COMPUTER SCIENCE
SCIENCE
An Interdisciplinary Approach

ROBERT SEDGEWICK
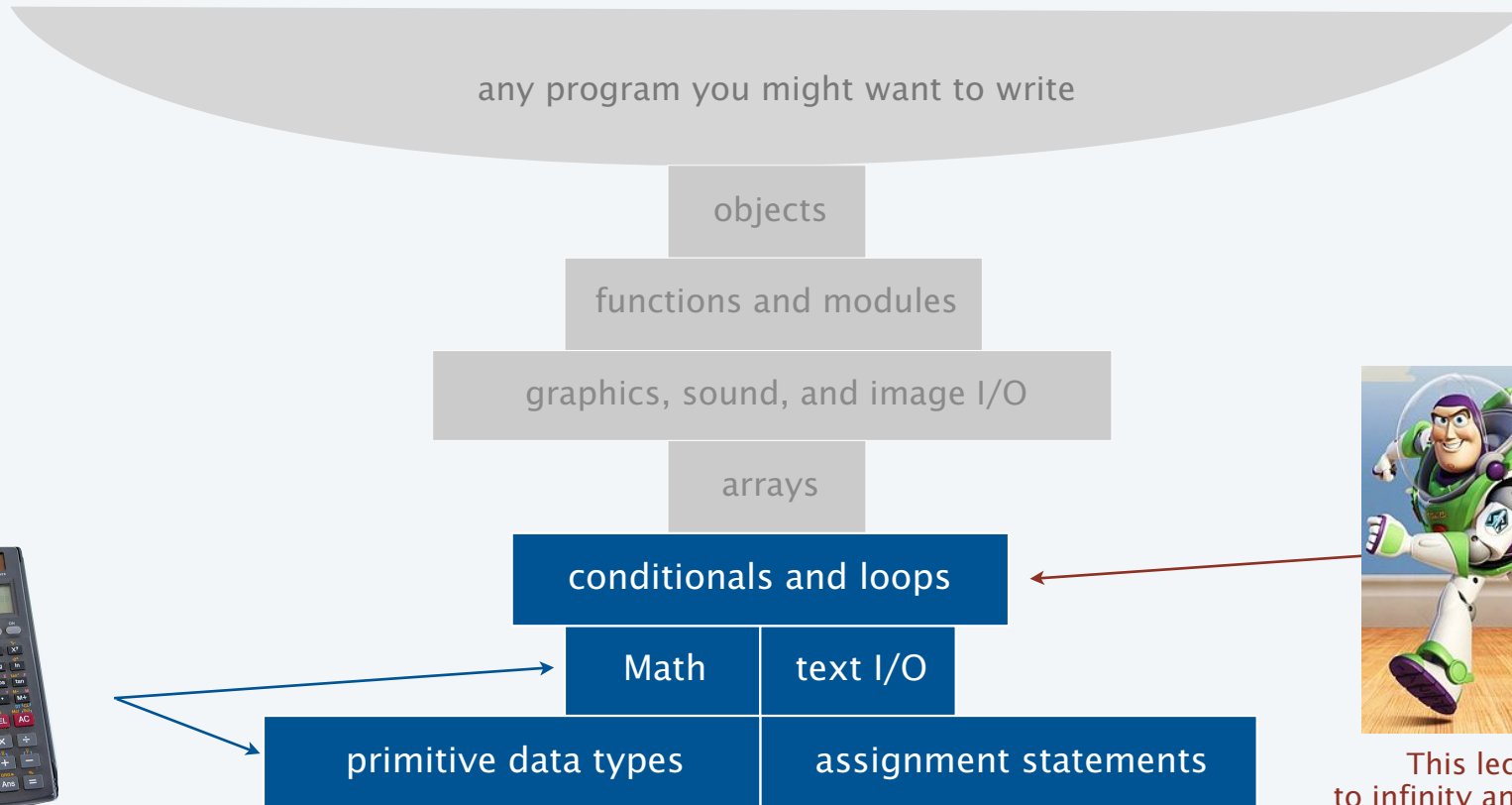**KEVIN WAYNE**

1.3

http://introcs.cs.princeton.edu

2. Conditionals and loops

2. Conditionals & Loops

- **Conditionals: the `if` statement**
- Loops: the `while` statement
- An alternative: the `for` loop
- Nesting
- Debugging

Context: basic building blocks for programming

any program you might want to write
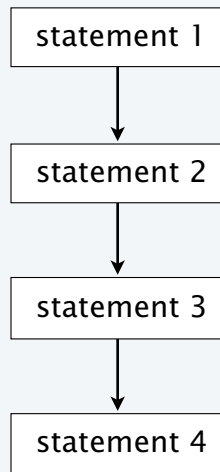
objects

functions and modules

graphics, sound, and image I/O

arrays

conditionals and loops

Math | text I/O

primitive data types | assignment statements

Previous lecture:
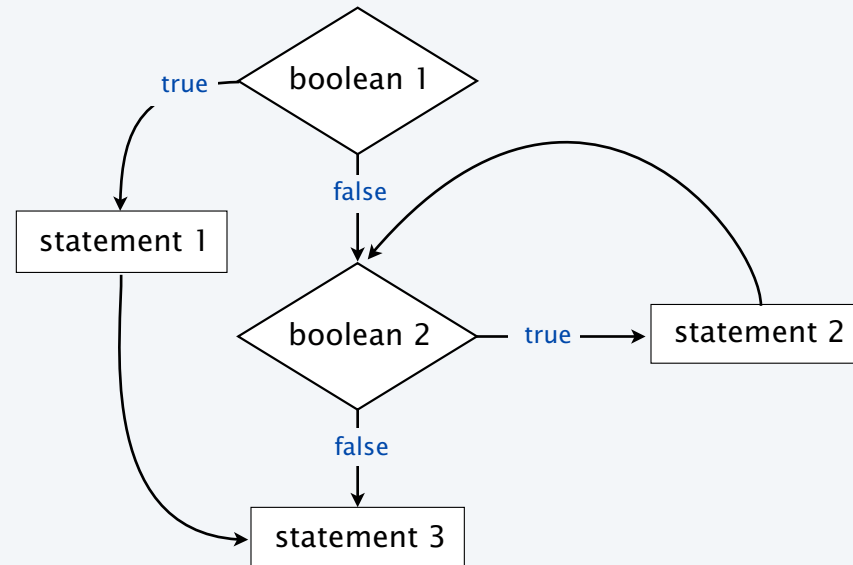equivalent to a calculator

This lecture:
to infinity and beyond!

