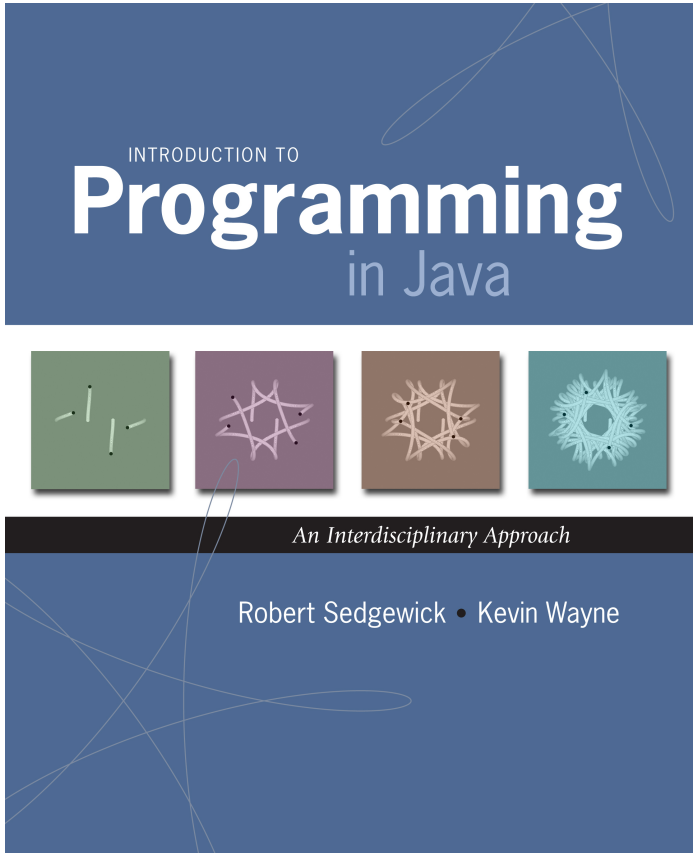
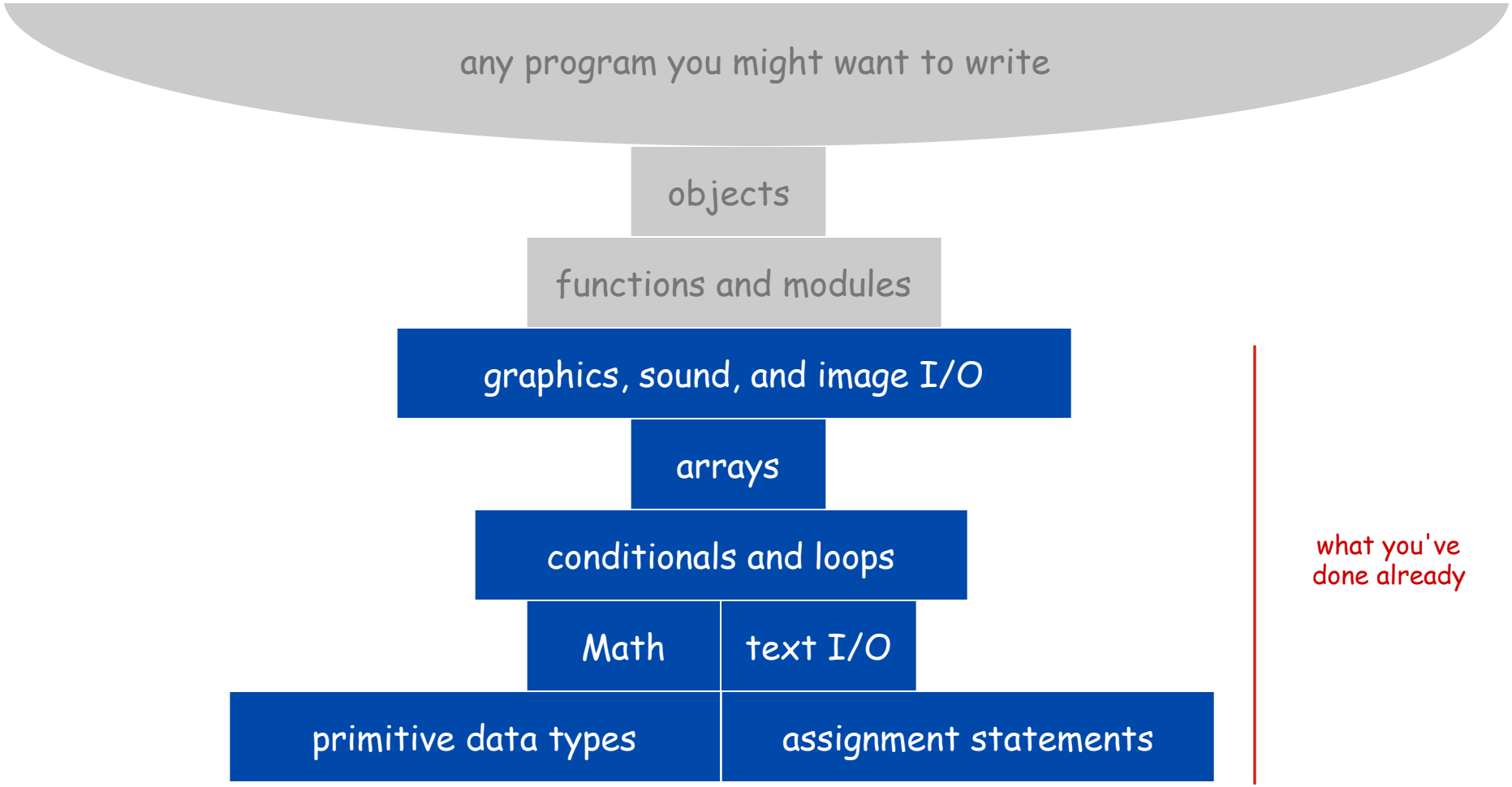
# Program Development



