Conditionals and Loops

Dr. 何明昕, He Mingxin, Max

program06 @ yeah.net

Email Subject：(AE|A2|A3) + *(Last 4 digits of ID) + Name*: *TOPIC*

Sakai: CS102A in 2018A

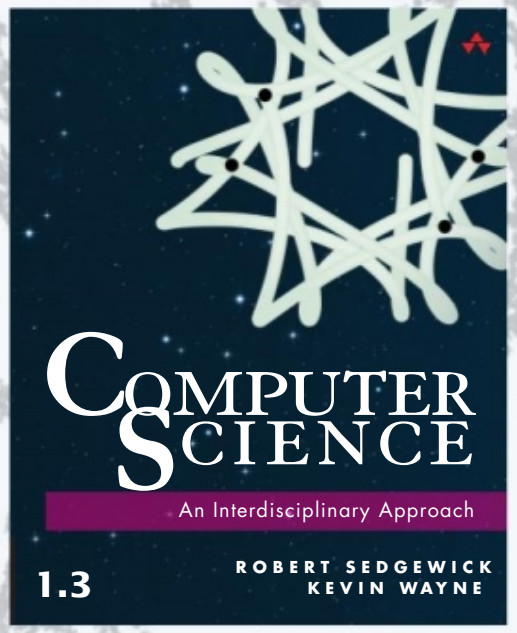
计算机程序设计基础

Introduction to Computer Programming

COMPUTER SCIENCE

SEDGEWICK / WAYNE

PART I: PROGRAMMING IN JAVA



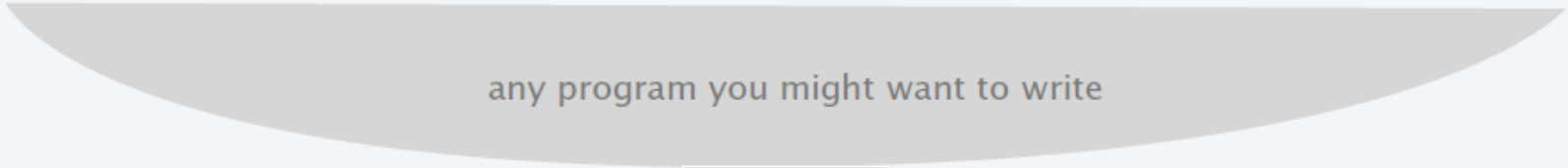
http://introcs.cs.princeton.edu

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



objects

functions and modules

graphics, sound, and image I/O

arrays

conditionals and loops

Math | text I/O

primitive data types | assignment statements

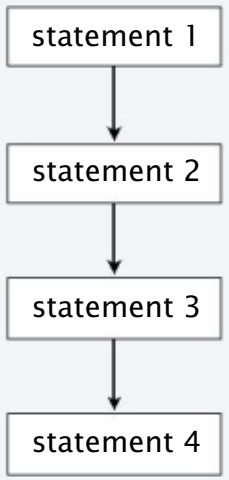
Previous lecture:
equivalent to a calculator

This lecture:
to infinity and beyond!