Conditionals and Loops

Control flow

- The sequence of statements that are actually executed in a program.
- Conditionals and loops enable us to choreograph control flow.
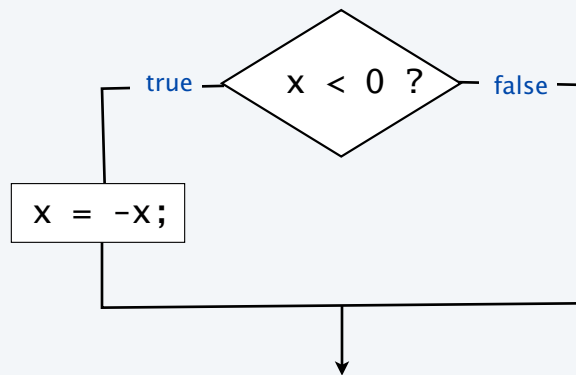

straight-line control flow
[previous lecture]

control flow with conditionals and a loop
[this lecture]

The `if` statement

Execute certain statements depending on the values of certain variables.
- Evaluate a `boolean` expression.
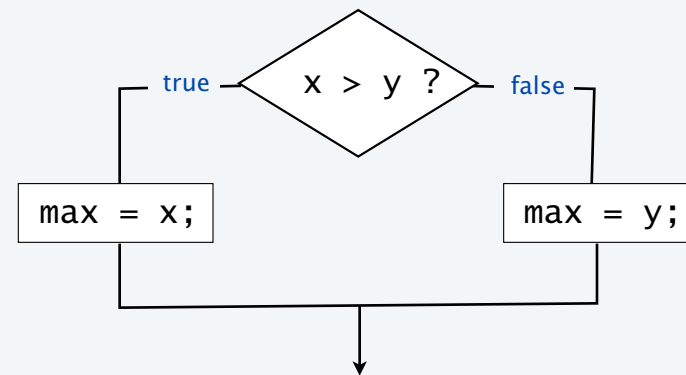- If `true`, execute a statement.
- The `else` option: If `false`, execute a different statement.

Example: `if (x < 0) x = -x;`

Replaces x with the absolute value of x

Example: `if (x > y) max = x;`
`else          max = y;`

Computes the maximum of x and y

Example of if statement use: simulate a coin flip
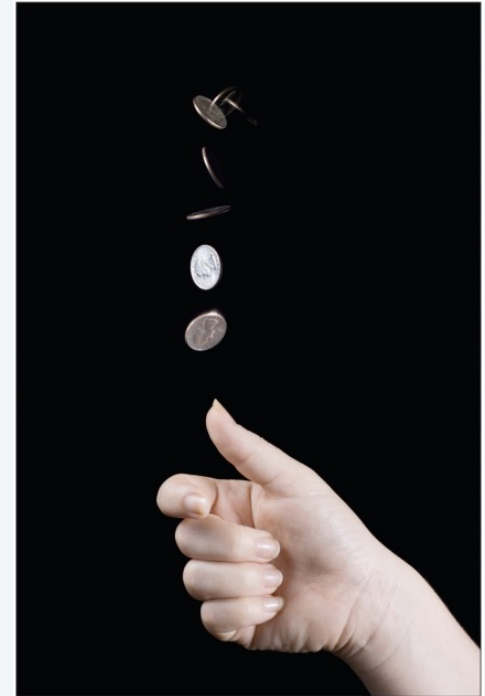
```
public class Flip
{
    public static void main(String[] args)
    {
        if (Math.random() < 0.5)
            System.out.println("Heads");
        else
            System.out.println("Tails");
    }
}
```

```
% java Flip
Heads

% java Flip
Heads

% java Flip
Tails

% java Flip
Heads
```

Example of `if` statement use: 2-sort

Q. What does this program do?

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

alternatives for if and else
⟵ can be a *sequence* of
statements, enclosed in braces

```
% java TwoSort 1234 99
99
1234

% java TwoSort 99 1234
99
1234
```

A. Reads two integers from the command line, then prints them out in numerical order.

Pop quiz on `if` statements

Q. Add code to this program that puts a, b, and c in numerical order.

```
public class ThreeSort
{
    public static void main(String[] args)
    {
        int a = Integer.parseInt(args[0]);
        int b = Integer.parseInt(args[1]);
        int c = Integer.parseInt(args[2]);




        System.out.println(a);
        System.out.println(b);
        System.out.println(c);
    }
}
```

```
% java ThreeSort 1234 99 1
1
99
1234

% java ThreeSort 99 1 1234
1
99
1234
```

Pop quiz on `if` statements

Q. Add code to this program that puts a, b, and c in numerical order.

A.

```
public class ThreeSort
{
    public static void main(String[] args)
    {
        int a = Integer.parseInt(args[0]);
        int b = Integer.parseInt(args[1]);
        int c = Integer.parseInt(args[2]);
        if (b < a)
        { int t = a; a = b; b = t; }      ← makes a smaller
        if (c < a)                              than b
        { int t = a; a = c; c = t; }      ← makes a smaller
        if (c < b)                          than both b and c
        { int t = b; b = c; c = t; }      ← makes b smaller
        System.out.println(a);                than c
        System.out.println(b);
        System.out.println(c);
    }
}
```

```
% java ThreeSort 1234 99 1
1
99
1234

% java ThreeSort 99 1 1234
1
99
1234
```

Example of `if` statement use: error checks

```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;
      System.out.println(a + " + " + b + " = " + sum);
      System.out.println(a + " * " + b + " = " + prod);
      if (b == 0) System.out.println("Division by zero");
      else        System.out.println(a + " / " + b + " = " + a / b);
      if (b == 0) System.out.println("Division by zero");
      else        System.out.println(a + " % " + b + " = " + a % b);
   }
}
```

