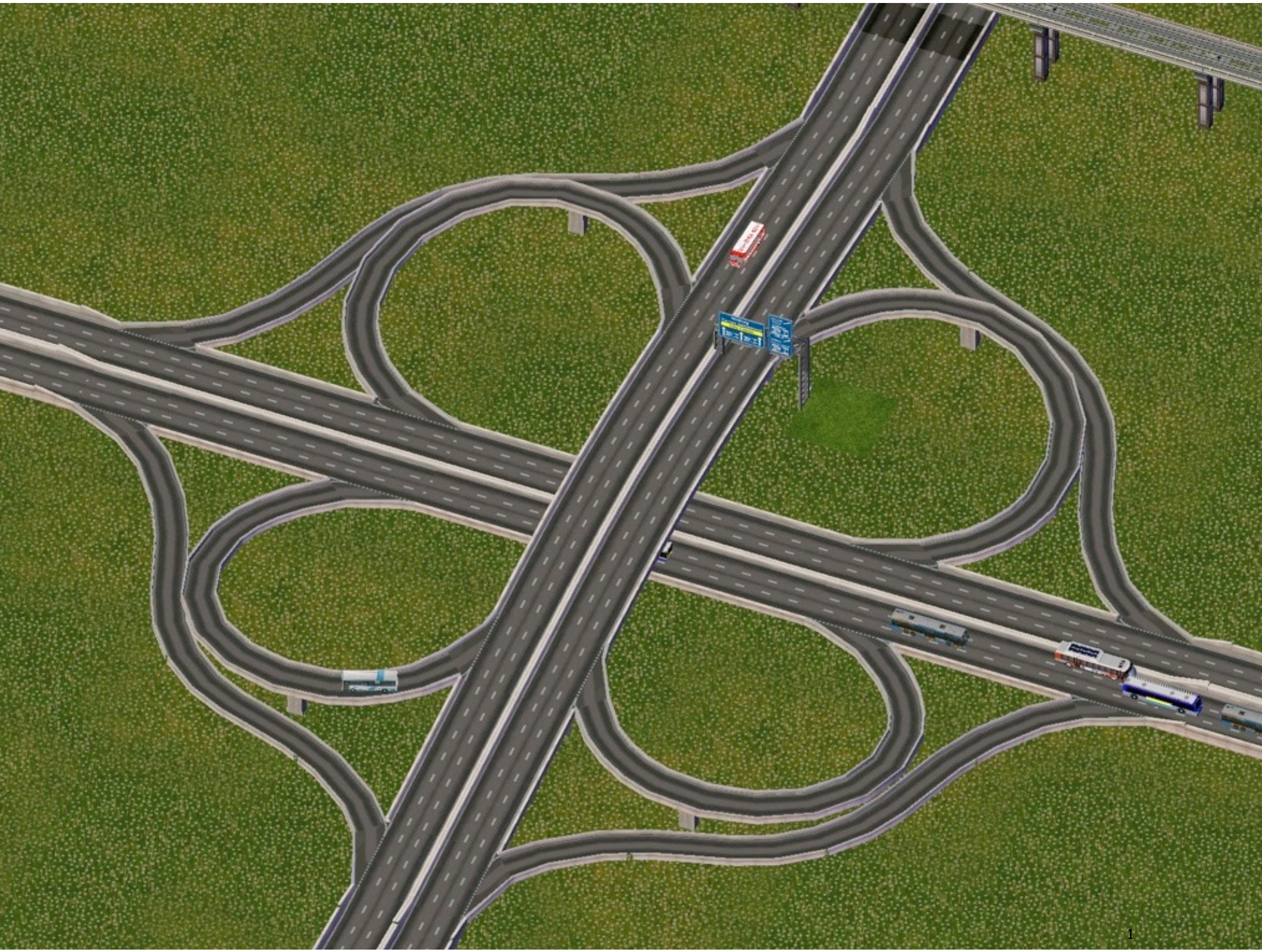
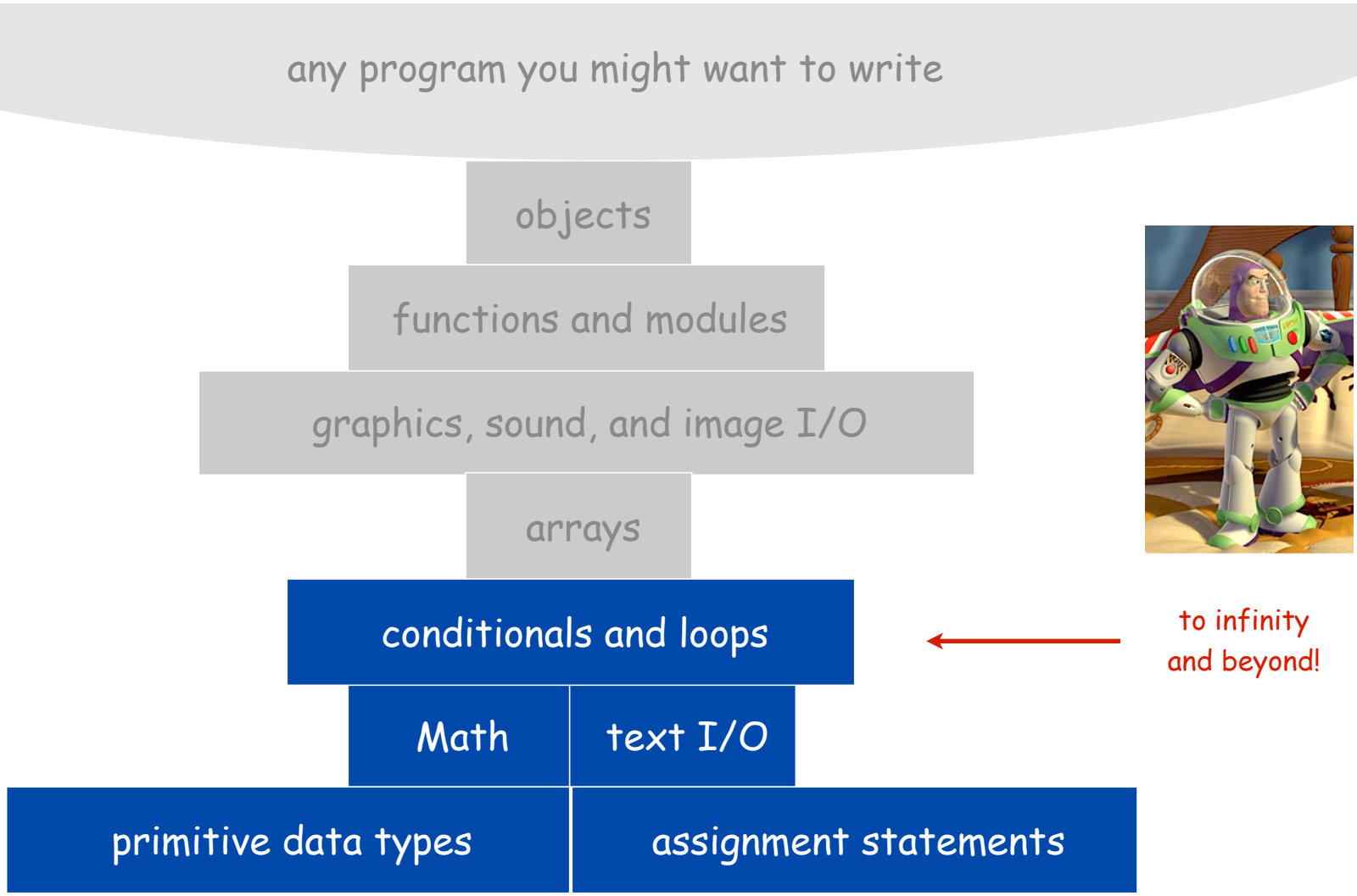