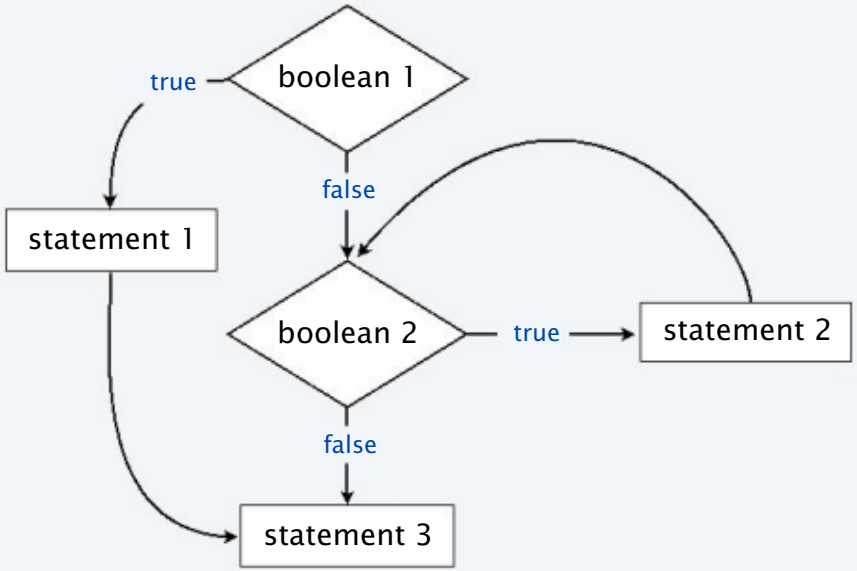
Conditionals and Loops

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]



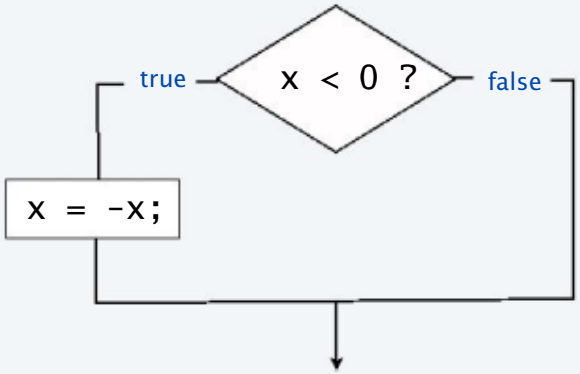
control flow with conditionals and a loop
[this lecture]

The `if` statement

Execute certain statements depending on the values of certain variables.

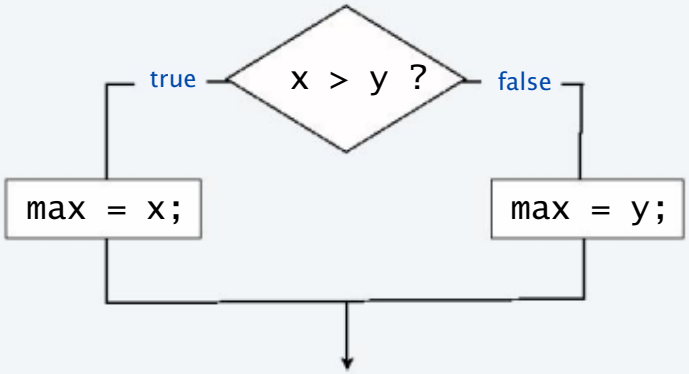
- Evaluate a `boolean` expression.
- If `true`, execute a statement.
- The `else` option: If `false`, execute a different statement.

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; }
      if (c < a)
         { int t = a; a = c; c = t; }
      if (c < b)
         { int t = b; b = c; c = t; }
      System.out.println(a);
      System.out.println(b);
      System.out.println(c);
   }
}
```

makes *a* smaller than *b*

makes *a* smaller than both *b* and *c*

makes *b* smaller than *c*

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

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

Example of `if` statement use: error checks

```
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.