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

% java IntOps 5 0
5 + 0 = 5
5 * 0 = 0
Division by zero
Division by zero
```

Good programming practice. Use conditionals to check for *and avoid* runtime errors.

Image sources

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

http://en.wikipedia.org/wiki/File:Buzz-lightyear-toy-story-3-wallpaper.jpg

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2789164/#!po=30.0000 [181e306f1.jpg]

2. Conditionals & Loops

- Conditionals: the `if` statement
- **Loops: the** `while` **statement**
- An alternative: the `for` loop
- Nesting
- Debugging

The while loop

Execute certain statements repeatedly until certain conditions are met.
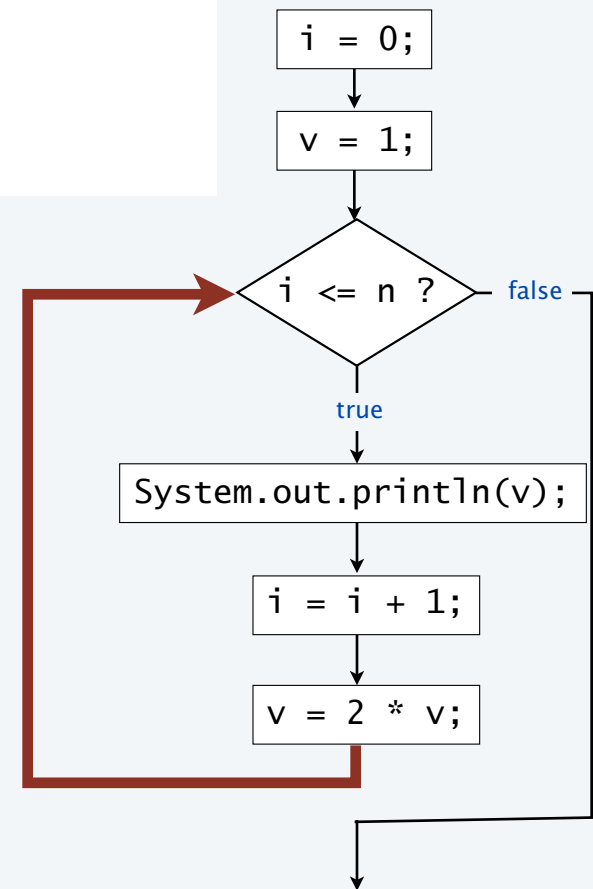- Evaluate a `boolean` expression.
- If `true`, execute a sequence of statements.
- Repeat.

Example:
```
int i = 0;
int v = 1;
while (i <= n)
{
    System.out.println(v);
    i = i + 1;
    v = 2 * v;
}
```

```
i = 0;

v = 1;

i <= n ?          false

true

System.out.println(v);

i = i + 1;

v = 2 * v;
```

Prints the powers of two from 2^0 to 2^n.

[stay tuned for a trace]

13

Example of `while` loop use: print powers of two

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

```
public class PowersOfTwo
{
    public static void main(String[] args)
    {
        int n = Integer.parseInt(args[0]);
        int i = 0;
        int v = 1;
        while (i <= n)
        {
            System.out.println(v);
            i = i + 1;
            v = 2 * v;
        }
    }
}
```

i	v	i <= n
0	1	true
1	2	true
2	4	true
3	8	true
4	16	true
5	32	true
6	64	true
7	128	false


```
% java PowersOfTwo 6
1
2
4
8
16
32
64
```

Prints the powers of two from 2^0 to 2^n .

Pop quiz on `while` loops

Q. Anything wrong with the following code?

```java
public class PQwhile
{
    public static void main(String[] args)
    {
        int n = Integer.parseInt(args[0]);
        int i = 0;
        int v = 1;
        while (i <= n)
            System.out.println(v);
            i = i + 1;
            v = 2 * v;
    }
}
```

Pop quiz on `while` loops

Q. Anything wrong with the following code?

```java
public class PQwhile
{
    public static void main(String[] args)
    {
        int n = Integer.parseInt(args[0]);
        int i = 0;
        int v = 1;
        while (i <= n)
        {   System.out.println(v);
            i = i + 1;
            v = 2 * v;   }
    }
}
```

Q. What does it do (without the braces)?

A. Goes into an *infinite loop*.

```
% java PQwhile 6
1
1
1
1
1
1
1
1
1
1
1
```

challenge: figure out
how to stop it
on your computer

A. Yes! Needs braces.

Goal. Implement square root function.

```
% java Sqrt 60481729.0
7777.0
% java Sqrt 2.0
1.4142136
```

Newton-Raphson method to compute $\sqrt{c}$

• Initialize $t_0 = c$.   if $t = c/t$ then $t^2 = c$
• Repeat until $t_i = c/t_i$ (up to desired precision):
    Set t_{i+1} to be the average of t_i and c / t_i.

i	t_i	$2/t_i$	average
0	2	1	1.5
1	1.5	1.3333333	1.4166667
2	1.4166667	1.4117647	1.4142157
3	1.4142157	1.4142114	1.4142136
4	1.4142136	1.4142136	

computing the square root of 2 to seven places

The square root of 9 is 3.

A) True.
B) False.
C) Who cares?

GLASBERGEN

Many students actually look forward to Mr. Atwadder's math tests.

17

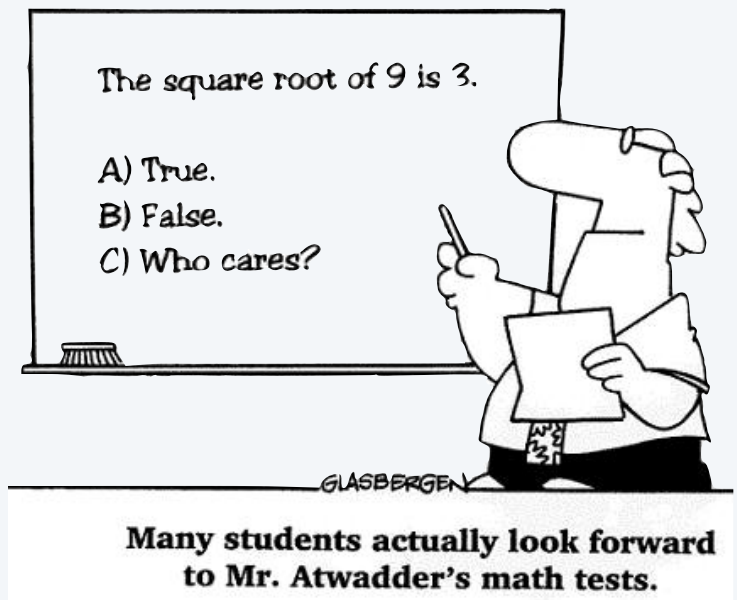# Example of `while` loop use: implement `Math.sqrt()`

Newton-Raphson method to compute $\sqrt{c}$

- Initialize $t_0 = c$.
- Repeat until $t_i = c/t_i$ (up to desired precision):

  Set t_{i+1} to be the average of t_i and c / t_i.

Isaac Newton
1642-1727

Scientists studied *computation* well before the onset of the *computer*.