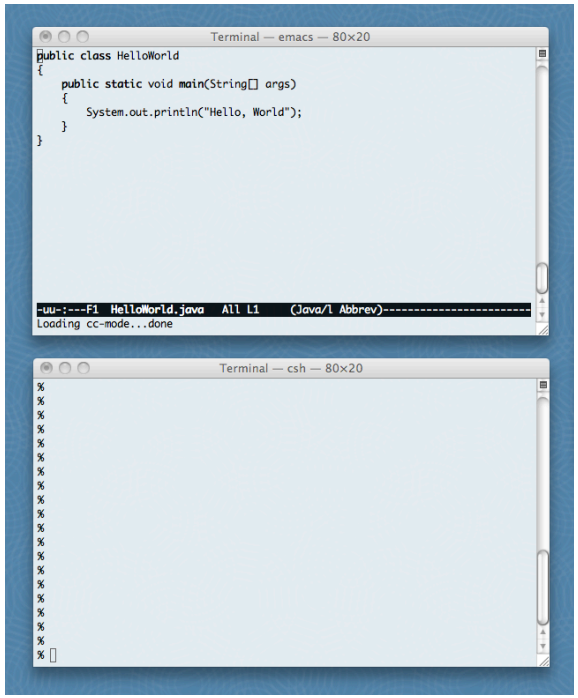
# A Foundation for Programming



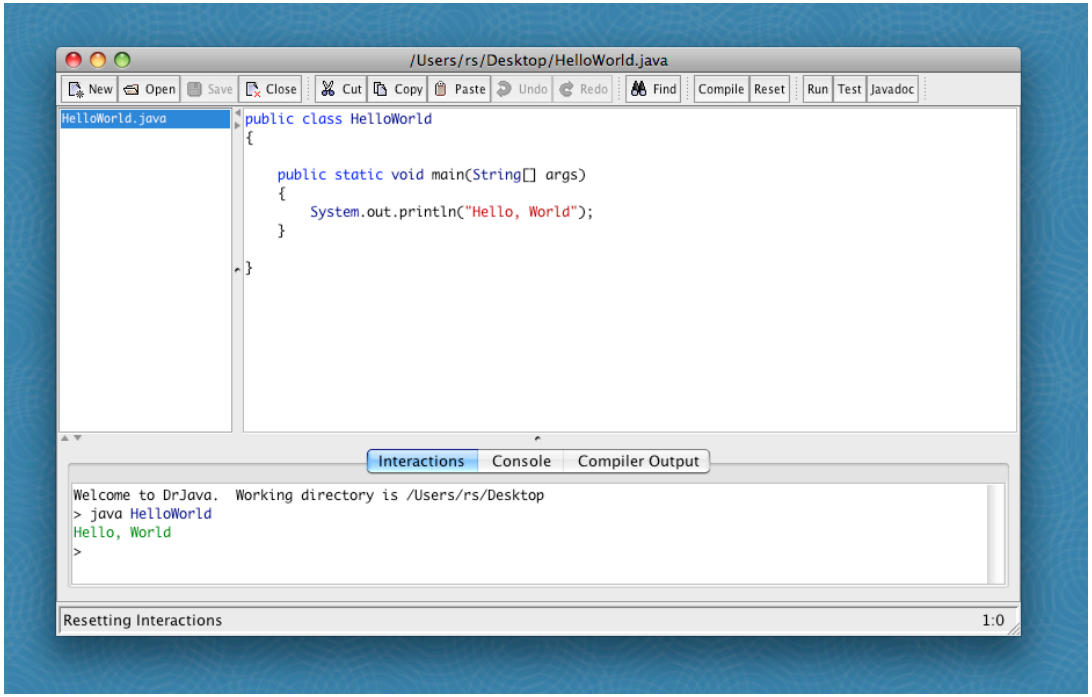
# Program Development

**Program development.** Creating a program and putting it to good use.

**Program development environment.** Software to support cycle of editing, compiling, and executing programs.




command line




Dr. Java

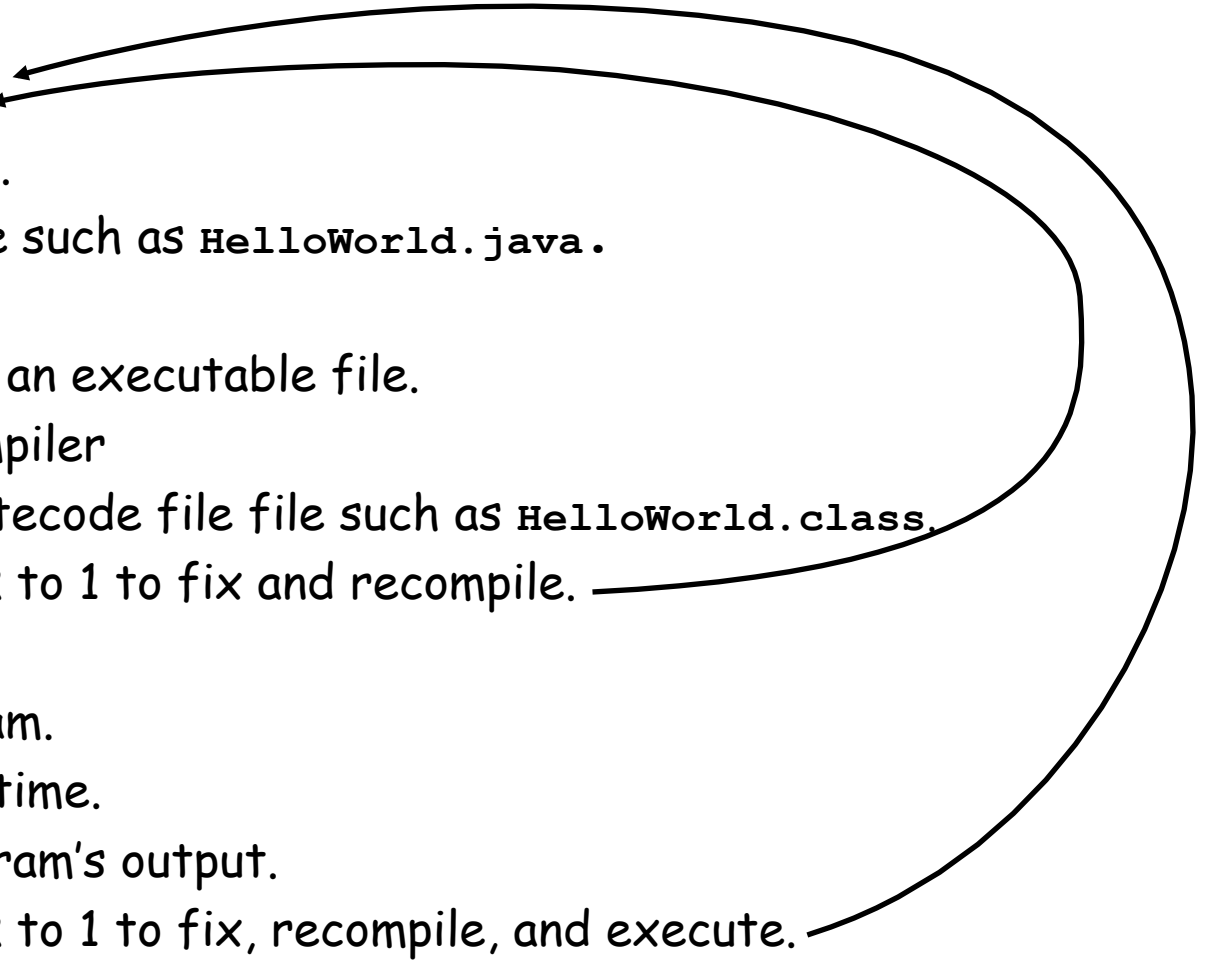
# Program Development in Java

0. Think about your problem.

1. Edit your program.
   - Use a text editor.
   - 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 file such as `HelloWorld.class`.
   - Mistake? Go back to 1 to fix and recompile.

3. Execute your program.
   - Use the Java runtime.
   - Result: your program's output.
   - Mistake? Go back to 1 to fix, recompile, and execute.