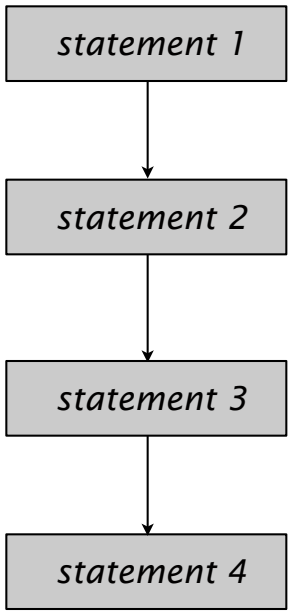
1.3 Conditionals and Loops



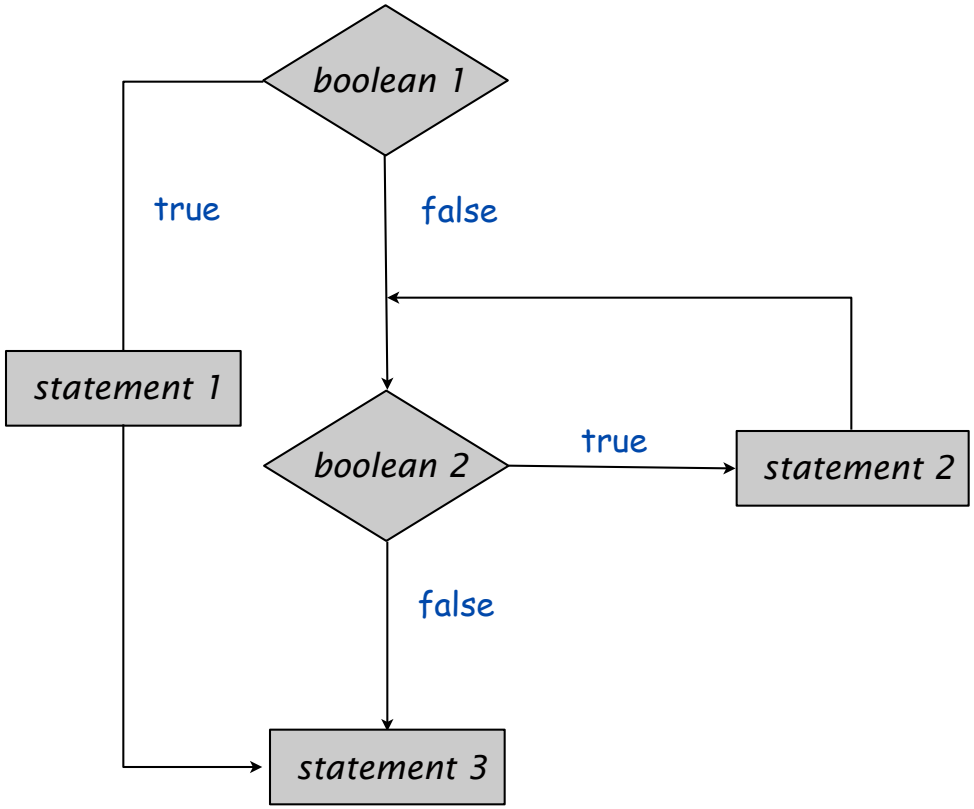
Conditionals and Loops

Control flow.

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



straight-line control flow



control flow with conditionals and loops

Conditionals

If Statement

The `if` statement. A common branching structure.

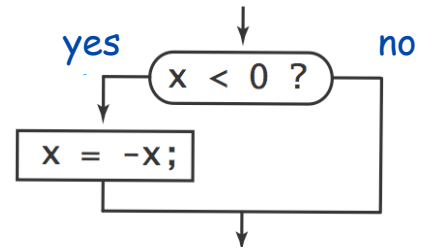
- Evaluate a `boolean` expression.
- If `true`, execute some statements.
- `else` option: If `false`, execute other statements.

boolean expression

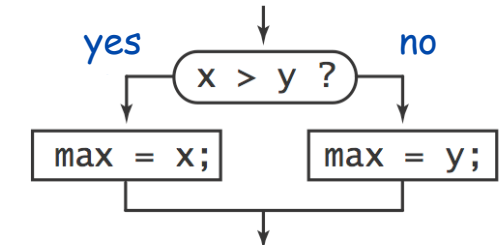
sequence of statements

```
if ( x > y )
{
   int t = x;
   x = y;
   y = t;
}
```

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




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



If Statement

Ex. Take different action depending on value of variable.

```
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
```

