A' '@'	compare
String	sequences of characters	"Hello World" "CS is fun"	concatenate
int	integers	17 12345	add, subtract, multiply, divide
double	floating-point numbers	3.1415 6.022e23	add, subtract, multiply, divide
boolean	truth values	true false	and, or, not

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.

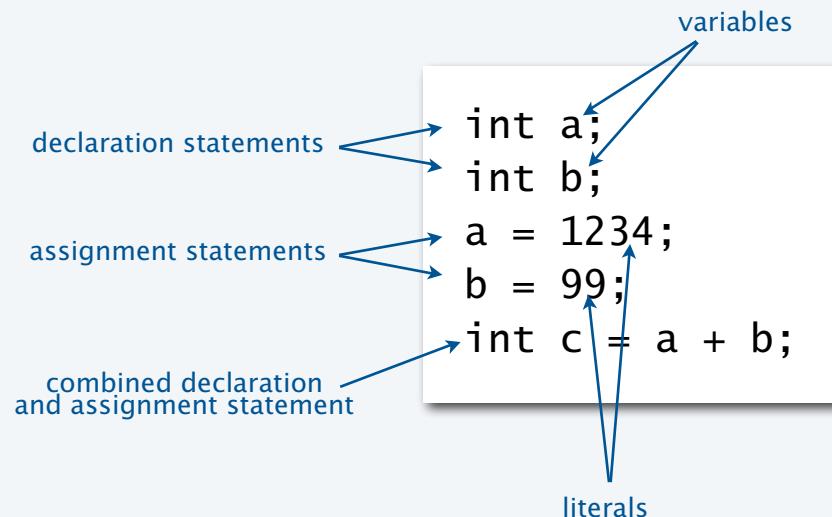
Basic Definitions

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

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

This code exchanges
the values of a and b.

A **trace** is a table of variable values after each statement.

	a	b	t
	undeclared	undeclared	undeclared
int a = 1234;	1234	undeclared	undeclared
int b = 99;	1234	99	undeclared
int t = a;	1234	99	1234
a = b;	99	99	1234
b = t;	99	1234	1234

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

<i>values</i>	sequences of characters
<i>typical literals</i>	"Hello, " "1 " " * "
<i>operation</i>	concatenate
<i>operator</i>	+

Examples of String operations (concatenation)

<i>expression</i>	<i>value</i>
"Hi, " + "Bob"	"Hi, Bob"
"1" + " 2 " + "1"	"1 2 1"
"1234" + " " + "99"	"1234 + 99"
"1234" + "99"	"123499"

Important note:

Character interpretation depends on context!

Ex 1: plus signs

"1234" + " " + " " + "99"
↑ ↑ ↑
operator operator operator
character

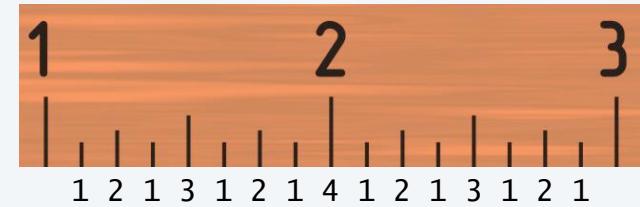
Ex 2: spaces

"1234" + " " + " " + "99"
↑ ↑ ↑
white space white space space characters
operator

Typical use: Input and output.

Example of computing with strings: subdivisions of a ruler

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



```
% java Ruler
1 2 1 3 1 2 1 4 1 2 1 3 1 2 1
```

	ruler1	ruler2	ruler3	ruler4
	undeclared	undeclared	undeclared	undeclared
ruler1 = "1";	1	undeclared	undeclared	undeclared
ruler2 = ruler1 + " 2 " + ruler1;	1	1 2 1	undeclared	undeclared
ruler3 = ruler2 + " 3 " + ruler2;	1	1 2 1	1 2 1 3 1 2 1	undeclared
ruler4 = ruler3 + " 4 " + ruler3;				1 2 1 3 1 2 1 4 1 2 1 3 1 2 1

Input and output

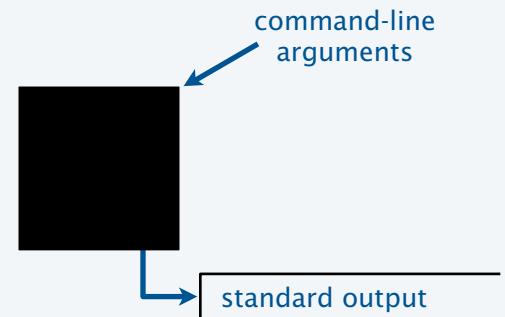
is necessary for us to provide data to our programs and to learn the result of computations.

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.



