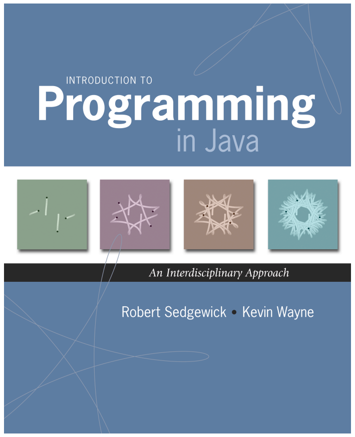
1.3 Conditionals and Loops



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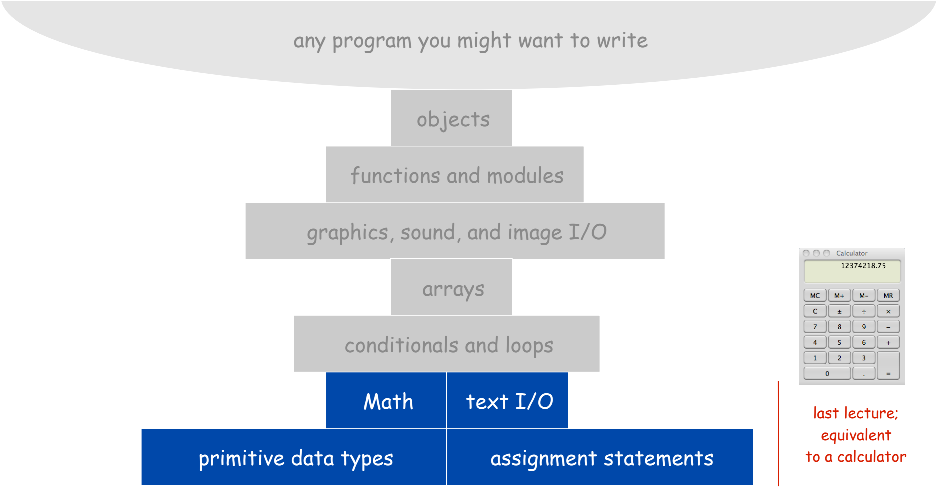
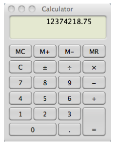
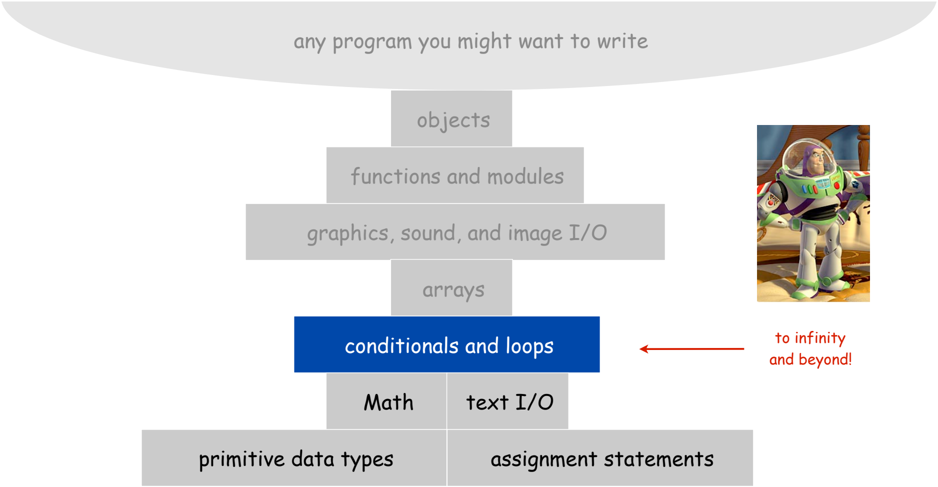
A Foundation for Programming





last lecture; equivalent to a calculator

A Foundation for Programming

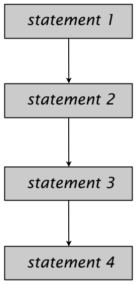


to infinity and beyond!