If Statement Examples

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

absolute value

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

maximum

```
if (x > y)
{
   int t = x;
   x = y;
   y = t;
}
```

2-sort

x > y before

x	y	t
1234	99	undefined
1234	99	1234
99	99	1234
99	1234	1234

x < y after

```
if (den == 0) System.out.println("Division by zero");
else          System.out.println("Quotient = " + num/den);
```

error check for division operation

```
double discriminant = b*b - 4.0*c;
if (discriminant < 0.0)
{
   System.out.println("No real roots");
}
else
{
   System.out.println((-b + Math.sqrt(discriminant))/2.0);
   System.out.println((-b - Math.sqrt(discriminant))/2.0);
}
```

error check for quadratic formula

Loops

While Loop

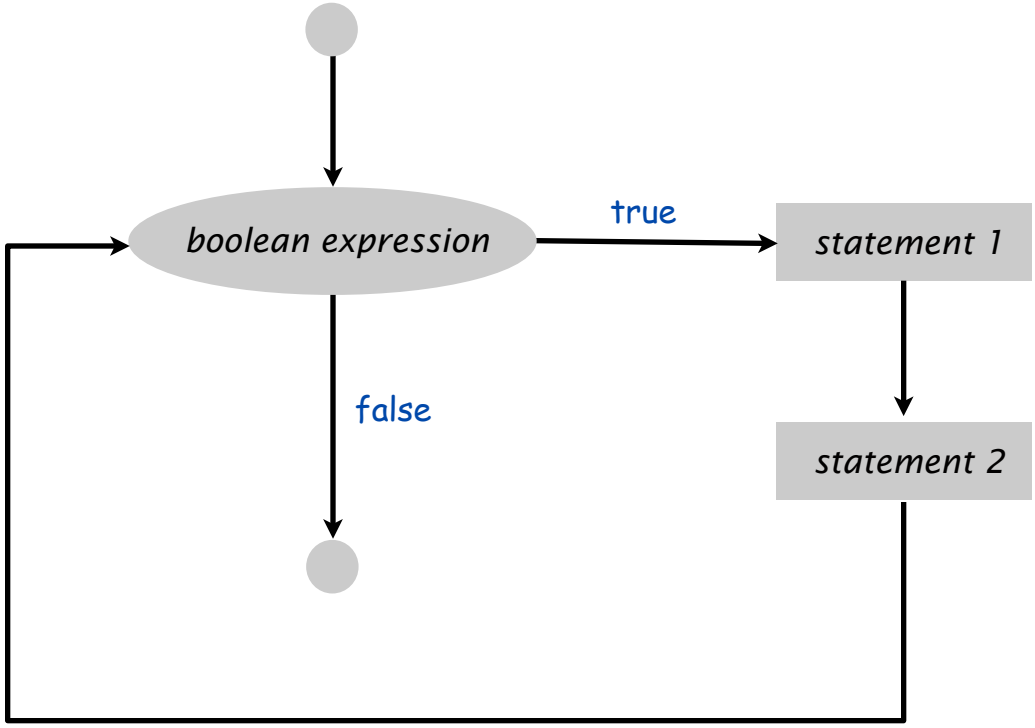
The `while` loop. A common repetition structure.

- Check a boolean expression.
- Execute a sequence of statements.
- Repeat.

loop continuation condition

```
while (boolean expression)
{
    statement 1;
    statement 2;
}
```

loop body



While Loop Example: Powers of Two

Ex. Print powers of 2 that are ≤ 2^n.

- Increment `i` from `0` to `n`.
- Double `v` each time.

```
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

n = 6

```
1
2
4
8
16
32
64
```

Powers of Two (full program)

```
public class PowersOfTwo
{
   public static void main(String[] args)
   {

      // last power of two to print
      int n = Integer.parseInt(args[0]);


      int i = 0;  // loop control counter
      int v = 1;  // current power of two
      while (i <= n)
      {
         System.out.println(v);
         i = i + 1;
         v = 2 * v;
      }
   }
}
```

print ith power of two

```
% java PowersOfTwo 3
1
2
4
8
% java PowersOfTwo 6
1
2
4
8
16
32
64
```

While Loop Challenge

Anything wrong with the following code?

```
public class PowersOfTwo {
   public static void main(String[] args) {
      int N = Integer.parseInt(args[0]);
      int i = 0;  // loop control counter
      int v = 1;  // current power of two
      while (i <= N)
         System.out.println(v);
         i = i + 1;
         v = 2 * v;
   }
}
```

While Loop Example: Square Root

Goal. Implement `Math.sqrt()`.

```
% java Sqrt 60481729
7777.0
```

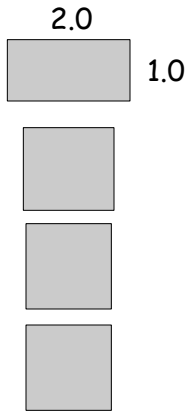
Newton-Raphson method to compute the square root of c:

- 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.

i	t	2/t	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



"A wonderful square root. Let's hope it can be used for the good of mankind."

While Loop Example: Square Root

Goal. Implement `Math.sqrt()`.

Newton-Raphson method to compute the square root of 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.

```
public class Sqrt
{
   public static void main(String[] args)
   {
      double EPS = 1E-15;
      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);
   }
}
```

error tolerance