2. Conditionals & Loops

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

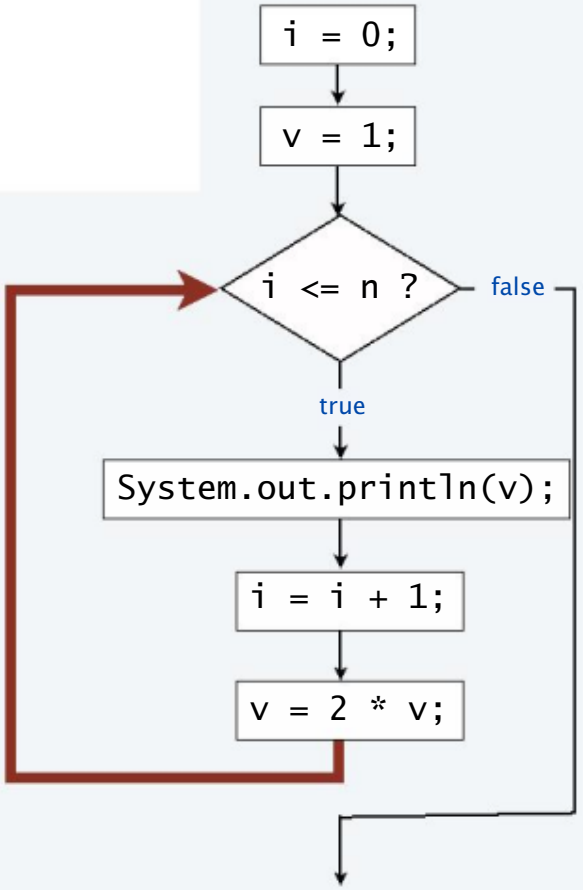
The `while` loop

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;
}
```



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

[stay tuned for a trace]

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

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

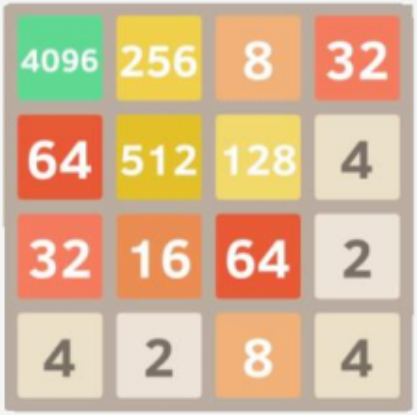
```
public class PowersOfTwo
{
   public static void main (String[] args)
   {
      int n = Integer.parseInt( args[0] );
      int i = 0;
      int v = 1;
      while (i <= n) {

         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?

```
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?

```
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;
      }
   }
}
```

A. Yes! Needs braces.

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
1
```

challenge: figure out how to stop it on your computer

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

Goal. Implement square root function.

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

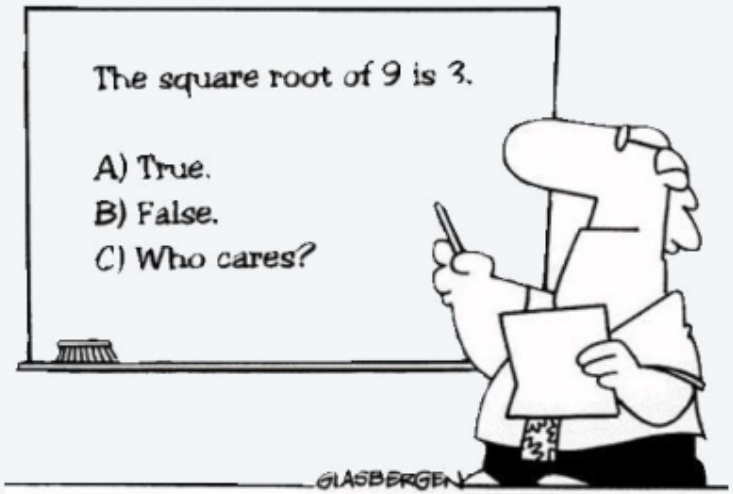
Newton-Raphson method to compute $\sqrt{c}$

- Initialize $t_0 = c$.
- 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 .

if $t = c/t$ then $t^2 = c$

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



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

Newton's method

From Wikipedia, the free encyclopedia

> *This article is about Newton's method for finding roots. For Newton's method for finding minima, see Newton's method in optimization.*

In numerical analysis, **Newton's method** (also known as the **Newton–Raphson method**), named after Isaac Newton and Joseph Raphson, is a method for finding successively better approximations to the roots (or zeroes) of a real-valued function. It is one example of a root-finding algorithm.

$$x : f(x) = 0 .$$

The Newton–Raphson method in one variable is implemented as follows:

The method starts with a function f defined over the real numbers x, the function's derivative f', and an initial guess x_0 for a root of the function f. If the function satisfies the assumptions made in the derivation of the formula and the initial guess is close, then a better approximation x_1 is

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)} .$$

Geometrically, $(x_1, 0)$ is the intersection of the x-axis and the tangent of the graph of f at $(x_0, f(x_0))$.