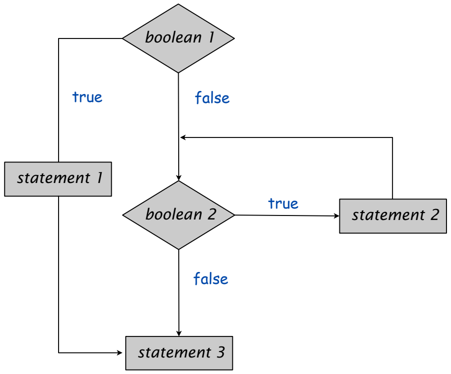
Conditionals and Loops

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

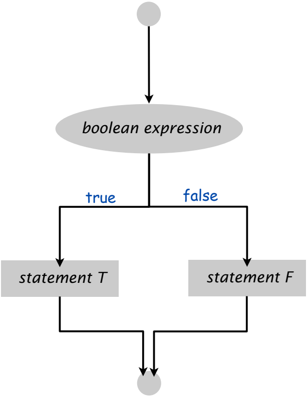
If Statement

The `if` statement. A common branching structure.

- Check `boolean` condition.
- If `true`, execute some statements.
- If `false`, execute other statements.

```
if (boolean expression)
{
    statement T;
}
else
{
    statement F;
}
```

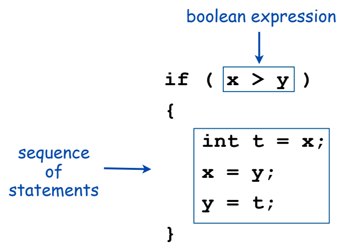
can be any sequence of statements



If Statement

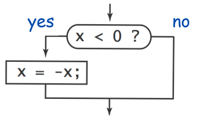
The `if` statement. A common branching structure.

- Evaluate a **`boolean`** expression.
- If **`true`**, execute some statements.
- If **`false`**, execute other statements.

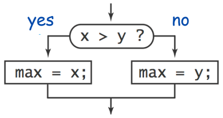


```
if ( x > y )
{
   int t = x;
   x = y;
   y = t;
}
```

```
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

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

put x and y into sorted order	`if (x > y)`
	`{`
	`   int t = x;`
	`   y = x;`
	`   x = t;`
	`}`

maximum of x and y	`if (x > y) max = x;`
	`else       max = y;`

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

error check for quadratic formula	`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);`
	`}`

If Statement Examples

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

put x and y into sorted order	`if (x > y)`
	`{`
	`   int t = x;`
	`   y = x;`
	`   x = t;`
	`}`

maximum of x and y	`if (x > y) max = x;`
	`else       max = y;`

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	`else`
	`{`
	`   System.out.println((-b + Math.sqrt(discriminant))/2.0);`
	`   System.out.println((-b - Math.sqrt(discriminant))/2.0);`
	`}`

While Loop

While Loop

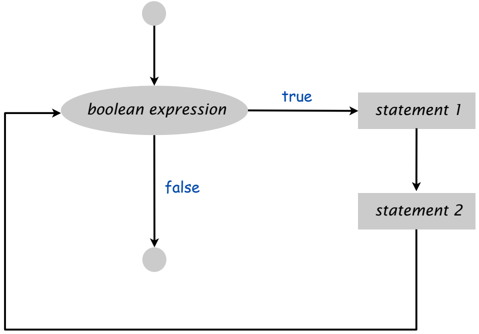
The **while** loop. A common repetition structure.

- 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 first `n` powers of 2.

- Increment `i` from `1` 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 4
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

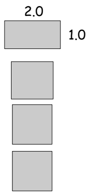
Goal. Implement `Math.sqrt()`.

```
% 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_i	$2/t_i$	average
0	2.0	1.0	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."