```
% java Sqrt 2.0
1.414213562373095
```

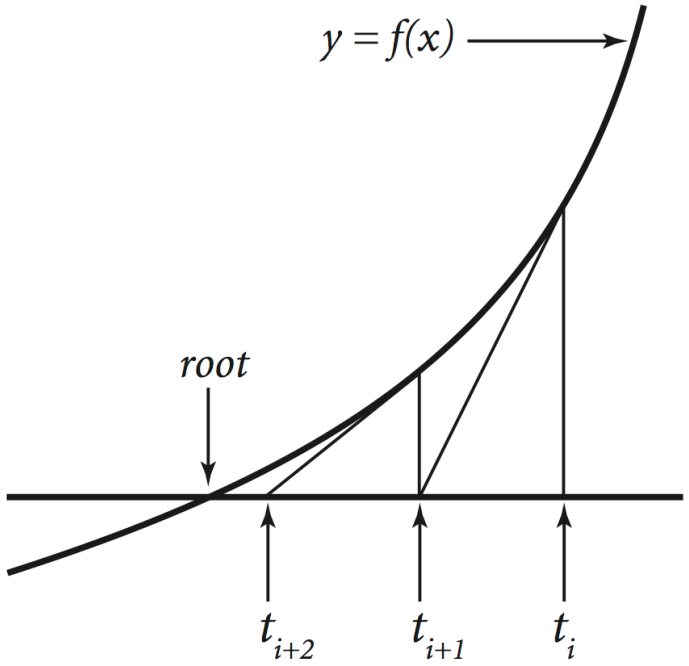
15 decimal digits of accuracy in 5 iterations

Newton-Raphson Method

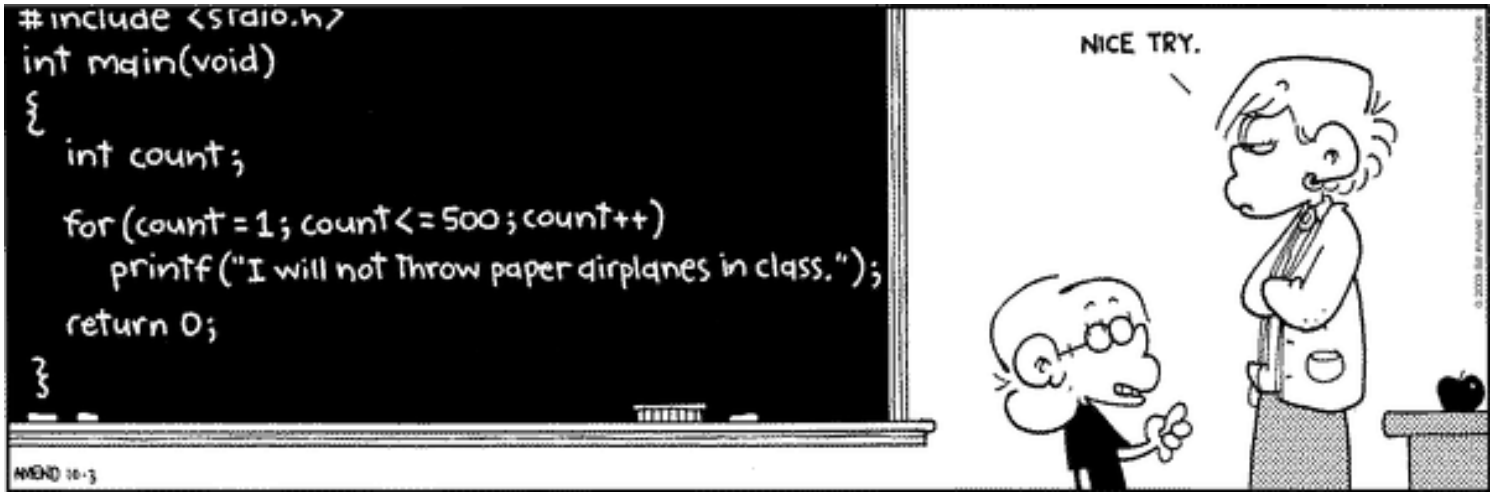
Square root method explained (some math omitted).

- Goal: find root of function f(x).
- 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.

$f(x) = x^2 - c$ to compute $\sqrt{c}$



The For Loop



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The For Loop

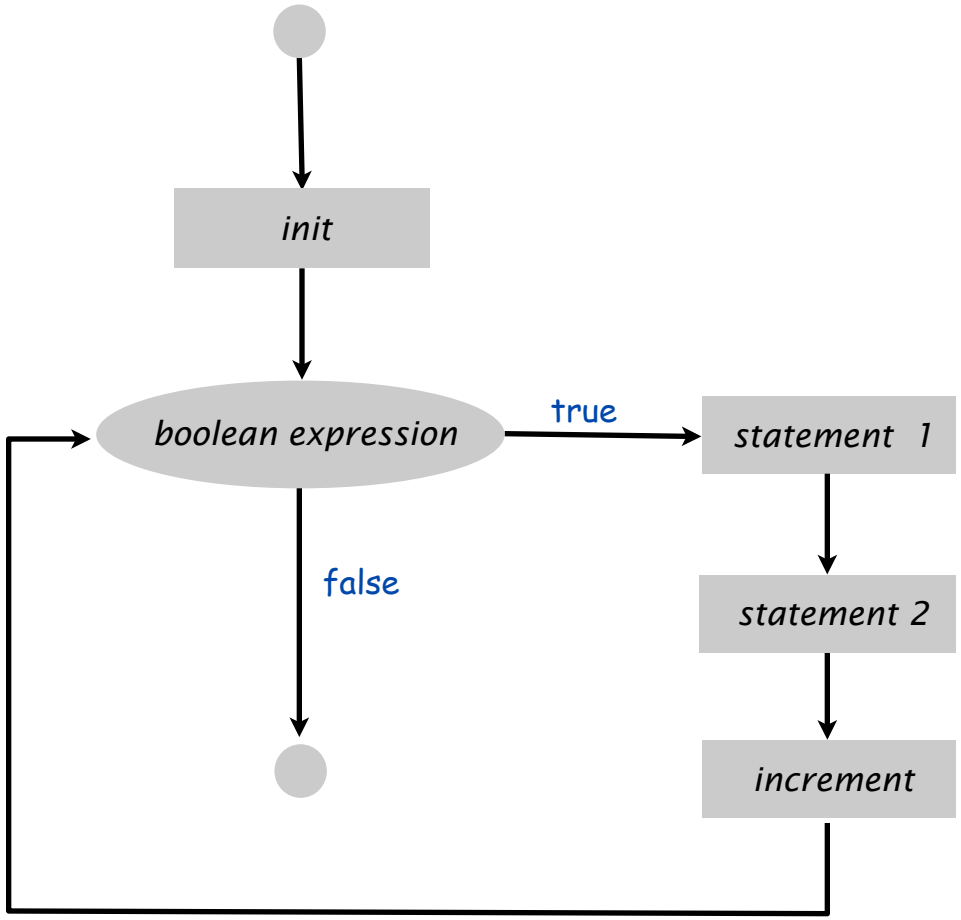
The `for` loop. Another common repetition structure.

- Execute initialization statement.
- Check boolean expression.
- Execute sequence of statements.
- Execute increment statement.
- Repeat.

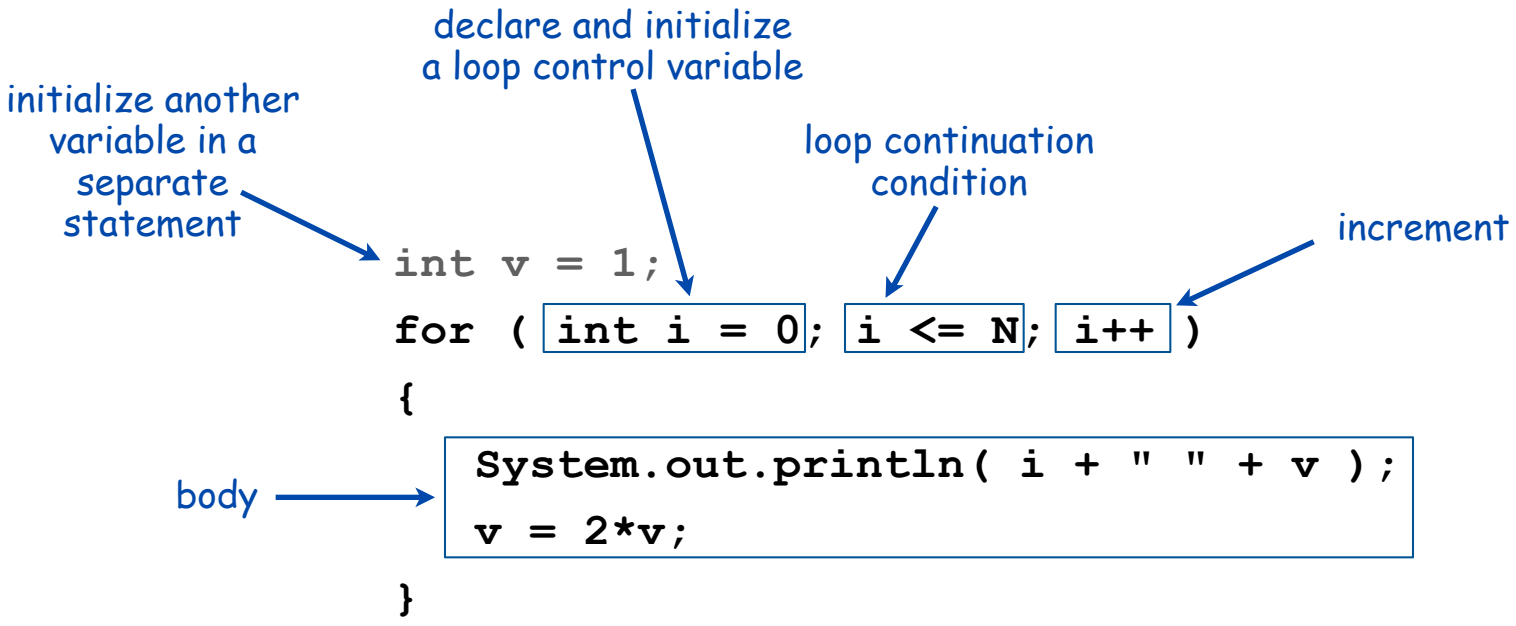
loop continuation condition