Bird's eye view of a Java program

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

```
public 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);
    }
}
```

Java automatically converts int values to String for output

```
% java Exchange 5 2
```

```
2  
5
```

```
% java Exchange 1234 99
```

```
99  
1234
```

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

int data type

values	integers between -2^{31} and $2^{31}-1$				
typical literals	1234 99 0 1000000				
operations	add	subtract	multiply	divide	remainder
operator	+	-	*	/	%

Important note:

Only 2^{32} different int values.



not quite the same as integers

Examples of int operations

expression	value	comment
5 + 3	8	
5 - 3	2	
5 * 3	15	
5 / 3	1	drop fractional part
5 % 3	2	remainder
1 / 0		runtime error

Precedence

expression	value	comment
3 * 5 - 2	13	* has precedence
3 + 5 / 2	5	/ has precedence
3 - 5 - 2	-4	left associative
(3 - 5) - 2	-4	better style

Typical usage: Math calculations; specifying programs (stay tuned).

Example of computing with integers and strings, with type conversion

```
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

```
% java IntOps 5 2
5 + 2 = 7
5 * 2 = 10
5 / 2 = 2
5 % 2 = 1
```

```
% java IntOps 1234 99
1234 + 99 = 1333
1234 * 99 = 122166
1234 / 99 = 12
1234 % 99 = 46
```

Note: $1234 = 12 \times 99 + 46$

Data type for computing with floating point numbers: double

double data type

values	real numbers				
typical literals	3.14159	2.0	1.4142135623730951	6.022e23	6.022×10^{23}
operations	add	subtract	multiply	divide	remainder
operator	+	-	*	/	%

Examples of double operations

expression	value
3.141 + .03	3.171
3.141 - .03	3.111
6.02e23/2	3.01e23
5.0 / 3.0	1.6666666666666667
10.0 % 3.141	0.577
Math.sqrt(2.0)	1.4142135623730951

Typical double values are *approximations*

Examples:

- no `double` value for π .
- no `double` value for $\sqrt{2}$
- no `double` value for $1/3$.

Special values

expression	value
1.0 / 0.0	Infinity
Math.sqrt(-1.0)	NaN

"not a number"

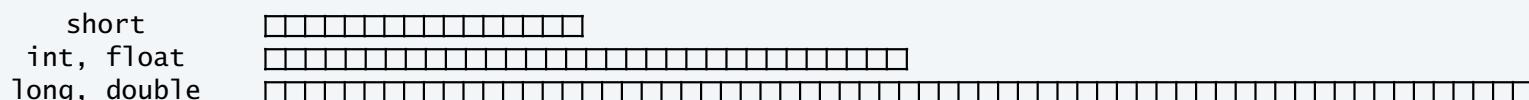
Typical use: Scientific calculations.

Other built-in numeric types

short data type		long data type	
<i>values</i>	integers between -2^{15} and $2^{15}-1$	<i>values</i>	integers between -2^{63} and $2^{63}-1$
<i>operations</i>	[same as int]	<i>operations</i>	[same as int]
float data type			
<i>values</i>	real numbers		
<i>operations</i>	[same as double]		

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

public class Math	
double abs(double a)	<i>absolute value of a</i>
double max(double a, double b)	<i>maximum of a and b</i>
double min(double a, double b)	<i>minimum of a and b</i>
double sin(double theta)	<i>sine function</i>
double cos(double theta)	<i>cosine function</i>
double tan(double theta)	<i>tangent function</i>
	Degrees in radians. Use <code>toDegrees()</code> and <code>toRadians()</code> to convert.
double exp(double a)	<i>exponential (e^a)</i>
double log(double a)	<i>natural log ($\log_e a$, or $\ln a$)</i>
double pow(double a, double b)	<i>raise a to the bth power (a^b)</i>
long round(double a)	<i>round to the nearest integer</i>
double random()	<i>random number in $[0..1]$</i>
double sqrt(double a)	<i>square root of a</i>
double E	<i>value of e (constant)</i>
double PI	<i>value of π (constant)</i>



You can discard your calculator now (please).

Example of computing with floating point numbers: quadratic equation

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

```
public 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*x + b*x + c.
        double discriminant = b*b - 4.0*c;
        double d = Math.sqrt(discriminant);
        double root1 = (-b + d) / 2.0;
        double root2 = (-b - d) / 2.0;

        // Print them out.
        System.out.println(root1);
        System.out.println(root2);
    }
}
```