Copyright 2004, Sidney Harris
http://www.sciencecartoonsplus.com

While Loop Example: Square Root

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
```

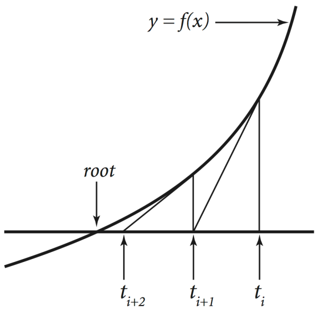
15 decimal digits of accuracy in 5 iterations

Newton-Raphson Method

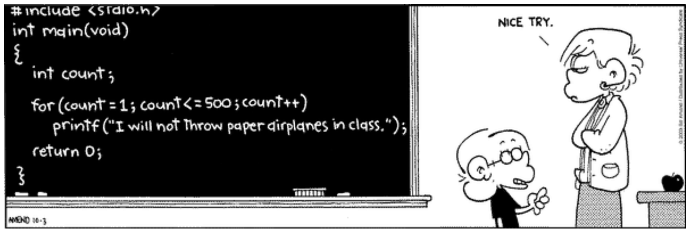
Square root method explained (some math omitted).

- 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 √c



The For Loop



#include <stdio.h>
int main(void)
{
int count;
for (count=1; count<=500; count++)
printf("I will not Throw paper airplanes in class.");
return 0;
}
AMEND 10-3
NICE TRY.

Copyright 2004, FoxTrot by Bill Amend
www.ucomics.com/foxtrot/2003/10/03

The For Loop

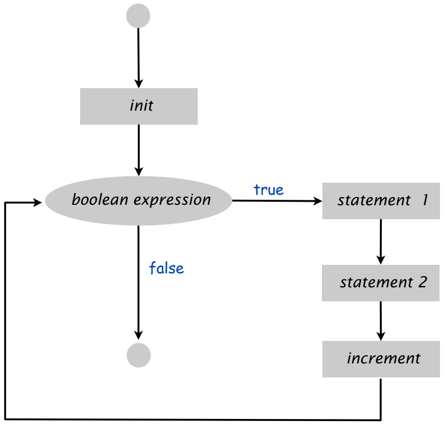
The `for` loop. Another common repetition structure.

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

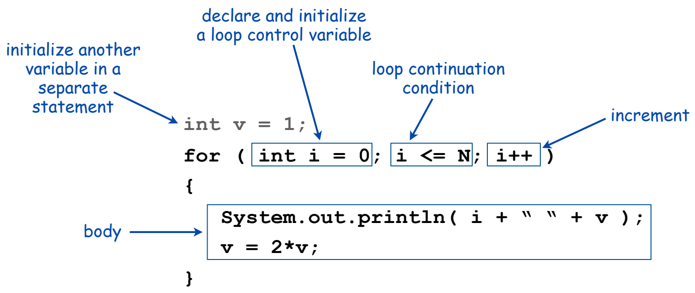
loop continuation condition

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

body



Anatomy of a For Loop



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

For Loops: Subdivisions of a Ruler

Create subdivision of a ruler.

- Initialize `ruler` to empty string.
- 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 "

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
```

Observation. Loops can produce a huge amount of output!

Loop Examples

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

print largest power of two less than or equal to N	`int v = 1;`
	`while (v <= N/2)`
	`   v = 2*v;`
	`System.out.println(v);`

compute a finite sum (1 + 2 + . . . + N)	`int sum = 0;`
	`for (int i = 1; i <= N; i++)`
	`   sum += i;`
	`System.out.println(sum);`

compute a finite product (N! = 1 × 2 × . . . × N)	`int product = 1;`
	`for (int i = 1; i <= N; i++)`
	`   product *= i;`
	`System.out.println(product);`

print a table of function values	`for (int i = 0; i <= N; i++)`
	`   System.out.println(i + " " + 2*Math.PI*i/N);`

print the ruler function (see Program 1.2.1)	`String ruler = " ";`
	`for (int i = 1; i <= N; i++)`
	`   ruler = ruler + i + ruler;`
	`System.out.println(ruler);`

Nesting

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

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).