```
for (init; boolean expression; increment)
{
    statement 1;
    statement 2;
}
```

body



Anatomy of a `for` Loop



prints table of powers of two

Anatomy of a `for` Loop

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

v	i	output
1		
1	0	
1	0	0 1
2	0	
2	1	
2	1	1 2
4	1	
4	2	
4	2	2 4
8	2	
8	3	
8	3	3 8

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++;
}
```

Why `for` loops? Can provide more compact and understandable code.

For Loops: Subdivisions of a Ruler

Create subdivision of a ruler.

- Initialize `ruler` to single space.
- For each value `i` from `1` to `N`:

  sandwich two copies of `ruler` on either side of `i`.

```
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 "

end-of-loop trace

For Loops: Subdivisions of a Ruler

```
% java Ruler 1
 1

% java Ruler 2
 1 2 1

% java Ruler 3
 1 2 1 3 1 2 1

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

% java Ruler 5
 1 2 1 3 1 2 1 4 1 2 1 3 1 2 1 5 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
```

$2^{100} - 1$ = 1,267,650,600,228,229,401,496,703,205,375 integers in output

Observation. Loops can produce a huge amount of output!

Loop Examples

```
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

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

print a table of function values

N = 4

```
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

Nesting

Nesting Conditionals and Loops

Nesting. Use a conditional or a loop within a conditional or a loop

- Enables complex control flows.
- Adds to challenge of debugging.

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

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


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

Nested If Statements

Ex. Pay a certain tax rate depending on income level.

Income	Rate
0 - 47,450	22%
47,450 – 114,650	25%
114,650 – 174,700	28%
174,700 – 311,950	33%
311,950 -	35%

5 mutually exclusive alternatives

Nested If Statements

Use nested if statements to handle multiple alternatives

```
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;
               }
         }
    }
```

Nested If-Else Statements

Use nested if statements to handle multiple alternatives

```
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

Nested If-Else Statements

Use nested if statements to handle multiple alternatives

```
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
within an if statement

Nested If-Else Statements

Use nested if statements to handle multiple alternatives

```
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
within an if statement
within an if statement

Nested If-Else Statements

Need all those braces? Not always:

```
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;
```

is shorthand for

```
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;
               }
         }
    }
```

but BE CAREFUL when nesting if-else statements (see Q&A p. 75).

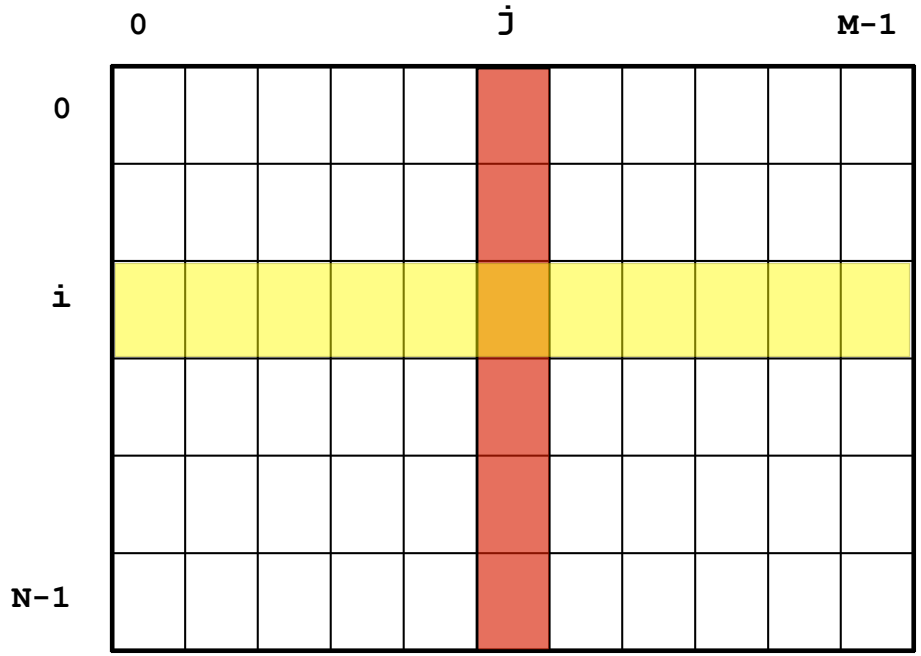
Nested If Statement Challenge

Anything wrong with the following code?

```
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;
```

Nested for loops

Ex. Visit each location in a two-dimensional table (stay tuned for arrays).




```
for (int i = 0; i < N; i++)
     for (int j = 0; j < M; j++)
           Do something at entry (i,j);
```