```
public class Sqrt
{
    public static void main(String[] args)
    {
        double EPS = 1E-15;  ← error tolerance (15 places)
        double c = Double.parseDouble(args[0]);
        double t = c;
        while (Math.abs(t - c/t) > t*EPS)
            t = (c/t + t) / 2.0;
        System.out.println(t);
    }
}
```
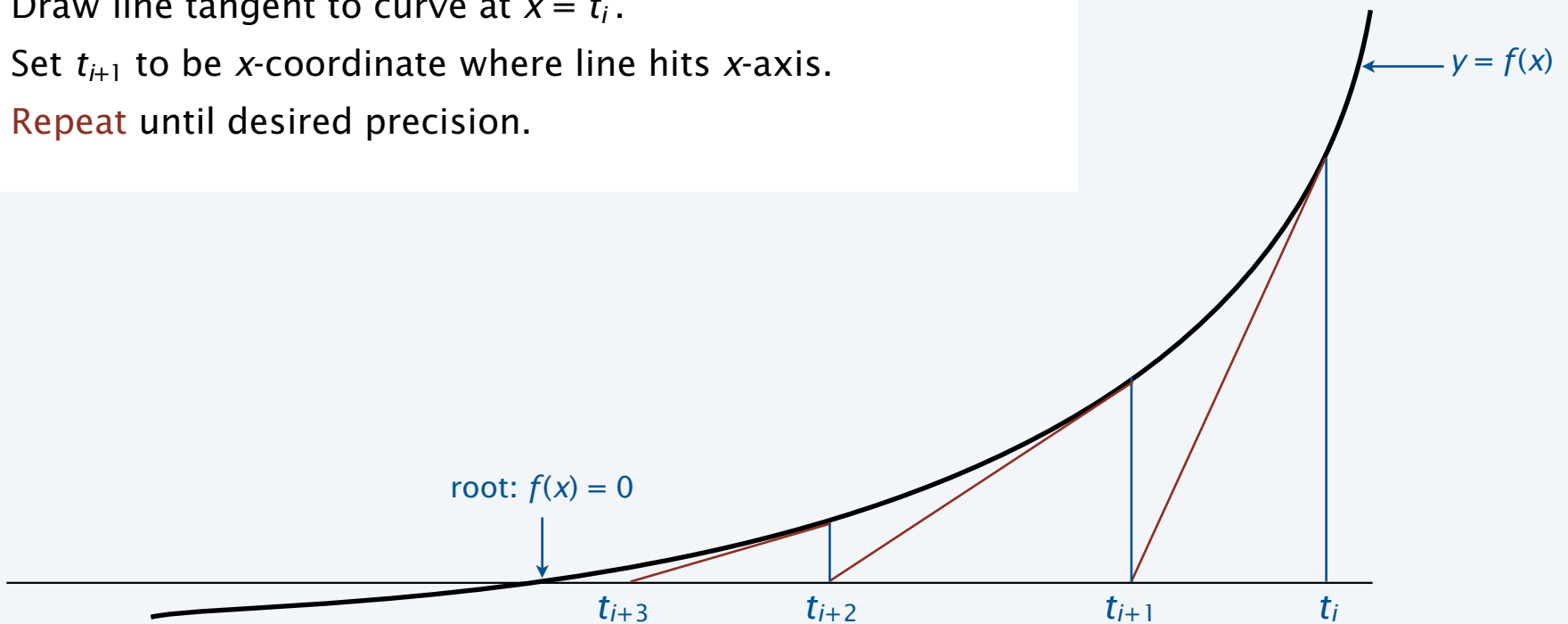
```
% java Sqrt 60481729.0
7777.0

% java Sqrt 2.0
1.414213562373095
```

Newton-Raphson method

Explanation (some math omitted)

- Goal: find *root* of function $f(x)$ (value of x for which $f(x) = 0$). ⟵ use $f(x) = x^2 - c$ for $\sqrt{c}$
- Start with estimate t_0.
- Draw line tangent to curve at $x = t_i$.
- Set t_{i+1} to be x-coordinate where line hits x-axis.
- Repeat until desired precision.

⟵ $y = f(x)$

root: $f(x) = 0$

t_{i+3} t_{i+2} t_{i+1} t_i

Image sources

2. Conditionals & Loops

- Conditionals: the `if` statement
- Loops: the `while` statement
- **An alternative: the `for` loop**
- Nesting
- Debugging

The for loop

An alternative repetition structure. ← Why? Can provide code that is more compact and understandable.

- Evaluate an *initialization statement*.
- Evaluate a *boolean expression*.
- If true, execute a *sequence of statements*, then execute an *increment statement*.
- Repeat.

Example: initialization statement

```
int v = 1;
for ( int i = 0; i <= n; i++ )
{
    System.out.println( i + " " + v );
    v = 2*v;
}
```

boolean expression

increment statement

Prints the powers of two from 2^0 to 2^n

Every for loop has an equivalent while loop:

```
int v = 1;
int i = 0;
while ( i <= n; )
{
    System.out.println( i + " " + v );
    v = 2*v;
    i++;
}
```

Examples of for loop use

```
int sum = 0;
for (int i = 1; i <= N; i++)
    sum += i;
System.out.println(sum);
```

Compute sum (1 + 2 + 3 + . . . + N)

sum	i
1	1
3	2
6	3
10	4

trace at end of loop for $N = 4$

```
long product = 1;
for (int i = 1; i <= N; i++)
    product *= i;
System.out.println(product);
```

Compute N! = 1 * 2 * 3 * . . . * N

product	i
1	1
2	2
6	3
24	4

```
for (int k = 0; k <= N; k++)
    System.out.println(k + " " + 2*Math.PI*k/N);
```

Print a table of function values

k	$\dfrac{2\pi k}{N}$
0	0
1	1.57079632...
2	3.14159265...
3	4.71238898...
4	6.28318530...