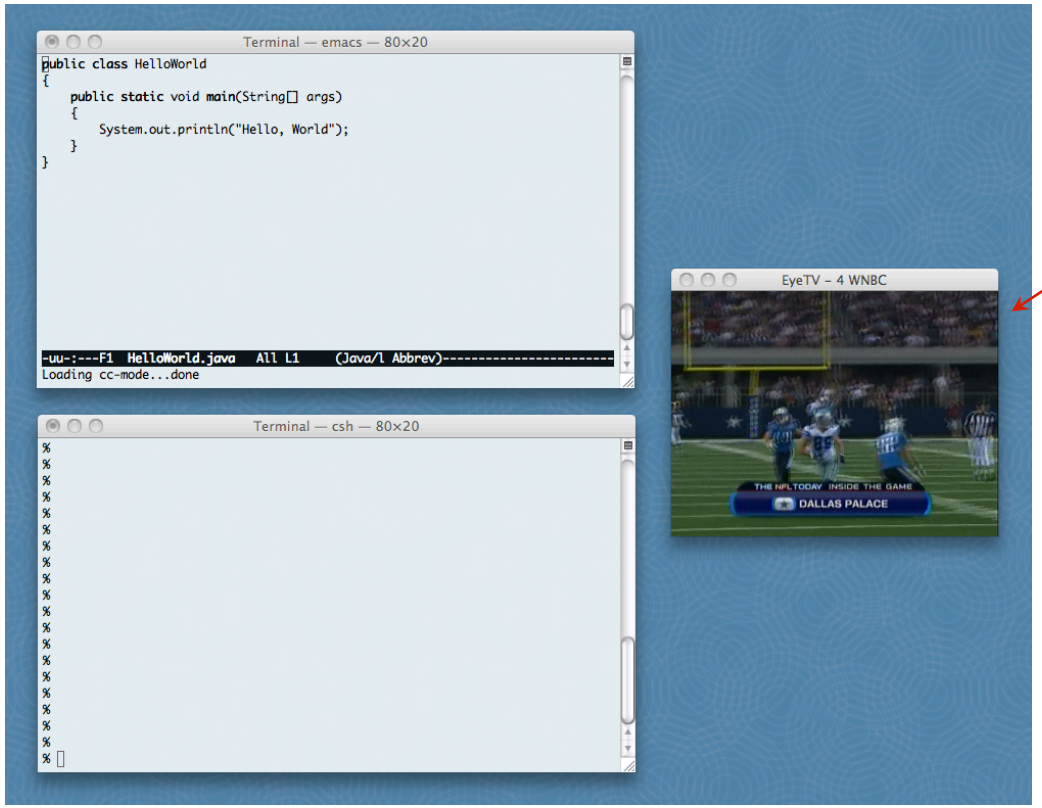


# Program Development in Java (using command line)

1. Edit your program using any text editor.
2. Compile it to create an executable file.
3. Execute your program.


editor running in virtual terminal →

second terminal for commands →

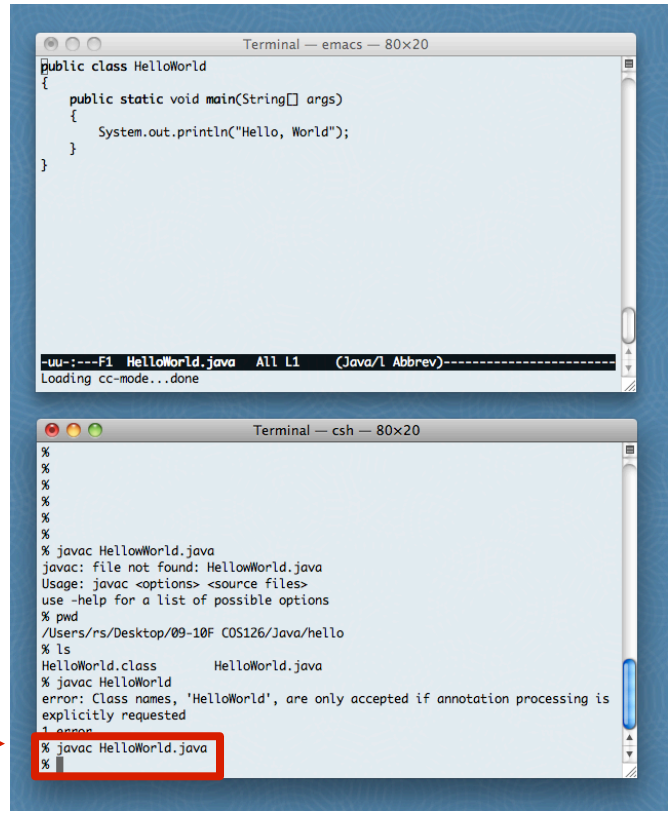



virtual TV ←

# Program Development in Java (using command line)

1. Edit your program.
2. Compile it by typing `javac HelloWorld.java` at the command line.
3. Execute your program.

creates `HelloWorld.class`

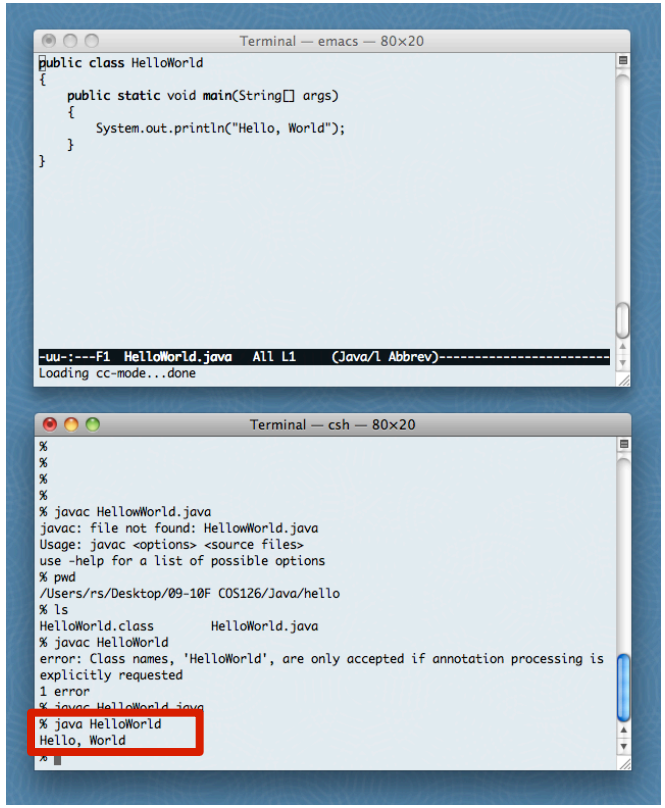



invoke Java compiler at command line

# Program Development in Java (using command line)

1. Edit your program.
2. Compile it to create an executable file.
3. Execute by typing `java HelloWorld` at the command line.