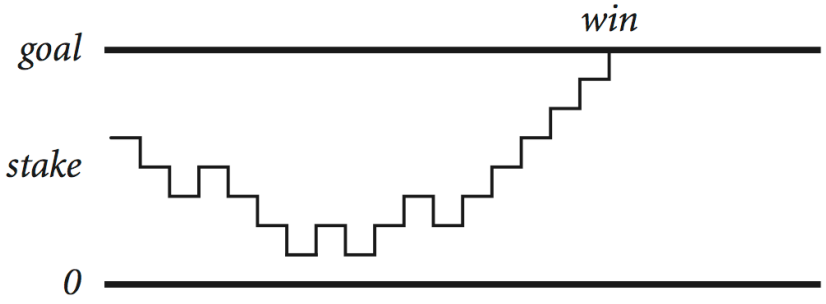
Nesting Example: Gambler's Ruin

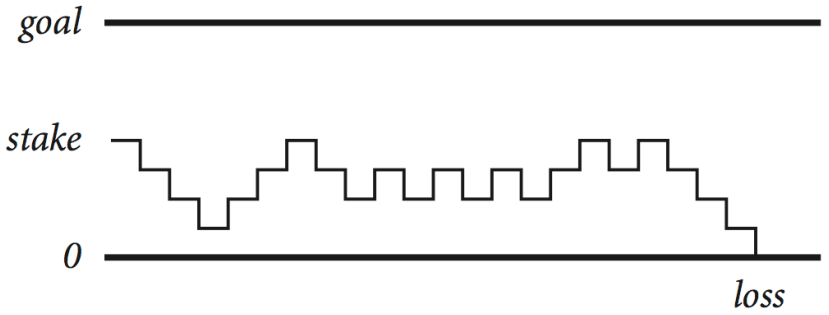
Gambler's ruin. Gambler starts with $stake and places $1 fair bets until going broke or reaching $goal.

- What are the chances of winning?
- How many bets will it take?

One approach. Monte Carlo simulation.

- Flip digital coins and see what happens.
- Repeat and compute statistics.





Nesting Example: Gambler's Ruin Simulation

```
public class Gambler
{
    public static void main(String[] args)
    {
      // Get parameters from command line.
      int stake  = Integer.parseInt(args[0]);
      int goal   = Integer.parseInt(args[1]);
      int trials = Integer.parseInt(args[2]);

      // Count wins among args[2] trials.
      int wins   = 0;
      for (int i = 0; i < trials; i++)
      {
         // Do one gambler's ruin experiment.
         int t = stake;
         while (t > 0 && t < goal)
         {
            // flip coin and update
            if (Math.random() < 0.5) t++;
            else                     t--;
         }
         if (t == goal) wins++;
      }
      System.out.println(wins + " wins of " + trials);
   }
}
```

if statement

Nesting Example: Gambler's Ruin Simulation

```
public class Gambler
{
    public static void main(String[] args)
    {
      // Get parameters from command line.
      int stake  = Integer.parseInt(args[0]);
      int goal   = Integer.parseInt(args[1]);
      int trials = Integer.parseInt(args[2]);

      // Count wins among args[2] trials.
      int wins   = 0;
      for (int i = 0; i < trials; i++)
      {
         // Do one gambler's ruin experiment.
         int t = stake;
         while (t > 0 && t < goal)
         {
            // flip coin and update
            if (Math.random() < 0.5) t++;
            else                     t--;
         }
         if (t == goal) wins++;
      }
      System.out.println(wins + " wins of " + trials);
   }
}
```

if statement within a while loop

Nesting Example: Gambler's Ruin Simulation

```
public class Gambler
{
    public static void main(String[] args)
    {
      // Get parameters from command line.
      int stake  = Integer.parseInt(args[0]);
      int goal   = Integer.parseInt(args[1]);
      int trials = Integer.parseInt(args[2]);

      // Count wins among args[2] trials.
      int wins   = 0;
      for (int i = 0; i < trials; i++)
      {
         // Do one gambler's ruin experiment.
         int t = stake;
         while (t > 0 && t < goal)
         {
            // flip coin and update
            if (Math.random() < 0.5) t++;
            else                     t--;
         }
         if (t == goal) wins++;
      }
      System.out.println(wins + " wins of " + trials);
   }
}
```

if statement
within a while loop
within a for loop

Digression: Simulation and Analysis

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
```

after a substantial wait….

Fact. Probability of winning = stake ÷ goal.

Fact. Expected number of bets = stake × desired gain.

Ex. 20% chance of turning $500 into $2500,
but expect to make one million $1 bets.

500/2500 = 20%

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

Remark. Both facts can be proved mathematically.
For more complex scenarios, computer simulation is often the best plan of attack.

Debugging

Debugging Example

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

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

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

$$17 = 17$$

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

Note: 1 is not prime. (else it would have to be in every factorization)

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

Debugging: 99% of Program Development

Programming. A process of finding and fixing mistakes.

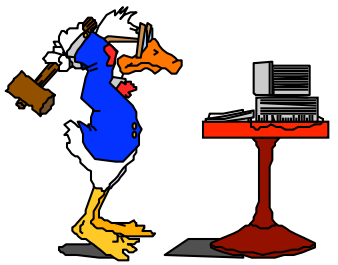
- Compiler error messages help locate syntax errors.
- Run program to find semantic and performance errors.

```
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)
            System.out.print(i + " ")
            N = N / i
      }
   }
}
```

Check whether i is a factor.

if i is a factor print it and divide it out

This program has bugs!

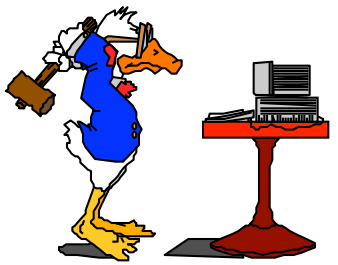


Debugging: Syntax Errors

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)
            System.out.print(i + " ")
            N = N / i
      }
   }
}
```



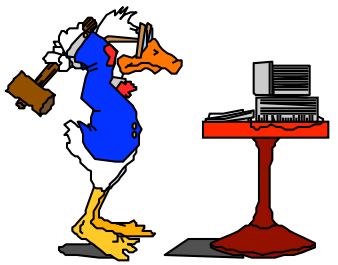
Debugging: Syntax Errors

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)
            System.out.print(i + " ")
            N = N / i
      }
   }
}
```

```
% javac Factors.java
Factors.java:6: ';' expected
      for (i = 0; i < N; i++)
      ^
1 error  <-- the FIRST error
```



Debugging: Syntax Errors

Syntax error. Illegal Java program.

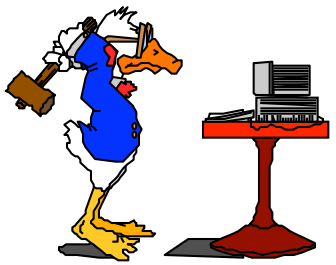
- Compiler error messages help locate problem.
- Goal: no errors and a file named `Factors.class`.