The process is repeated as

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

until a sufficiently accurate value is reached.

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 );
   }
}
```

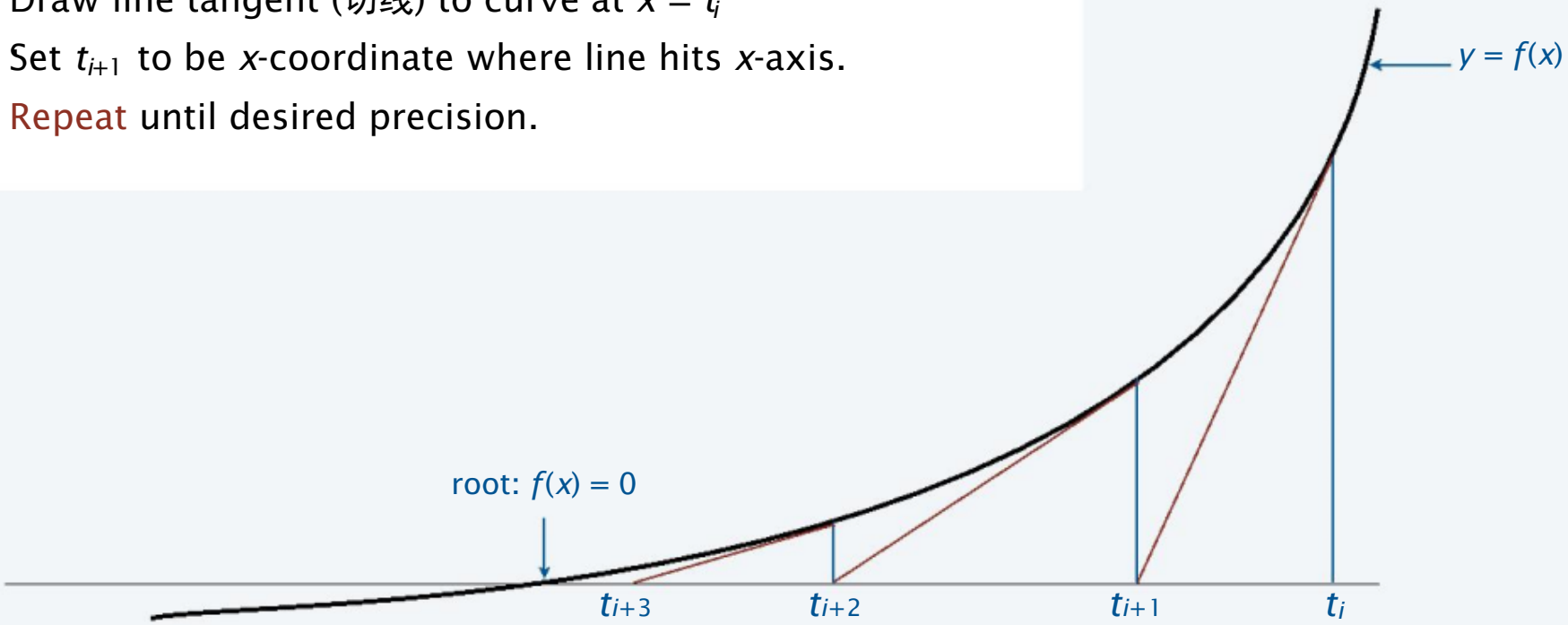
```
% java Sqrt 60481729.0
7777.0

% 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 (切线) to curve at $x = t_i$
- Set t_{i+1} to be x-coordinate where line hits x-axis.
- Repeat until desired precision.