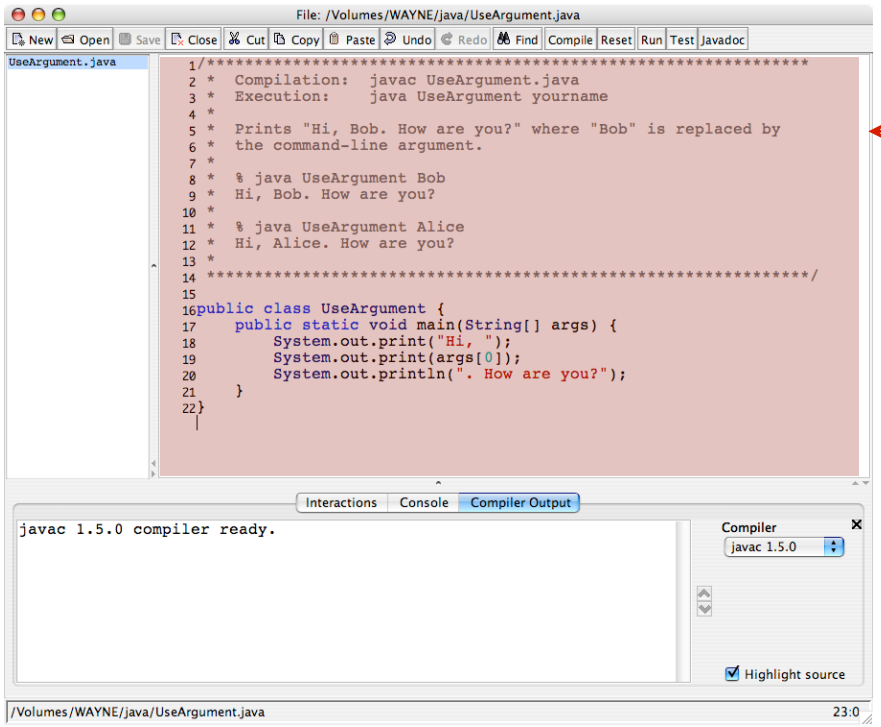
uses `HelloWorld.class`




invoke Java runtime at command line

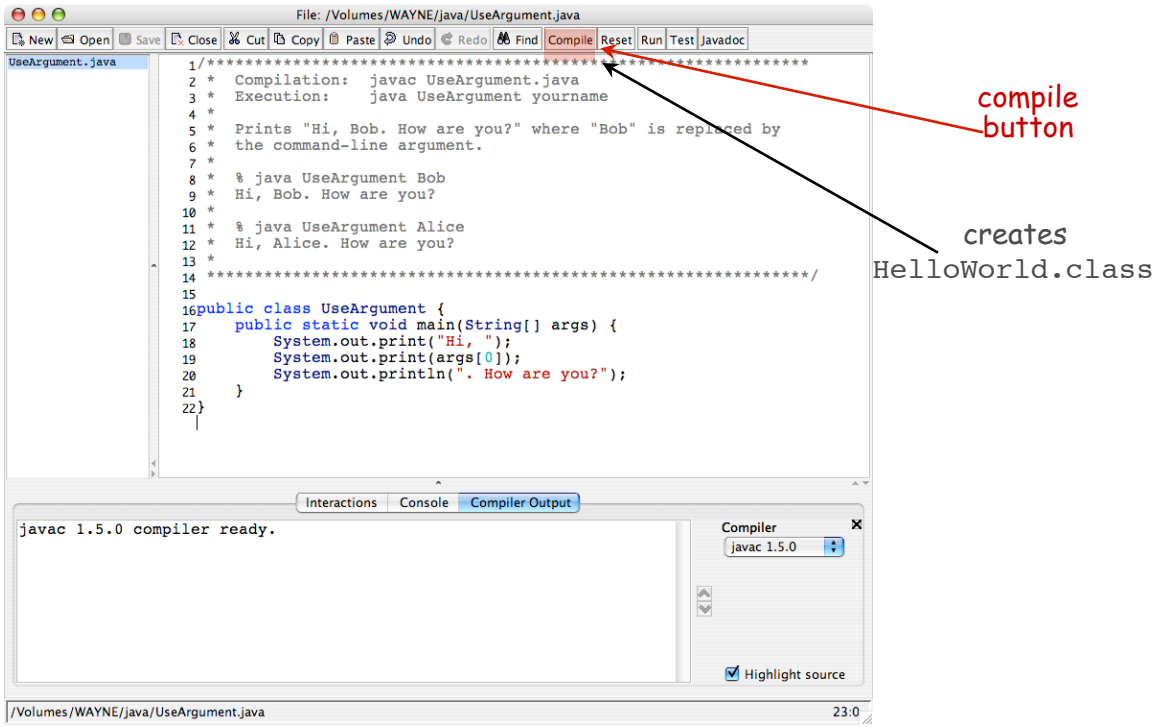
# Program Development in Java (using Dr. Java)

1. Edit your program using the built-in text editor.
2. Compile it to create an executable file.
3. Execute your program.



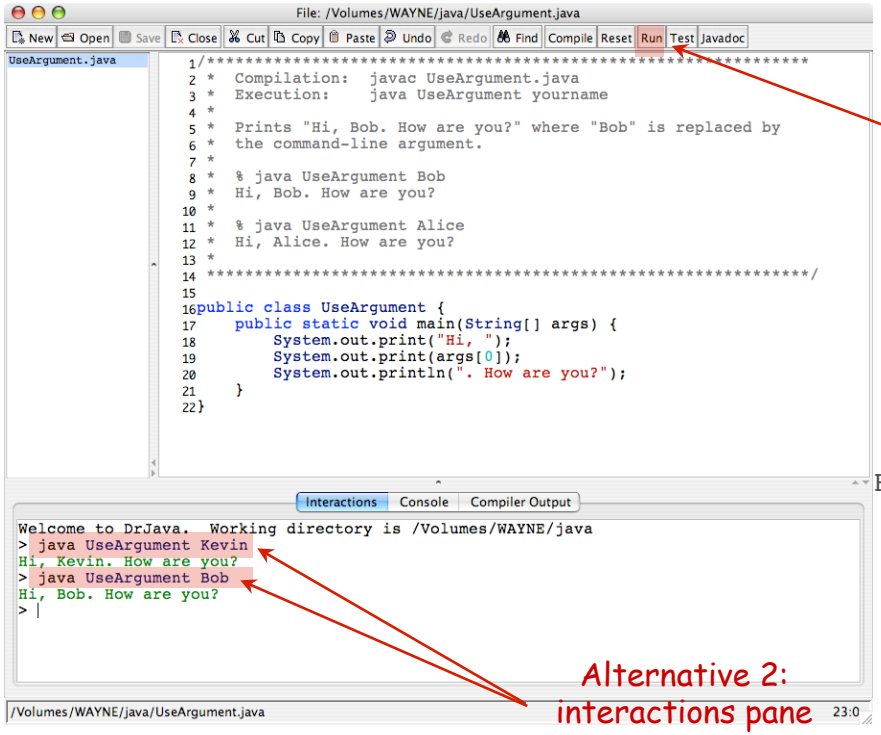
# Program Development in Java (using Dr. Java)

1. Edit your program.
2. Compile it by clicking the "compile" button.
3. Execute your program.



# Program Development in Java (using Dr. Java)

1. Edit your program.
2. Compile it to create an executable file.
3. Execute by clicking the "run" button or using Interactions pane.