```
int v = 1;
while (v <= N/2)
    v = 2*v;
System.out.println(v);
```

Print largest power of 2 less than or equal to N

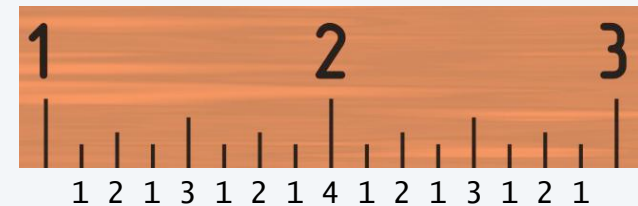| v |
|----|
| 2 |
| 4 |
| 8 |
| 16 |

trace at end of loop for $N = 23$

Example of `for` loop use: subdivisions of a ruler

Create subdivisions of a ruler to 1/*N* inches.

- Initialize `ruler` to one space.

- For each value `i` from `1` to `N`:
  sandwich `i` between two copies of `ruler`.

```java
public class Ruler
{
    public static void main(String[] args)
    {
        int N = Integer.parseInt(args[0]);
        String ruler = " ";
        for (int i = 1; i <= N; i++)
            ruler = ruler + i + ruler;
        System.out.println(ruler);
    }
}
```

Note: Small program can produce huge amount of output.

1 2 1 3 1 2 1 4 1 2 1 3 1 2 1

i	ruler
1	"1"
2	"1 2 1"
3	"1 2 1 3 1 2 1"
4	"1 2 1 3 1 2 1 4 1 2 1 3 1 2 1"

End-of-loop trace

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

```
% java Ruler 100
Exception in thread "main"
java.lang.OutOfMemoryError
```

$2^{100} - 1$ integers in output (!)

Pop quiz on for loops

Q. What does the following program print?

```java
public class PQfor
{
   public static void main(String[] args)
   {
      int f = 0, g = 1;
      for (int i = 0; i <= 10; i++)
      {
         System.out.println(f);
         f = f + g;
         g = f - g;
      }
   }
}
```

Pop quiz on for loops

Q. What does the following program print?

```java
public class PQfor
{
   public static void main(String[] args)
   {
      int f = 0, g = 1;
      for (int i = 0; i <= 10; i++)
      {
         System.out.println(f);
         f = f + g;
         g = f - g;
      }
   }
}
```

A.

Beginning-of-loop trace

i	f	g
0	0	1
1	1	0
2	1	1
3	2	1
4	3	2
5	5	3
6	8	5
7	13	8
8	21	13
9	34	21
10	55	34

↑
values printed

2. Conditionals & Loops

- Conditionals: the `if` statement
- Loops: the `while` statement
- An alternative: the `for` loop
- **Nesting**
- Debugging

Nesting conditionals and loops

Nesting

- Any "statement" within a conditional or loop may itself be a conditional or a loop statement.

- Enables complex control flows.

- Adds to challenge of debugging.

Example:

```
for (int t = 0; t < trials; t++)
{
    int cash = stake;
    while (cash > 0 && cash < goal)
        if (Math.random() < 0.5) cash++;
        else                     cash--;
    if (cash == goal) wins++;
}
```

if-else statement
within a while loop
within a for loop

[Stay tuned for an explanation of this code.]

Example of nesting conditionals: Tax rate calculation

income	rate
0 – $47,450	22%
$47,450 – $114,649	25%
$114,650 – $174,699	28%
$174,700 – $311,949	33%
$311,950 +	35%

Goal. Given income, calculate proper tax rate.

```
if (income <  47450) rate = 0.22;
else
   {
     if (income < 114650) rate = 0.25;
     else
        {
          if (income < 174700) rate = 0.28;
          else
             {
               if (income < 311950) rate = 0.33;
               else              rate = 0.35;
             }
        }
   }
```

if statement
within an if statement

if statement
within an if statement
within an if statement

if statement
within an if statement
within an if statement
within an if statement

Pop quiz on nested `if` statements

Q. Anything wrong with the following code?

```
public class PQif
{
   public static void main(String[] args)
   {
      double income = Double.parseDouble(args[0]);
      double rate = 0.35;
      if (income <  47450) rate = 0.22;
      if (income < 114650) rate = 0.25;
      if (income < 174700) rate = 0.28;
      if (income < 311950) rate = 0.33;
      System.out.println(rate);
   }
}
```

Pop quiz on nested `if` statements

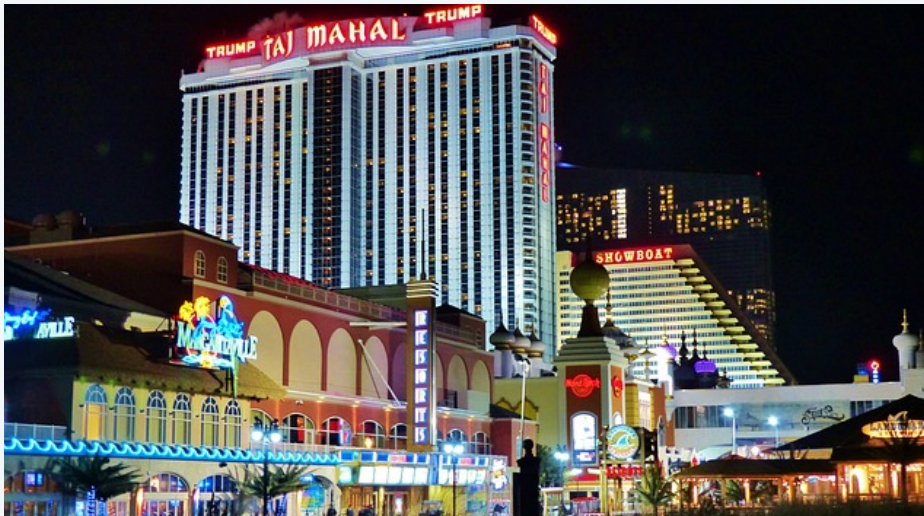Q. Anything wrong with the following code?