```
% java Quadratic -3.0 2.0
2.0
1.0
x2 - 3x + 2

% java Quadratic -1.0 -1.0
1.618033988749895
-0.6180339887498949
x2 - x - 1

% java Quadratic 1.0 1.0
NaN
NaN
x2 + x + 1

% java Quadratic 1.0 hello
java.lang.NumberFormatException: hello

% java Quadratic 1.0
java.lang.ArrayIndexOutOfBoundsException
```

Need two arguments.
(Fact of life: Not all error messages are crystal clear.)

Data type for computing with true and false: boolean

boolean data type

<i>values</i>	true	false	
<i>literals</i>	true	false	
<i>operations</i>	and	or	not
<i>operator</i>	&&		!

Truth-table definitions

a	!a	a	b	a && b	a b
true	false	false	false	false	false
false	true	false	true	false	true
		true	false	false	true
		true	true	true	true

Q. a XOR b?

Recall first lecture

A. $(\neg a \&\& b) \mid\mid (a \&\& \neg b)$

Proof

a	b	$\neg a \&\& b$	$a \&\& \neg b$	$(\neg a \&\& b) \mid\mid (a \&\& \neg b)$
false	false	false	false	false
false	true	true	false	true
true	false	false	true	true
true	true	false	false	false

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.

operator	meaning	true	false
<code>==</code>	equal	<code>2 == 2</code>	<code>2 == 3</code>
<code>!=</code>	not equal	<code>3 != 2</code>	<code>2 != 2</code>
<code><</code>	less than	<code>2 < 13</code>	<code>2 < 2</code>
<code><=</code>	less than or equal	<code>2 <= 2</code>	<code>3 <= 2</code>
<code>></code>	greater than	<code>13 > 2</code>	<code>2 < 13</code>
<code>>=</code>	greater than or equal	<code>3 >= 2</code>	<code>2 >= 3</code>

Examples

non-negative discriminant?

`(b*b - 4.0*a*c) >= 0.0`

Typical double values are approximations so beware of `==` comparisons

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.

```
public class LeapYear
{
    public static void main(String[] args)
    {
        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);
    }
}
```

```
% java LeapYear 2016
true
```

```
% java LeapYear 1993
false
```

```
% java LeapYear 1900
false
```

```
% java LeapYear 2000
true
```



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PART I: PROGRAMMING IN JAVA

Image sources

http://commons.wikimedia.org/wiki/File:Calculator_casio.jpg

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.

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

```
% javac BadCode.java
BadCode.java:5: operator * cannot be applied to java.lang.String,int
        String s = "123" * 2;
                           ^
1 error
```

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 "+".
- Make numeric types match if no loss of precision.

expression	type	value
"x: " + 99	String	"x: 99"
11 * 0.25	double	2.75

Explicitly defined for function call.

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.

(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) * 2.0`

b. `(7 / 2.0) * 2`

c. `"2" + 2`

d. `2.0 + "2"`

Pop quiz on type conversion

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

a. `(7 / 2) * 2.0` 6.0, a **double** (7/2 is 3, an **int**)

b. `(7 / 2.0) * 2` 7.0, a **double**

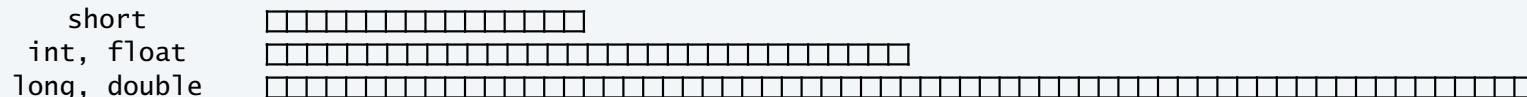
c. `"2" + 2` 22, a **String**

d. `2.0 + "2"` 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.



First launch of Ariane 5, 1996

Example of type conversion put to good use: pseudo-random integers

System method `Math.random()` returns a pseudo-random `double` value in $[0, 1)$.

Problem: Given N , generate a pseudo-random *integer* between 0 and $N-1$.

```
public class RandomInt
{
    public static void main(String[] args)
    {
        int N = Integer.parseInt(args[0]);           ← String to int (system method)
        double r = Math.random();
        int t = (int) (r * N);                      ← int to double (automatic)
        System.out.println(t);
    }
}
```

Annotations in the code:

- `String to int (system method)`: Points to the call to `Integer.parseInt(args[0])`.
- `double to int (cast)`: Points to the cast from `double` to `int` in the assignment `t = (int) (r * N);`.
- `int to double (automatic)`: Points to the implicit conversion from `int` back to `double` when multiplying by `r`.

```
% java RandomInt 6  
3
```

```
% java RandomInt 6  
0
```

```
% java RandomInt 10000  
3184
```

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.

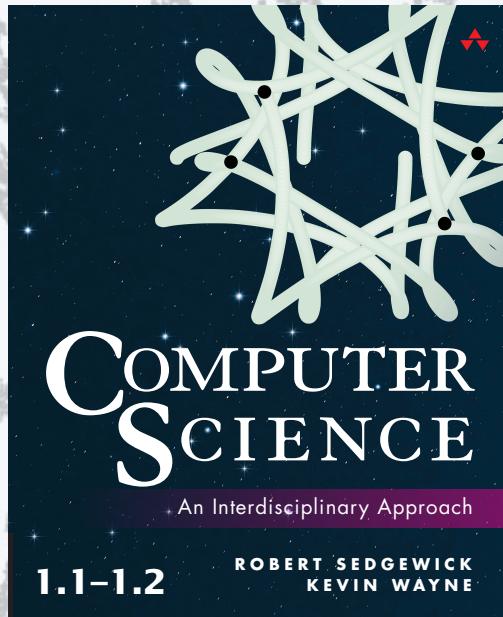
Pay attention to the type of your data.



The Java compiler is your *friend*: it will help you identify and fix type errors in your code.



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1. Basic Programming Concepts