Alternative 1: run button (ok if no args)

both use `HelloWorld.class`

Alternative 2: interactions pane (to provide args)

# A Short History

# Program Development Environments: A Short History

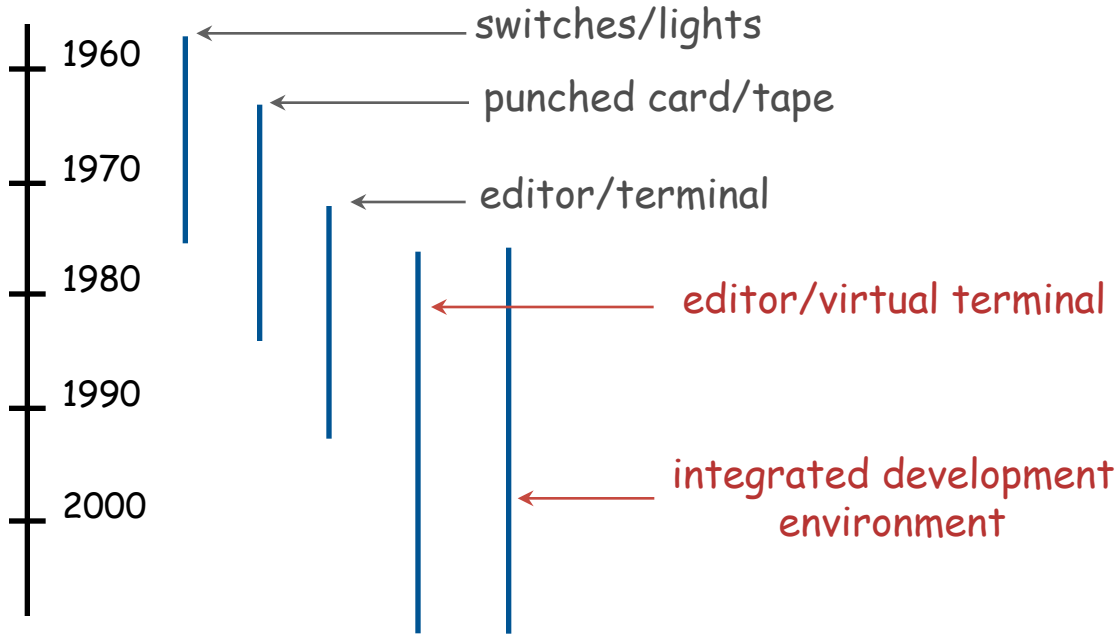
Historical context is important in computer science.

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

First requirement in any computer system: program development.

Widely-used methods:

- Switches/lights.
- Punched cards.
- Terminal.
- Editor/virtual terminal.
- IDE.



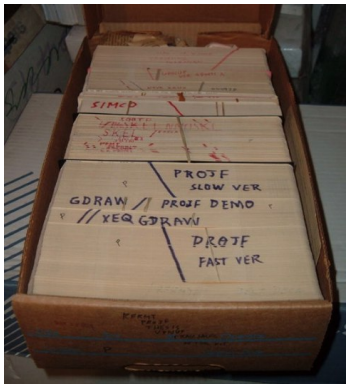
# Switches and Lights

Use switches to enter binary program code, lights to read results.

PDP-8, circa 1970

# Punched Cards / Line Printer

Use punched cards for program code, line printer for output.




IBM System 360, circa 1975

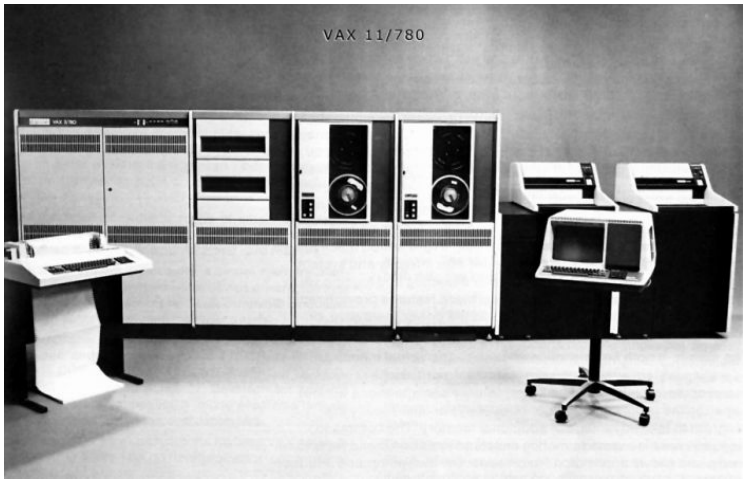



15

# Timesharing Terminal

Use terminal for editing program, reading output, and controlling computer.

VAX 11/780 circa 1977

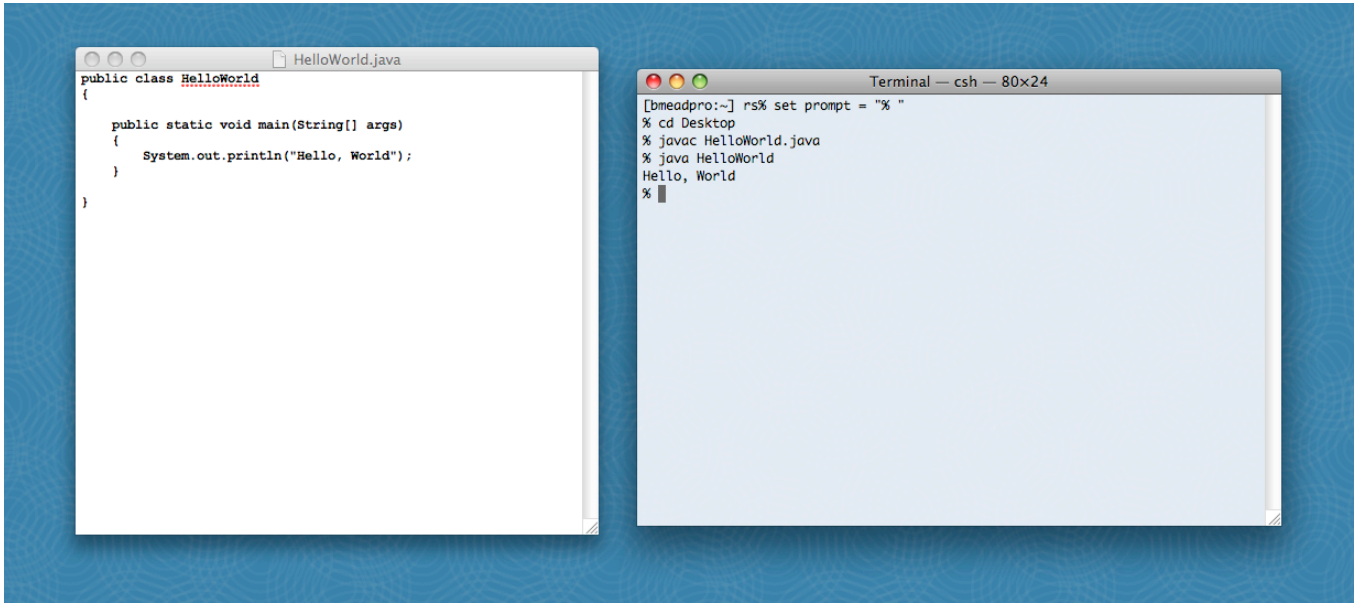



VT-100 terminal

Timesharing: allowed many people to simultaneously use a single machine.