If-Else 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;
```

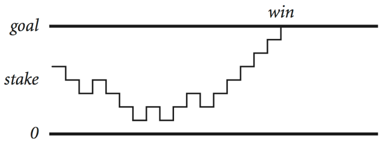
Nesting Example: Gambler's Ruin

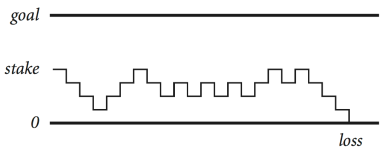
Gambler's ruin. Gambler starts with $stake and places $1 fair bets until going broke or reaching $goal.

- 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
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.

Control Flow Summary

Control flow.

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

Control Flow	Description	Examples
Straight-line programs	All statements are executed in the order given.	
Conditionals	Certain statements are executed depending on the values of certain variables.	`if` `if-else`

Loops	Certain statements are executed repeatedly until certain conditions are met.	`while`
		`for`
		`do-while`

Debugging

Admiral Grace Murray Hopper

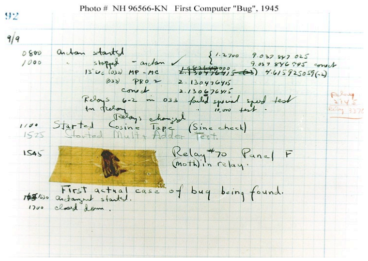


Photo # NH 96566-KN First Computer "Bug", 1945

92

9/9

0800 anctan started
1000 " stopped - anctan ✓ {1.2700 9.037 847 025 / 9.037 846 995 conect
13"uc (032) MP-MC ~~2.130476415~~ 4.615925059(-2)
(033) PRO 2 2.130476415
conect 2.130676415
Relays 6-2 in 033 failed special speed test
in relay " 11.000 test.
Relays changed
1100 Started Cosine Tape (Sine check)
1525 Started Mult + Adder Test.
1545 Relay #70 Panel F
(moth) in relay.
First actual case of bug being found.
1630 antangent started.
1700 closed down.

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

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.

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

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 = 2×7^2

17 = 17

11,111,111,111,111,111 = 2,071,723 × 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.

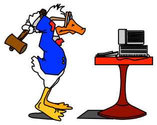
- Compiler error messages help locate syntax errors.
- Run program to find semantic and performance errors.

```
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!

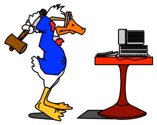


Debugging: Syntax Errors

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

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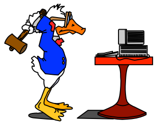
```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0])
      for (i = 0; i < N; i++)
      {
         while (N % i == 0)
            System.out.print(i + " ")
            N = N / i
      }
   }
}
```

```
% javac Factors.java
Factors.java:6: ';' expected
        for (i = 2; i < N; i++)
         ^
1 error
```

the FIRST error



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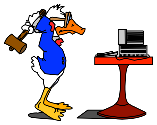
```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0]) ;
      for ( int i = 0; i < N; i++ )
      {
         while (N % i == 0)
            System.out.print(i + " ") ;
            N = N / i ;
      }
   }
}
```

need terminating semicolons

need to declare variable i

Syntax (compile-time) errors



Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

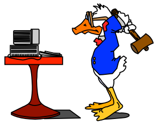
- Run program to identify problem.
- Add print statements if needed to produce trace.

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

```
% javac Factors.java
% java Factors
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: 0
        at Factors.main(Factors.java:5)
```

oops, need argument

you will see this message!



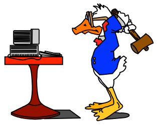
Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

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

```
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)
```



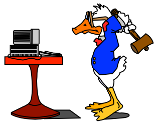
Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

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

```
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

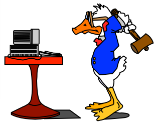
Semantic error. Legal but wrong Java program.

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

```
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 2 2 2 2
```

??? infinite loop



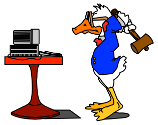
Debugging: Semantic Errors

Semantic error. Legal but wrong Java program.

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

```
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 (run-time) error:
indents do not imply braces



Debugging: The Beat Goes On

Success? Program factors 98 = 2 2 7.

- Time to try it for other inputs.
- Add trace to find and fix (minor) problems.

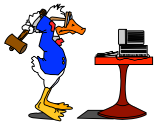
```
public class Factors
{
   public static void main(String[] args)
   {
      long N = Long.parseLong(args[0])
      for (int i = 2; i < N; i++)
      {  // Check whether i is a factor.
         while (N % i == 0)
         {  // If so, print and divide.
            System.out.print(i + " ");
     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

```
% java Factors 98
2 7 7 %
% java Factors 5
%
% java Factors 6
2 %
```

need newline

??? no output

??? where's the 3?



Debugging: The Beat Goes On

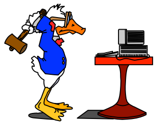
Success? Program factors 98 = 2 2 7.

- Time to try it for other inputs.
- Add trace to find and fix (minor) problems.

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

- Remove trace to try larger inputs.
- [stay tuned].

```
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 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

Corner case:
print largest
factor
(and new line)

Time to add comments
(if not earlier).

Debugging Your Program. [summary]

1. Create the program.

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

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

4. Enjoy the satisfaction of a working program!
   [but stay tuned for more debugging]