```java
public class PQif
{
    public static void main(String[] args)
    {
        double income = Double.parseDouble(args[0]);
        double rate = 0.35;
        if (income <  47450) rate = 0.22;
    else if (income < 114650) rate = 0.25;
    else if (income < 174700) rate = 0.28;
    else if (income < 311950) rate = 0.33;
        System.out.println(rate);
    }
}
```

Note. Braces are not needed in this case, but BE CAREFUL when nesting if-else statements because of potential ambiguity (see Q&A p. 75).

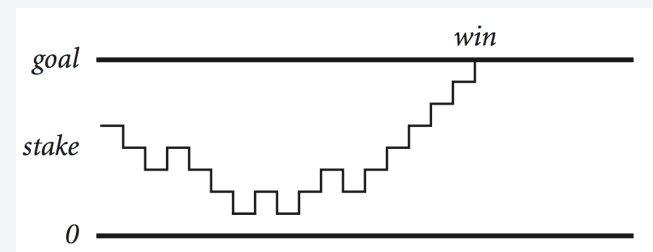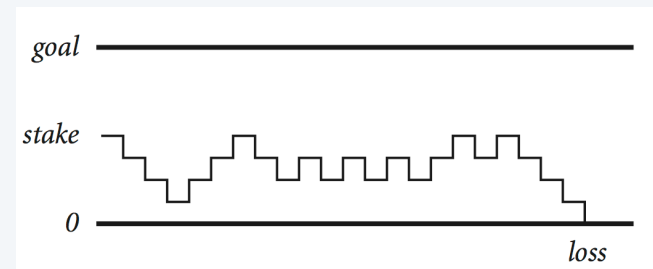A. Yes! Need `else` clauses. Without them, code is equivalent to:

```java
if (income < 311950) rate = 0.33;
else                 rate = 0.35;
```

Gambler's ruin problem

A gambler starts with $*stake* and places $1 fair bets.
- Outcome 1 (loss): Gambler goes broke with $0.
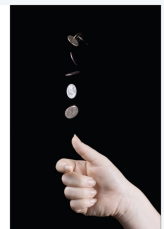- Outcome 2 (win): Gambler reaches $*goal*.

Q. What are the chances of winning?
Q. How many bets until win or loss?

One approach: Monte Carlo simulation.
- Use a *simulated coin flip*.
- Repeat and compute statistics.

Example of nesting conditionals and loops: Simulate gamber's ruin

Gambler's ruin simulation

- Get command-line arguments.

- Run all the experiments.

  - Run one experiment.

    - Make one bet.

  - If goal met, count the win.

- Print #wins and # trials.

```java
public class Gambler
{
    public static void main(String[] args)
    {
        int stake  = Integer.parseInt(args[0]);
        int goal   = Integer.parseInt(args[1]);
        int trials = Integer.parseInt(args[2]);

        int wins   = 0;
        for (int t = 0; t < trials; t++)
        {
            int cash = stake;
            while (cash > 0 && cash < goal)
            {
                if (Math.random() < 0.5) cash++;
                else                     cash--;
            }
            if (t == goal) wins++;
        }
        System.out.println(wins + " wins of " + trials);
    }
}
```

for loop

while loop
within a for loop

if statement
within a while loop
within a for loop

```
% java Gambler 5 25 1000
191 wins of 1000
```

Digression: simulation and analysis

Facts (known via mathematical analysis for centuries)

- Probability of winning = stake ÷ goal.
- Expected number of bets = stake × desired gain.

Christiaan Huygens
1629-1695

Early scientists were fascinated by the study of games of chance.

Example

- 20% chance of turning $500 into $2500.
- Expect to make 1 *million* $1 bets.

500/2500 = 20%

500*(2500 - 500) = 1,000,000

uses about 1 *billion* coin flips →

stake goal trials