2. Conditionals & Loops

- Conditionals: the `if` statement
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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:

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

initialization statement

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	$\frac{2\pi k}{N}$
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`.

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

```
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 );
   }
}
```

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 (!)

Note: Small program can produce huge amount of output.

Pop quiz on `for` loops

Q. What does the following program print?

```
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;
      }
   }
}
```

Compute the Fibonacci numbers, also called the Fibonacci sequence.

Pop quiz on `for` loops

Q. What does the following program print?

```
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;
      }
   }
}
```

```
int t = f;
f = f + g;
g = t;
```

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

Fibonacci number

From Wikipedia, the free encyclopedia

In mathematics, the **Fibonacci numbers** are the numbers in the following integer sequence, called the **Fibonacci sequence**, and characterized by the fact that every number after the first two is the sum of the two preceding ones:[1][2]

$$1,\ 1,\ 2,\ 3,\ 5,\ 8,\ 13,\ 21,\ 34,\ 55,\ 89,\ 144,\ \ldots$$

Often, especially in modern usage, the sequence is extended by one more initial term:

$$0,\ 1,\ 1,\ 2,\ 3,\ 5,\ 8,\ 13,\ 21,\ 34,\ 55,\ 89,\ 144,\ \ldots$$ [3]

By definition, the first two numbers in the Fibonacci sequence are either 1 and 1, or 0 and 1, depending on the chosen starting point of the sequence, and each subsequent number is the sum of the previous two.

The sequence F_n of Fibonacci numbers is defined by the recurrence relation:

$$F_n = F_{n-1} + F_{n-2},$$

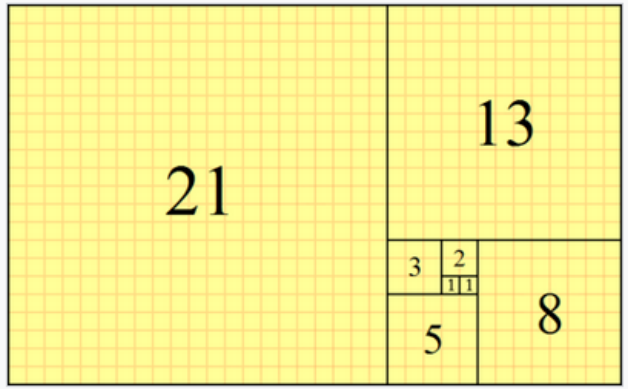
with seed values[1][2]

$$F_1 = 1,\ F_2 = 1$$

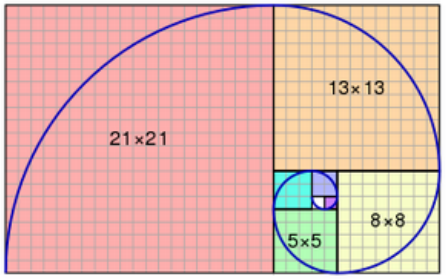
or[5]

$$F_0 = 0,\ F_1 = 1.$$

Fibonacci numbers appear to have first arisen in perhaps 200 BC in work by Pingala on enumerating possible patterns of poetry formed from syllables of two lengths. The Fibonacci sequence is named after Italian mathematician Leonardo of Pisa, known as Fibonacci. His 1202 book *Liber Abaci* introduced the sequence to Western European mathematics,[6] although the sequence had been described earlier in Indian mathematics.[7][8][9] The sequence



A tiling with squares whose side lengths are successive Fibonacci numbers



The Fibonacci spiral: an approximation of the golden spiral created by drawing circular arcs connecting the opposite corners of squares in the Fibonacci tiling;[4] this one uses squares of sizes 1, 1, 2, 3, 5, 8, 13 and 21.

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 (0 < cash && 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

Goal. Given income, calculate proper tax rate.