```
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)
            System.out.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.
- Two kinds: runtime (program crashes) and logic (program gets wrong answer).

```
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;
      }
   }
}
```

(this is really a "pilot error")

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

you will see this message!

Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

- Run program to identify problem.
- Two kinds: runtime (program crashes) and logic (program gets wrong answer).

```
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;
      }
   }
}
```

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

Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

- Run program to identify problem.
- Two kinds: runtime (program crashes) and logic (program gets wrong answer).

```
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;
      }
   }
}
```

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

Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

- Run program to identify problem.
- Two kinds: runtime (program crashes) and logic (program gets wrong answer).

```
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;
      }
   }
}
```

```
% javac Factors.java
% 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
??? infinite loop
```

Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

- Run program to identify problem.
- Two kinds: runtime (program crashes) and logic (program gets wrong answer).

```
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;  }
      }
   }
}
```

Semantic (logic) error:
indents do not imply braces

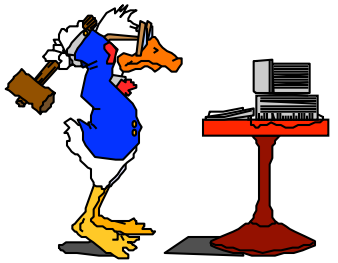
Debugging: The Beat Goes On

Success? Program factors 98 = 2 7 7.

- Time to try it for other inputs.

```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]);
      for (int i = 2; i < N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            System.out.print(i + " ");
            N = N / i;
         }
      }
   }
}
```

```
% java Factors 98
2 7 7 %        <-- need newline
% java Factors 5
%              <-- ??? no output
% java Factors 6
2 %            <-- ??? where's the 3?
```



Debugging: The Beat Goes On

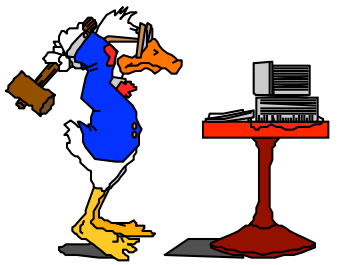
Success? Program factors 98 = 2 7 7.

- Time to try it for other inputs.
- Add print statements to produce a 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)
         {
            System.out.println(i + " ");
            N = N / i;
         }
         System.out.println("TRACE " + i + " " + N);
      }
   }
}
```

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

AHA!
Print out N
after for loop
(if it is not 1)



Debugging: Success?

Success? Program seems to work

- Add code for corner case, add comments.
- Remove trace to try larger inputs

```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]);
      for (int i = 2; i < N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            // System.out.print(i + " ");
            N = N / i;
         }
// System.out.println("TRACE " + i + " " + N);
      }
      if (N > 1) System.out.println(N);
      else       System.out.println();
   }
}
```

"Comment out" trace code (may need it later)

Corner case: print largest factor (and new line)

Time to document code (if not earlier).

??? %$%@$#!! 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
```

Debugging: Performance Errors

Performance error. Apparently correct program, but too slow.

- Are all iterations of inner loop necessary?
- Improve or change underlying algorithm.

```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]);
      for (int i = 2; i < N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            System.out.print(i + " ");
            N = N / i;
         }
      }
      if (N > 1) System.out.println(N);
      else       System.out.println();
   }
}
```

```
% java Factors 11111111
11 73 101 137
% java Factors 11111111111
21649 513239
% java Factors 111111111111
11 239 4649 909091
% java Factors 1111111111111111
2071723
```

very long wait

Debugging: Performance Errors

Performance error. Apparently correct program, but too slow.

- Are all iterations of inner loop necessary?
- Improve or change underlying algorithm.

```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]);
      for (int i = 2; i * i < N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            System.out.print(i + " ");
            N = N / i;
         }
      }
      if (N > 1) System.out.println(N);
      else       System.out.println();
   }
}
```

Fixes performance error: terminate when i*i > N since no larger factors left

```
% java Factors 11111111
11 73 101 137
% java Factors 11111111111
21649 513239
% java Factors 11111111111111
11 239 4649 909091
% java Factors 1111111111111111
2071723 5363222357
%
```

Debugging: Back to Semantic Errors!

Fresh semantic error. Fast program (now), but new logic error.

- Was performance fix exactly right?
- Again, consider (possibly new) corner cases.

```
% java Factors 24
2 2 2 3
% java Factors 25
25
% java Factors 49
49
%
```

```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]);
      for (int i = 2; i * i < N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            System.out.print(i + " ");
            N = N / i;
         }
      }
      if (N > 1) System.out.println(N);
      else       System.out.println();
   }
}
```

Can't handle perfect squares!

Debugging: Back to Semantic Errors!

Fresh semantic error. Fast program (now), but new logic error.

- Was performance fix exactly right?
- Again, consider (possibly new) corner cases.

```
% java Factors 24
2 2 2 3
% java Factors 25
5 5
% java Factors 49
7 7
%
```

```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]);
      for (int i = 2; i * i <= N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            System.out.print(i + " ");
            N = N / i;
         }
      }
      if (N > 1) System.out.println(N);
      else       System.out.println();
   }
}
```

Execute loop body if i * i == N

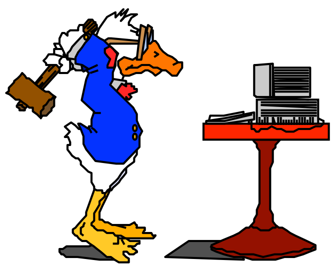
Program Development: Analysis

Q. How large an integer can I factor?

```
% java Factors 2147483647
2147483647

% java Factors 2147483646
2 3 3 7 11 31 151 331

% java Factors 9223372036854775807
7 7 73 127 337 92737 649657

% java Factors 9201111169755555703
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 . . .
```

- 2147483647 ← largest `int` (a Mersenne prime: 2^{31}-1)
- 2147483646 ← 2nd-largest `int`
- 9223372036854775807 ← largest `long` (but not a Mersenne prime)
- 9201111169755555703 ← largest prime `long`

Oh no! Another semantic error?



Debugging: Back to Semantic Errors Again!

Another semantic error. Very big prime (another corner case) has logic error.