# Editor and Virtual Terminal on a Personal Computer

Use an editor to create and make changes to the program text.
Use a virtual terminal to invoke the compiler and run the executable code.




Pros. Works with any language, useful for other tasks, used by pros.
Cons. Good enough for large projects?

# Integrated Development Environment

Use a customized application for all program development tasks.

Ex 1. DrJava.


- Ideal for novices.
- Easy-to-use language-specific tools.

Ex 2. Eclipse.


- Widely used by professionals.
- Powerful debugging and style-checking tools.
- Steep learning curve.
- Overkill for short programs.

# Lessons from Short History

First requirement in any computer system: program development.

Program development environment must support cycle of editing, compiling, and executing programs.

Two approaches that have served for decades:

- Editor and virtual terminal.
- Integrated development environment.

Xerox Alto 1978

Macbook Air 2008

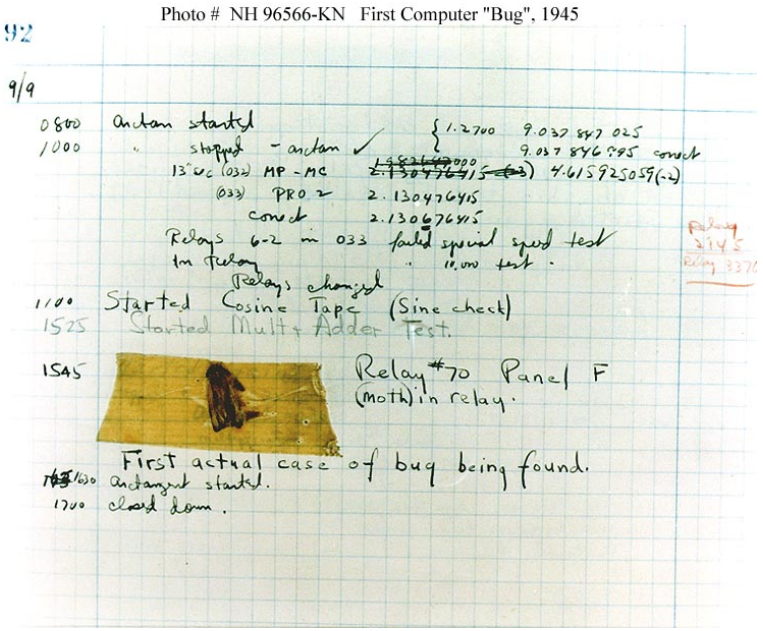
# Debugging

Admiral Grace Murray Hopper

# 95% of Program Development

Def. A bug is a mistake in a computer program.

Programming is primarily a process of finding and fixing bugs.




Good news. Can use computer to test program.

Bad news. Cannot use computer to automatically find all bugs.

profound idea [stay tuned]

# 95% of Program Development

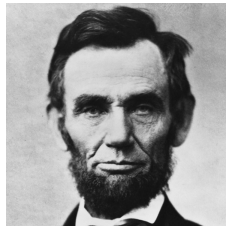
Debugging. Always a logical explanation.

- What would the machine do?
- Explain it to the teddy bear.

You will make many mistakes as you write programs. It's normal.

> *"As soon as we started programming, we found out to our surprise that it wasn't as easy to get programs right as we had thought. I can remember the exact instant when I realized that a large part of my life from then on was going to be spent in finding mistakes in my own programs."* — *Maurice Wilkes*

> *"If I had eight hours to chop down a tree, I would spend six hours sharpening an axe."* — *Abraham Lincoln*



# Debugging Example

Factor. Given an integer $N > 1$, compute its prime factorization.

$$3{,}757{,}208 = 2^3 \times 7 \times 13^2 \times 397$$

$$98 = 2 \times 7^2$$

$$17 = 17$$

$$11{,}111{,}111{,}111{,}111 = 2{,}071{,}723 \times 5{,}363{,}222{,}357$$

Application. Break RSA cryptosystem (factor 200-digit numbers).

# Debugging Example

Factor. Given an integer N > 1, compute its prime factorization.

Brute-force algorithm. For each putative factor i = 2, 3, 4, …, check if N is a multiple of i, and if so, divide it out.

| i | N | *output* | i | N | *output* | i | N | *output* |
|---|---|---|---|---|---|---|---|---|
| 2 | 3757208 | 2 2 2 | 9 | 67093 | | 16 | 397 | |
| 3 | 469651 | | 10 | 67093 | | 17 | 397 | |
| 4 | 469651 | | 11 | 67093 | | 18 | 397 | |
| 5 | 469651 | | 12 | 67093 | | 19 | 397 | |
| 6 | 469651 | | 13 | 67093 | 13 13 | 20 | 397 | |
| 7 | 469651 | 7 | 14 | 397 | | | | 397 |
| 8 | 67093 | | 15 | 397 | | | | |

3757208/8

# Debugging: 95% of Program Development

Programming. A process of finding and fixing mistakes.

- Compiler error messages help locate syntax errors.
- Run program to find semantic and performance errors.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0])
      for (i = 0; i < n; i++) {
         while (n % i == 0)
            StdOut.print(i + " ")
            n = n / i

      }
   }
}
```

check if i is a factor

as long as i is a factor, divide it out

this program has many bugs!

# Debugging: Syntax Errors

Syntax error. Illegal Java program.

- Compiler error messages help locate problem.
- Goal: no errors and a file named `Factors.class`.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0])
      for (i = 0; i < n; i++) {
         while (n % i == 0)
            StdOut.print(i + " ")
            n = n / i

      }
   }
}
```

```
% javac Factors.java
Factors.java:4: ';' expected
      for (i = 0; i < n; i++)
      ^
1 error
```

the first error

# Debugging: Syntax Errors

Syntax error. Illegal Java program.

- Compiler error messages help locate problem.
- Goal: no errors and a file named `Factors.class`.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 0; i < n; i++) {
         while (n % i == 0)
            StdOut.print(i + " ");
            n = n / i;
      }
   }
}
```

need to declare variable i

need terminating semicolons

syntax (compile-time) errors

# Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

- Run program to identify problem.
- Add print statements if needed to produce trace.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 0; i < n; i++) {
         while (n % i == 0)
            StdOut.print(i + " ");
            n = n / i;
      }
   }
}
```

```
% javac Factors.java
% java Factors                    <-- oops, no argument
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: 0
        at Factors.main(Factors.java:5)
```

# Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

- Run program to identify problem.
- Add print statements if needed to produce trace.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 0; i < n; i++) {
         while (n % i == 0)
            StdOut.print(i + " ");
            n = n / i;
      }
   }
}
```

need to start at 2 because 0 and 1 cannot be factors

```
% javac Factors.java
% java Factors 98
Exception in thread "main"
java.lang.ArithmeticExeption: / by zero
        at Factors.main(Factors.java:8)
```

# Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

- Run program to identify problem.
- Add print statements if needed to produce trace.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 2; i < n; i++) {
         while (n % i == 0)
            StdOut.print(i + " ");
            n = n / i;
      }
   }
}
```

indents do not imply braces

```
% javac Factors.java
% java Factors 13
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 ...
```

infinite loop!