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

```
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:

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

A workable Program. And why?

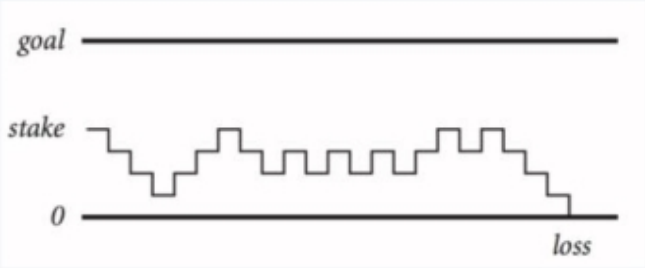
PQif.java

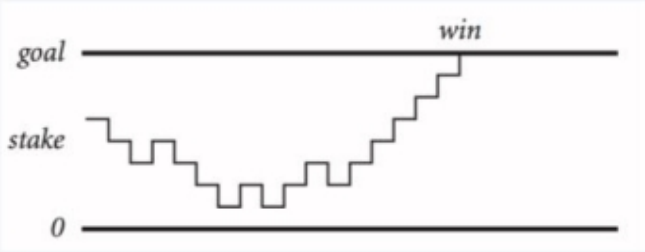
```
1  public class PQif {
2     public static void main (String[] args) {
3        double income = Double.parseDouble( args[0] );
4        double rate = 0.35;
5        if (income < 311950) rate = 0.33;
6        if (income < 174700) rate = 0.28;
7        if (income < 114650) rate = 0.25;
8        if (income < 47450)  rate = 0.22;
9        System.out.println( rate );
10    }
11 }
```

Comparing with:

```
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 );
   }
}
```

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.

```
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 (cash == 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.

2. Conditionals & Loops

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

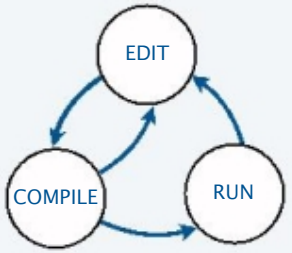
Debugging

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.



"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.

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 × 2 × 2 × 7 × 13 × 13 × 397

98 = 2 × 7× 7

17 = 17

11,111,111,111,111,111 = 2,071,723 × 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
      }
   }
}
```

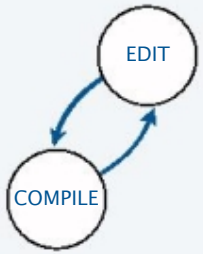



This program has bugs!

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



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

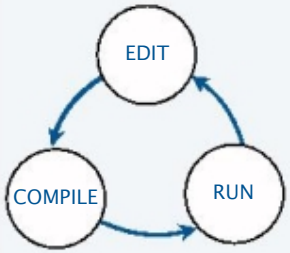
need terminating semicolons

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.



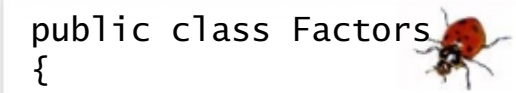
```
% javac Factors.java
% java Factors        <-- oops, need argument
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: 0
       at Factors.main(Factors.java:5)
```

```
% java Factors 98        you will see this message!
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
```

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

98 = 2 × 7× 7 ✓



```
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 start at 2 since 0 and 1 are not factors

need braces

This working program still has bugs!

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).

```
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.

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

```
% 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
```

```
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 $i \le n/i$
- 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 111111111111111
11 239 4649 909091
% java Factors 1111111111111111
2071723 5363222357
```

might work, but way too slow

immediate

```
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();
   }
}
```

implement the change

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*

```
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();
   }
}
```

Lesson. Performance matters!

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.

COMPILE your program to create an executable file.

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

TEST your program on realistic and real input data.

SUBMIT your program for independent testing and approval.

syntax error

runtime error

semantic error

performance error

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