- Q: How big can candidate factor **i** be?
- A: Too big to be an **int** !

```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]);
      for (long i = 2; i * i <= N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            System.out.print(i + " ");
            N = N / i;
         }
      }
      if (N > 1) System.out.println(N);
      else       System.out.println();
   }
}
```

long i now big enough to be square root of biggest **N**

```
% java Factors 92011111169755555703
92011111169755555703
```

Program Development: Back to Analysis

Q. Once again, how large an integer can I factor?

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


% java Factors 92011111169755555703
92011111169755555703
```

after 45 seconds of computing....

in largest factor ⟶

digits	(i < N)	(i*i <= N)
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, using analytic number theory

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

Debugging Your Program

Debugging Your Program. [summary]

1. Edit the program (type in code).

2. Compile it.

   Compiler says: That's not a legal program !

   Back to step 1 to fix your syntax errors.

3. Run it.

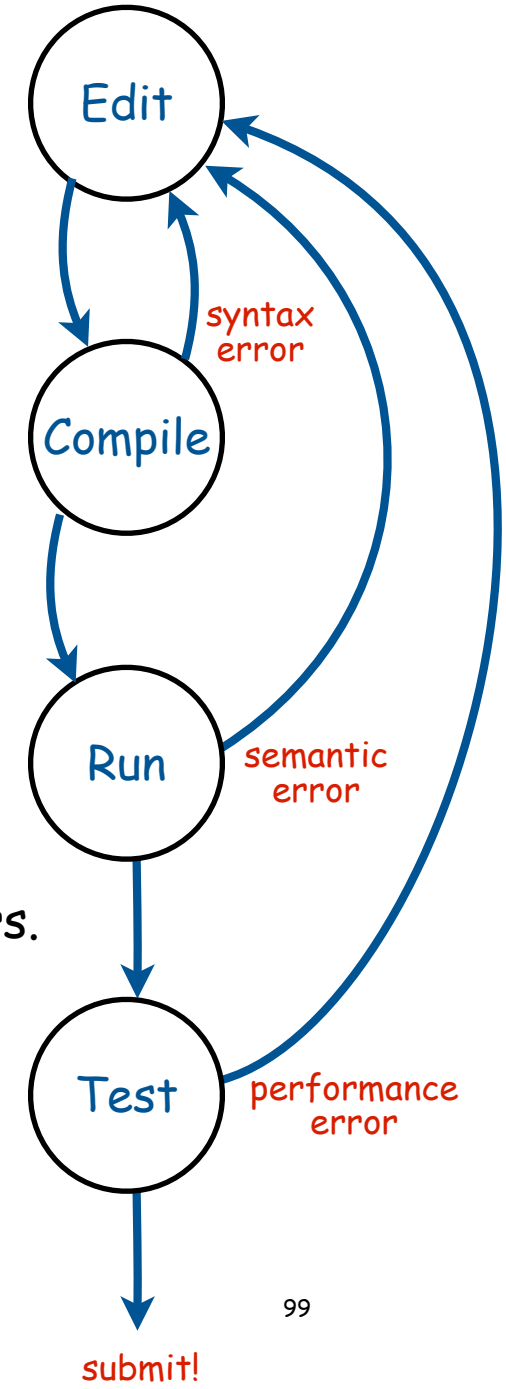
   Result is bizarrely (or subtly) wrong !

   Back to step 1 to fix your semantic (runtime and/or logic) errors.

4. Test it.

   Too slow?

   Back to step 1 to try a different algorithm.



99% of program development

Debugging. Cyclic process of editing, compiling, and fixing errors.

- 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. "

Sir Maurice Wilkes

Good news: Can use computer to test program.

Bad news: Conditionals/loops open up huge number of possibilities.

Really bad news: Cannot use computer to automatically find all bugs. ← stay tuned

The First Bug ?

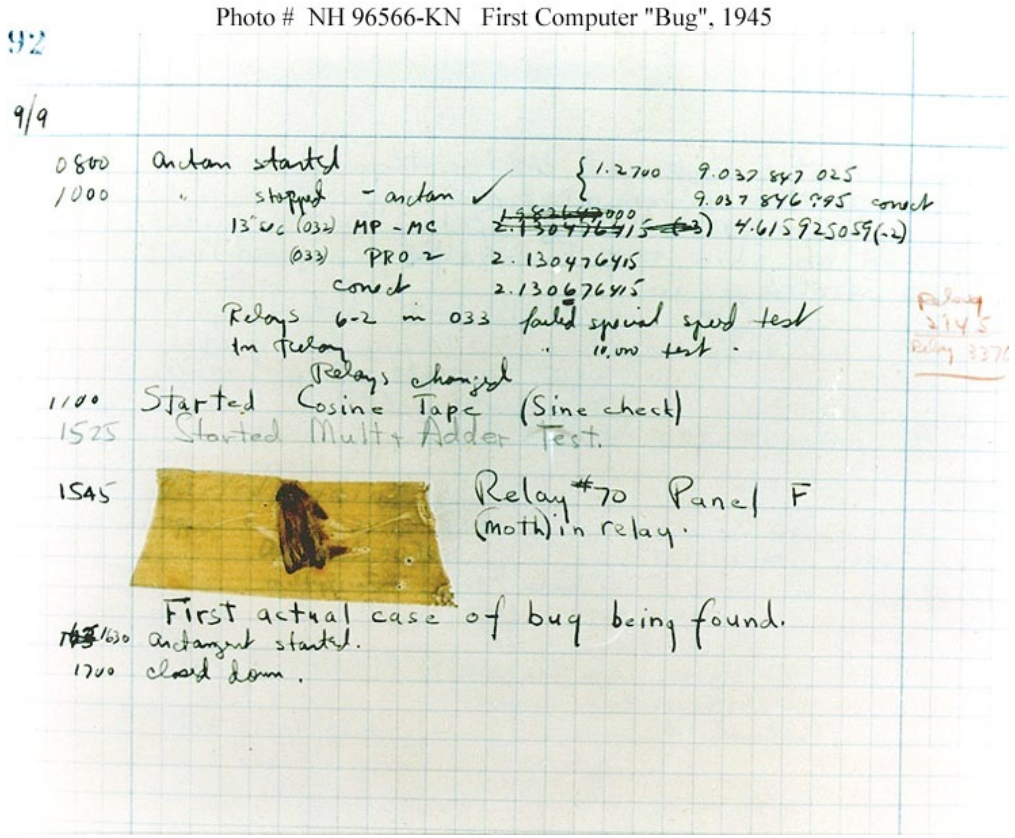


Photo # NH 96566-KN First Computer "Bug", 1945

9/9

0800 Arctan started
1000 " stopped - arctan ✓
13°c (032) MP - MC 4.615925059(-2)
(033) PRO 2 2.13047615
correct 2.13067615
Relays 6-2 in 033 failed special speed test
In relay " 10,000 test.
Relays changed
1100 Started Cosine Tape (Sine check)
1525 Started Multy Adder Test.
1545 Relay #70 Panel F
(moth) in relay.
First actual case of bug being found.
1700 closed down.

http://www.history.navy.mil/photos/images/h96000/h96566kc.htm


Lieutenant Grace Murray Hopper