```
% java Gambler    5 25 1000
191 wins of 1000

% java Gambler    5 25 1000
203 wins of 1000

% java Gambler 500 2500 1000
197 wins of 1000
```

Remarks

- Computer simulation can help validate mathematical analysis.
- For this problem, mathematical analysis is simpler (if you know the math).
- For more complicated variants, computer simulation may be the *best* plan of attack.

35

Image sources

http://pixabay.com/en/atlantic-city-ocean-holiday-316301/

http://en.wikipedia.org/wiki/Christiaan_Huygens#mediaviewer/File:Christiaan_Huygens.jpg

2. Conditionals & Loops

- Conditionals: the `if` statement
- Loops: the `while` statement
- An alternative: the `for` loop
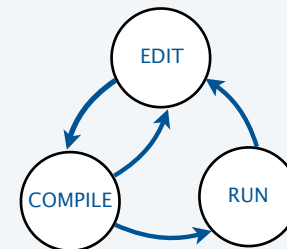- Nesting
- **Debugging**

Debugging

is 99% of program development in any programming language, *even for experts.*

Bug: A mistake in a program.

Debugging: The process of eliminating bugs.

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

EDIT

COMPILE   RUN

" 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

Impossible ideal: "Please compile, execute, and debug my program." Why is this impossible? Stay tuned.

Bottom line: Programming is primarily a *process* of finding and fixing mistakes.

38

Debugging

is challenging because conditionals and loops *dramatically increase* the number of possible outcomes.

program structure	no loops	n conditionals	1 loop
number of possible execution sequences	1	2^n	no limit

Most programs contain *numerous* conditionals and loops, with nesting.

Good news. Conditionals and loops provide structure that helps us understand our programs.

Old and low-level languages have a *goto* statement that provides arbitrary structure. Eliminating *goto*s was controversial until Edsgar Dijkstra published the famous note "*Goto considered harmful*" in 1968.

" *The quality of programmers is a decreasing function of the number of goto statements in the programs they produce.* "

– Edsgar Dijkstra

Debugging a program: a running example

Problem: Factor a large integer n.

Application: Cryptography.

Surprising fact: Security of internet commerce depends on difficulty of factoring large integers.
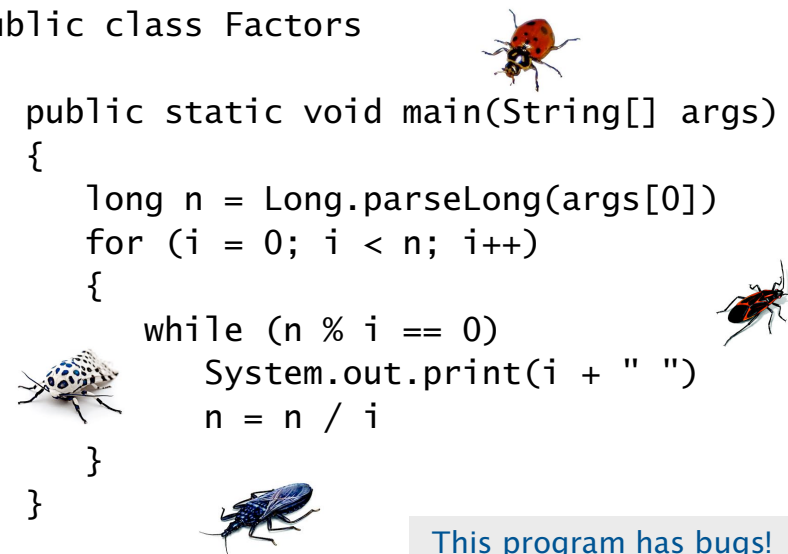
$$3,757,208 = 2 \times 2 \times 2 \times 7 \times 13 \times 13 \times 397$$

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

$$17 = 17$$

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

Method

• Consider each integer i less than n

• While i divides n evenly
  Print i (it is a factor of n).
  Replace n with n/i .

Rationale:
1. Any factor of n/i is a factor of n.
2. i may be a factor of n/i.

```
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)
                System.out.print(i + " ")
                n = n / i
        }
    }
}
```
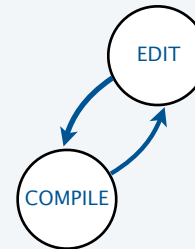
This program has bugs!

Debugging a program: syntax errors

Is your program a legal Java program?

- Java compiler can help you find out.
- Find the *first* compiler error (if any).
- Repeat.
- Result: An executable Factors.class file

EDIT

COMPILE

Trying to tell a computer what to do

```
% javac Factors.java
Factors.java:5: ';' expected
        long n = Long.parseLong(args[0])
                                         ^
...
```

```
% javac Factors.java
Factors.java:6: cannot find symbol
symbol  : variable i
location: class FactorsX
          for (       i = 0; i < n; i++)
                      ^
...
```

```
% javac Factors.java
%
```

```
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)
                System.out.print(i + " ") ;
            n = n / i ;
        }
    }
}
```
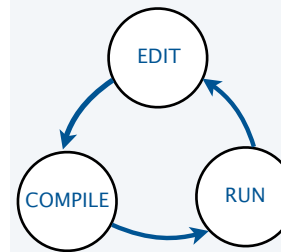
need to declare type of i

need terminating semicolons

This legal program still has bugs!

Debugging a program: runtime and semantic errors

Does your legal Java program do what you want it to do?

- You need to run it to find out.
- Find the *first* runtime error (if any).
- Fix and repeat.


```
% javac Factors.java
% java Factors          ← oops, need argument
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: 0
        at Factors.main(Factors.iava:5)
```

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

```
% java Factors 98
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
```

```
% java Factors 98
2 7 7%
```

$98 = 2 \times 7 \times 7$ ✓

need to start at 2
since 0 and 1
are not factors

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

need braces

This working program still has bugs!

42

Debugging a program: testing

Does your legal Java program *always* do what you want it to do?
- You need to test on many types of inputs it to find out.
- Add trace code to find the first error.
- Fix the error.
- Repeat.

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

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

```
% java Factors 6
2  ←──── ??? where's the 3?
```

```
% javac Factors.java
% java Factors 5
TRACE 2 5
TRACE 3 5
TRACE 4 5
% java Factors 6
2
TRACE 2 3
```

AHA! Need to print out *n*
(if it is not 1).

```java
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)
            {
                System.out.print(i + " ");
                n = n / i;
            }
System.out.println("TRACE " + i + " " + n);
        }
    }
}
```

Debugging a program: testing

Does your legal Java program *always* do what you want it to do?
- You need to test on many types of inputs it to find out.
- Add trace code to find the first error.
- Fix the error.
- Repeat.

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

???
%$%@$#!!
forgot to recompile

```java
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)
            {
                System.out.print(i + " ");
                n = n / i;
            }
        }
        if (n > 1) System.out.println(n);
        else       System.out.println();
    }
}
```

Note: This working program still has a bug (stay tuned).

Debugging a program: performance

Is your working Java program fast enough to solve your problem?

• You need to test it on increasing problem sizes to find out.

• May need to change the algorithm to fix it.

• Repeat.

Method

change the *algorithm*: no need to check when
$i \cdot i > n$ since all smaller factors already checked

• Consider each integer $i \leq n/i$

• While *i* divides n evenly
    print *i* (it is a factor of *n*)
    replace *n* with *n/i* .

```
% java Factors 11111111
11 73 101 137
% java Factors 11111111111
21649 513239
% java Factors 1111111111111
11 239 4649 909091
% java Factors 111111111111111111
2071723 5363222357 ⟵ immediate
```

might work,
but way too slow

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

Debugging a program: performance analysis

Q. How large an integer can I factor?