# Debugging: The Beat Goes On

Success. Program factors $98 = 2 \times 7^2$.

- But that doesn't mean it works for all inputs.
- Add trace to find and fix (minor) problems.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 2; i < n; i++) {
         while (n % i == 0) {
            StdOut.print(i + " ");
            n = n / i;
         }
      }
   }
}
```

```
% java Factors 98
2 7 7 %
```
need newline

```
% java Factors 5
```
??? no output

```
% java Factors 6
2 %
```
??? missing the 3

# Debugging: The Beat Goes On

Success. Program factors $98 = 2 \times 7^2$.

- But that doesn't mean it works for all inputs.
- Add trace to find and fix (minor) problems.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 2; i < n; i++) {
         while (n % i == 0) {
            StdOut.println(i + " ");
            n = n / i;
         }
         StdOut.println("TRACE: " + i + " " + n);
      }
   }
}
```

```
% java Factors 5
TRACE 2 5
TRACE 3 5
TRACE 4 5

% java Factors 6
2
TRACE 2 3
```

Aha!
i loop should
go up to n

# Debugging: Success?

Success. Program now seems to work.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 2; i <= n; i++) {
         while (n % i == 0) {
            StdOut.print(i + " ");
            n = n / i;
         }
      }
      StdOut.println();
   }
}
```

```
% java Factors 5
5

% java Factors 6
2 3

% java Factors 98
2 7 7

% java Factors 3757208
2 2 2 7 13 13 397
```

# Debugging: Performance Error

Performance error. Correct program, but too slow.

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 2; i <= n; i++) {
         while (n % i == 0) {
            StdOut.print(i + " ");
            n = n / i;
         }
      }
      StdOut.println();
   }
}
```

```
% java Factors 11111111
11 73 101 137

% java Factors 11111111111
21649 51329

% java Factors 111111111111
11 239 4649 909091

% java Factors 1111111111111111
2071723 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 …
```

# Debugging: Performance Error

Performance error. Correct program, but too slow.

Solution. Improve or change underlying algorithm.

fixes performance error:
if n has a factor, it has one
less than or equal to its square root

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 2; i <= n/i; i++) {
         while (n % i == 0) {
            StdOut.print(i + " ");
            n = n / i;
         }
      }
      StdOut.println();
   }
}
```

```
% java Factors 98
2 7 7

% java Factors 11111111
11 73 101

% java Factors 11111111111111
11 239 4649

% java Factors 1111111111111111
2071723
```

missing last factor
(sometimes)

# Debugging: Performance Error

Caveat. Optimizing your code tends to introduce bugs.

Lesson. Don't optimize until it's absolutely necessary.

need special case to print biggest factor (unless it occurs more than once)

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (int i = 2; i <= n/i; i++) {
         while (n % i == 0) {
            StdOut.print(i + " ");
            n = n / i;
         }
      }
      if (n > 1) System.out.println(n);
      else       System.out.println();
   }
}
```

"corner case"

```
% java Factors 11111111
11 73 101 137

% java Factors 11111111111
21649 51329

% java Factors 111111111111
11 239 4649 909091

% java Factors 1111111111111111
2071723 5363222357
```

# Program Development: Analysis

Q. How large an integer can I factor?

```
% java Factors 3757208
2 2 2 7 13 13 397

% java Factors 92011111169755555703
92011111169755555703
```

after a few minutes of computing....

largest factor

| digits | (i <= N) | (i <= N/i) |
|---|---|---|
| 3 | instant | instant |
| 6 | 0.15 seconds | instant |
| 9 | 77 seconds | instant |
| 12 | 21 hours † | 0.16 seconds |
| 15 | 2.4 years † | 2.7 seconds |
| 18 | 2.4 millennia † | 92 seconds |

† estimated

Note. Can't break RSA this way (experts are still trying).

# Debugging

Programming. A process of finding and fixing mistakes.

1. Create the program.

2. Compile it.
   Compiler says: That's not a legal program.
   Back to step 1 to fix syntax errors.

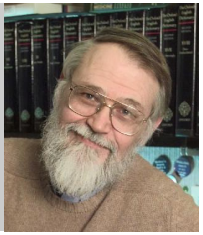
3. Execute it.
   Result is bizarrely (or subtly) wrong.
   Back to step 1 to fix semantic errors.

4. Enjoy the satisfaction of a working program!

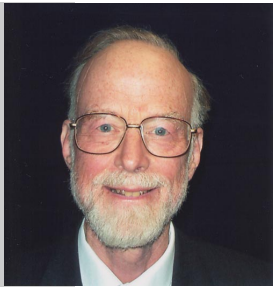
5. Too slow? Back to step 1 to try a different algorithm.

# Debugging is Hard

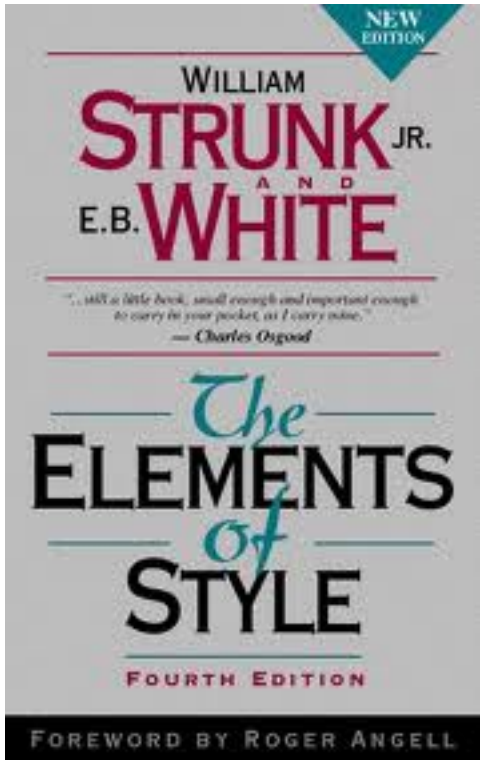
*" Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it. "* — *Brian Kernighan*

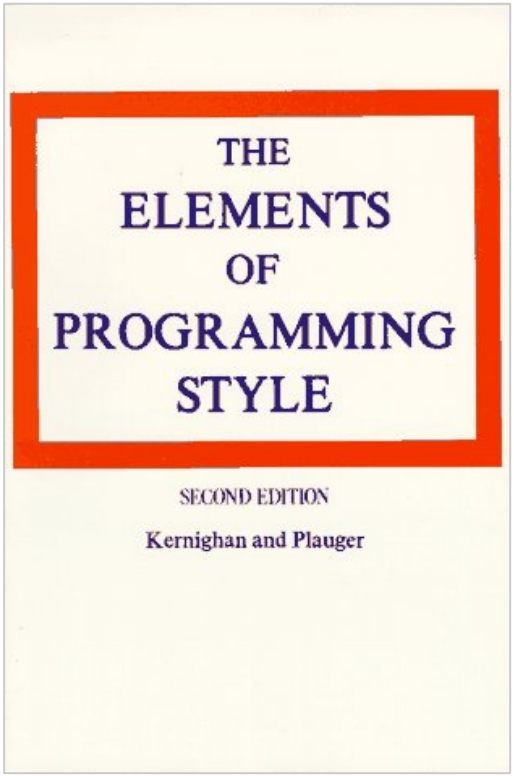


*" There are two ways of constructing a software design. One way is to make it so simple that there are obviously no deficiencies. And the other way is to make it so complicated that there are no obvious deficiencies. "* — *C. A. R. Hoare*