```
% java Factors 9201111169755555703
9201111169755555703
```

digits in largest factor	i < N	i <= N/i
3	instant	instant
6	instant	instant
9	77 seconds	instant
12	21 hours†	instant
15	2.4 years†	2.7 seconds
18	2.4 millenia†	92 seconds

† *estimated, using analytic number theory*

Lesson. Performance matters!

```
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)
            {
                System.out.print(i + " ");
                n = n / i;
            }
        }
        if (n > 1) System.out.println(n);
        else       System.out.println();
    }
}
```
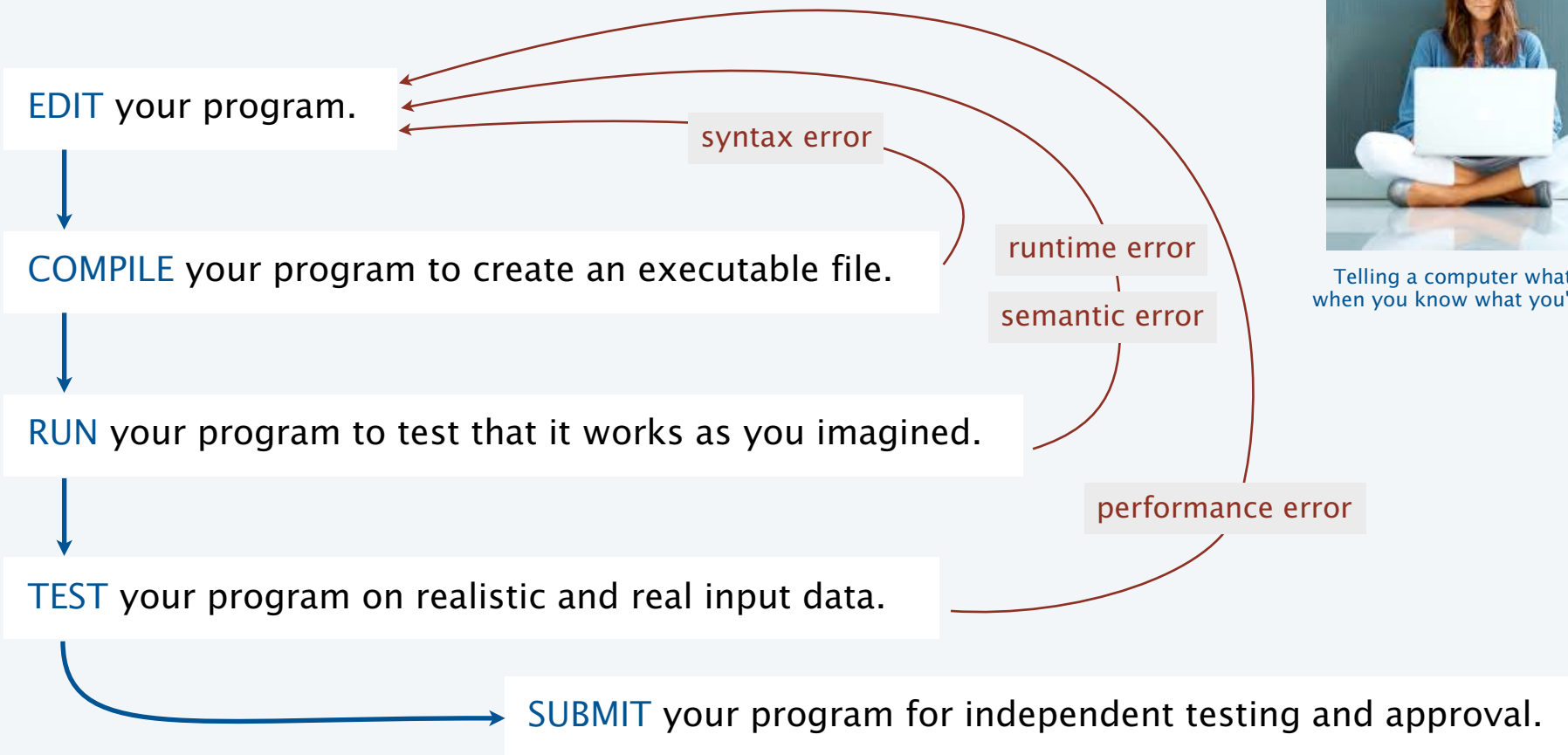
experts are still trying to develop better algorithms for this problem

Note. Internet commerce is still secure: it depends on the difficulty of factoring 200-digit integers.
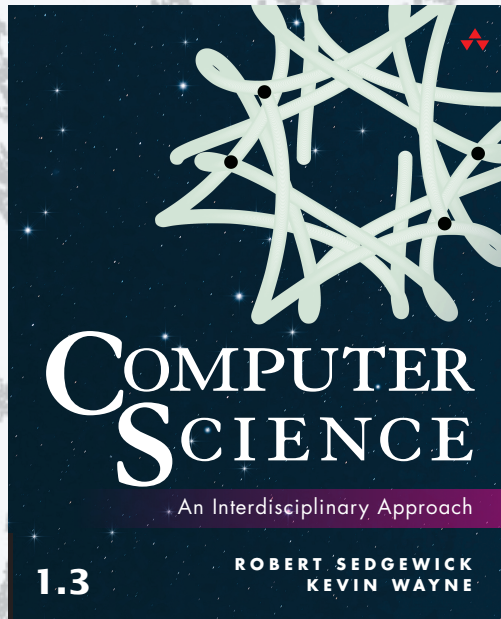
Debugging your program: summary

Program development is a *four*-step process, with feedback.

EDIT your program.

syntax error

COMPILE your program to create an executable file.

runtime error

semantic error

RUN your program to test that it works as you imagined.

performance error

TEST your program on realistic and real input data.

SUBMIT your program for independent testing and approval.

Telling a computer what to do when you know what you're doing

COMPUTER
SCIENCE

An Interdisciplinary Approach

ROBERT SEDGEWICK
KEVIN WAYNE

1.3

http://introcs.cs.princeton.edu

2. Conditionals & Loops