# Programming Style



# Three Versions of the Same Program

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

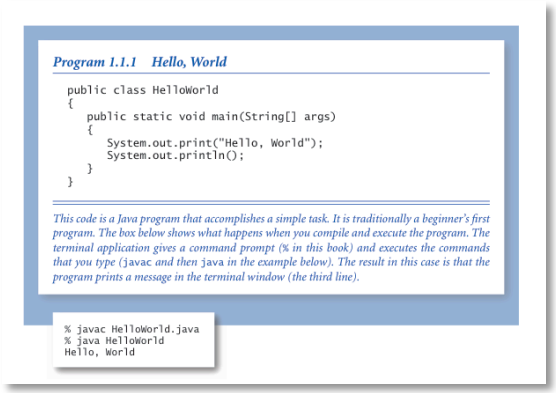
```
/*************************************************************
 *  Compilation:  javac HelloWorld.java
 *  Execution:    java HelloWorld
 *
 *  Prints "Hello, World".
 *  By tradition, this is everyone's first program.
 *
 *  % java HelloWorld
 *  Hello, World
 *
 *************************************************************/

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"); } }
```

# Programming Style

## Different styles are appropriate in different contexts.

- Booksite.
- Textbook.
- COS 126 assignment.
- Java system libraries.



*Program 1.1.1 Hello, World*

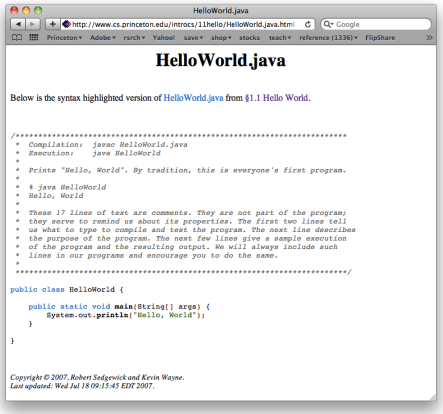
```
public class HelloWorld
{
   public static void main(String[] args)
   {
      System.out.print("Hello, World");
      System.out.println();
   }
}
```

*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
```

## Enforcing consistent style can:

- Stifle creativity.
- Confuse style rules with language rules.



HelloWorld.java

http://www.cs.princeton.edu/introcs/11hello/HelloWorld.java.html

**HelloWorld.java**

Below is the syntax highlighted version of HelloWorld.java from §1.1 Hello World.

```
/*************************************************************************
 *  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 are comments. They are not part of the program;
 *  they serve to remind us about its properties. The first two lines tell
 *  us what to type to compile and test the program. The next line describes
 *  the purpose of the program. The next few lines give a sample execution
 *  of the program and the resulting output. We will always include such
 *  lines in our programs and encourage you to do the same.
 *
 *************************************************************************/

public class HelloWorld {

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

Copyright © 2007, Robert Sedgewick and Kevin Wayne.
Last updated: Wed Jul 18 09:15:45 EDT 2007.

## Emphasizing consistent style can:

- Make it easier to spot errors.
- Make it easier for others to read and use code.
- Enable IDE to provide useful visual cues.

# Naming Conventions

Best practices.

- Be consistent.
- Choose descriptive variables names.
- Obey Java conventions on upper/lowercase.

| purpose | good | bad | worse |
|---|---|---|---|
| factoring program | `Factors.java` | `factors.java` | `f.java` |
| is it a leap year? | `isLeapYear` | `leapyear` | `_$11110001` |
| loop-index variable | `i` | `ithTimeThroughLoop` | `fred` |
| read an int from standard input | `readInt()` | `int()` | `i()` |
| days per week | `DAYS_PER_WEEK` | `DPW` | `SEVEN` |

# Whitespace

Add whitespace to make your program more readable.

```
public class Factors{
   public static void main(String[] args)
{
      long n=Long.parseLong(args[0]);
      for (long i=2;i<=n;i++){
         while (n%i==0) {
            StdOut.print(i+" ");
            n=n/i;
         }
      }
   }
}
```

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);
      for (long i = 2; i <= n; i++) {
         while (n % i == 0) {
            StdOut.print(i + " ");
            n = n / i;
         }
      }
   }
}
```

Best practices.

- Be consistent.
- One statement per line.
- Space between binary operators.

# Indenting

Indent and add blank lines to reveal structure and nesting.

```
public class Factors {
public static void main(String[] args)
{
long n = Long.parseLong(args[0]);
for (long i = 2; i <= n; i++)
{  while (n % i == 0) {
   StdOut.print(i + " ");
      n = n / i; }
   }
}
}
```

```
public class Factors {

   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);

      for (long i = 2; i <= n; i++) {
         while (n % i == 0) {
            StdOut.print(i + " ");
            n = n / i;
         }
      }

   }
}
```

Best practices.

- Be consistent.
- 4 spaces per level of indentation.
- Blank lines between logical blocks of code.

# Comments

Annotate what or why you are doing something, rather than how.

```
//  an end-of-line comment

/*************************************************
 *  A block comment draws attention
 *  to itself.
 *************************************************/
```

Best practices.

- Comment logical blocks of code.
- Ensure comments agree with code.
- Comment every important variable.
- Comment any confusing code (or rewrite so that it's clear).
- Include header that describe purpose of program, how to compile, how to execute, any dependencies, and a sample execution.

COS 126 students:
also name, precept, and login

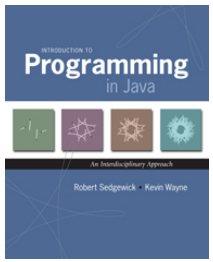
# Comments

```
/*************************************************************************
 *  Compilation:  javac Factors.java
 *  Execution:    java Factors n
 *  Dependencies: StdOut.java
 *
 *  Computes the prime factorization of n using brute force.
 *
 *    % java Factors 4444444444
 *    2 2 11 41 271 9091
 *
 *************************************************************************/

public class Factors {

    public static void main(String[] args) {

        // integer to be factored
        long n = Long.parseLong(args[0]);

        // for each potential factor i of n
        for (long i = 2; i <= n; i++) {

            // if i is a factor of n, repeatedly divide it out
            while (n % i == 0) {
                StdOut.print(i + " ");
                n = n / i;
            }
        }
    }
}
```

# Coding Standards


De facto Java coding standard.

`http://www.oracle.com/technetwork/java/codeconvtoc-136057.html`




Less pedantic version of Sun standard.

`http://introcs.cs.princeton.edu/11style`

COS 126 students:
follow these guidelines

Automated tool to enforce coding standard.

`http://checkstyle.sourceforge.net`

used when you click
"Check all Submitted Files"

# U.S.S. Grace Murray Hopper