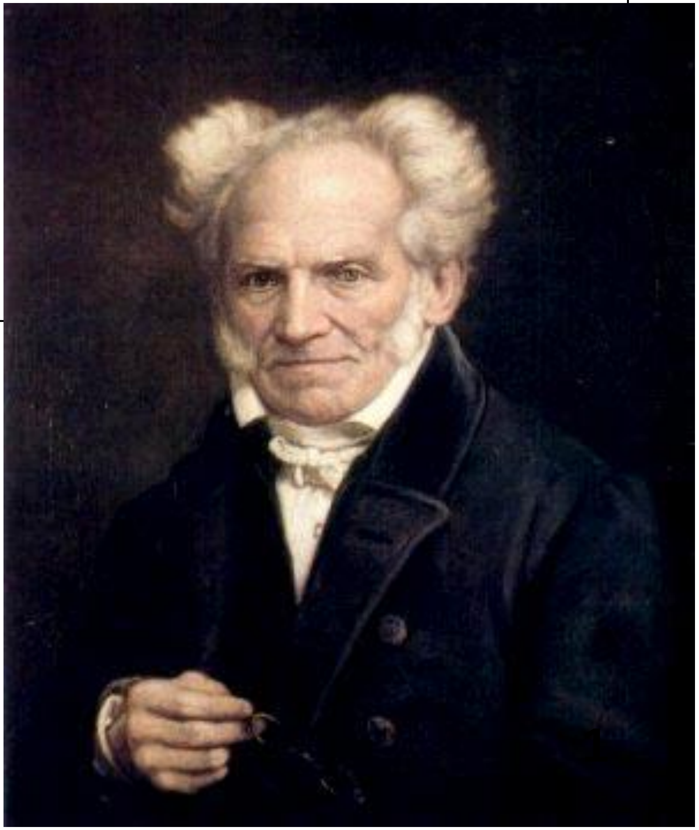
Topic 5
for loops and nested loops

“Always to see the general in the particular is the very foundation of genius.”

-Arthur Schopenhauer



Based on slides by Marty Stepp and Stuart Reges
from http://www.buildingjavaprograms.com/

Repetition with `for` loops

- So far, repeating a statement is redundant:

```
System.out.println("Mike says:");
System.out.println("Do Practice-It problems!");
System.out.println("Do Practice-It problems!");
System.out.println("Do Practice-It problems!");
System.out.println("Do Practice-It problems!");
System.out.println("Do Practice-It problems!");
System.out.println("It makes a HUGE difference.");
```

- Java's **`for` loop** statement performs a task many times.

```
System.out.println("Mike says:");
for (int i = 1; i <= 5; i++) {    // repeat 5 times
    System.out.println("Do Pratice-It problems!");
}
System.out.println("It makes a HUGE difference.");
```

for loop syntax

```
for (<initialization>; <test>; <update>) {
    <statement>;
    <statement>;
    ...
    <statement>;
}
```

header

body

- Perform ***<initialization>*** once.
- Repeat the following:
  - Check if the ***<test>*** is true. If not, stop.
  - Execute the ***<statement>***s.
  - Perform the ***<update>***.

Initialization

```
for (int i = 1; i <= 5; i++) {
    System.out.println("Do Practice-It!");
}
```

- Tells Java compiler what variable to use in the loop
  - Performed once as the loop begins
  - The variable is called a *loop counter or loop control variable*
    - can use any name, not just `i`
    - can start at any value, not just `1`

Test

```
for (int i = 1; i <= 5; i++) {
    System.out.println("Do Practice-It!");
}
```

- Tests the loop counter variable against a limit
  - Uses comparison operators:

<	less than
<=	less than or equal to
>	greater than
>=	greater than or equal to

== equality != not equals

Body

```
for (int i = 1; i <= 5; i++) {
    System.out.println("Do Practice-It!");
}
```

- If the test is true, the statements in the body of the loop execute in sequential order one time
- The body of the loop is between the curly braces
- If the body is one statement the curly braces are not required, but by convention we still add them
- After the body of the loop completes the update statement is executed.

Update

```
for(int i = 1; i <= 5; i++) {
    System.out.println("Do Practice-It!");
}
```

- Perform update step
  - – Generally adding one to loop control variable
  - – Could be other operations such as subtracting one, multiplying

Aside: Increment and Decrement Operators

shortcuts to increase or decrease a variable's value by 1

Shorthand	Equivalent longer version
<variable>`++;`	***<variable>*** `= ` ***<variable>*** `+ 1;`
<variable>`--;`	***<variable>*** `= ` ***<variable>*** `- 1;`

```
int x = 2;
x++;                  // x = x + 1;
                      // x now stores 3

double gpa = 2.5;
gpa--;                // gpa = gpa - 1;
                      // gpa now stores 1.5
```

Aside: Modify-and-assign operators

shortcuts to modify a variable's value

Shorthand	Equivalent longer version
<variable> `+=` ***<exp>***`;`	***<variable>*** `=` ***<variable>*** `+` `(`***<exp>***`);`
<variable> `-=` ***<exp>***`;`	***<variable>*** `=` ***<variable>*** `-` `(`***<exp>***`);`
<variable> `*=` ***<exp>***`;`	***<variable>*** `=` ***<variable>*** `*` `(`***<exp>***`);`
<variable> `/=` ***<exp>***`;`	***<variable>*** `=` ***<variable>*** `/` `(`***<exp>***`);`
<variable> `%=` ***<exp>***`;`	***<variable>*** `=` ***<variable>*** `%` `(`***<exp>***`);`

```
x += 3;              // x = x + 3;
gpa -= 0.5;          // gpa = gpa - 0.5;
number *= 2 + 1;     // number = number * (2 + 1);
```

Clicker 1

- What is output by the following code?

```
int x = 2;
int y = 5;
x *= 3 + y + x;
System.out.println(x + " " + y);
```

A. `20 5`

B. `2 5`

C. `13 5`

D. `20 10`

E. Something other than A - D

`for` loop is **NOT** a method

- The `for` loop is a ***control structure***
  - a syntactic structure that *controls* the execution of other statements.

- Example:
  - “Shampoo hair. Rinse. **Repeat**.”

Repetition over a range

```
System.out.println("1 squared = " + 1 * 1);
System.out.println("2 squared = " + 2 * 2);
System.out.println("3 squared = " + 3 * 3);
System.out.println("4 squared = " + 4 * 4);
System.out.println("5 squared = " + 5 * 5);
System.out.println("6 squared = " + 6 * 6);
```

  - Intuition: "I want to print a line for each number from 1 to 6"

- The `for` loop does exactly that!

```
for (int i = 1; i <= 6; i++) {
    System.out.println(i + " squared = " + (i * i));
}
```

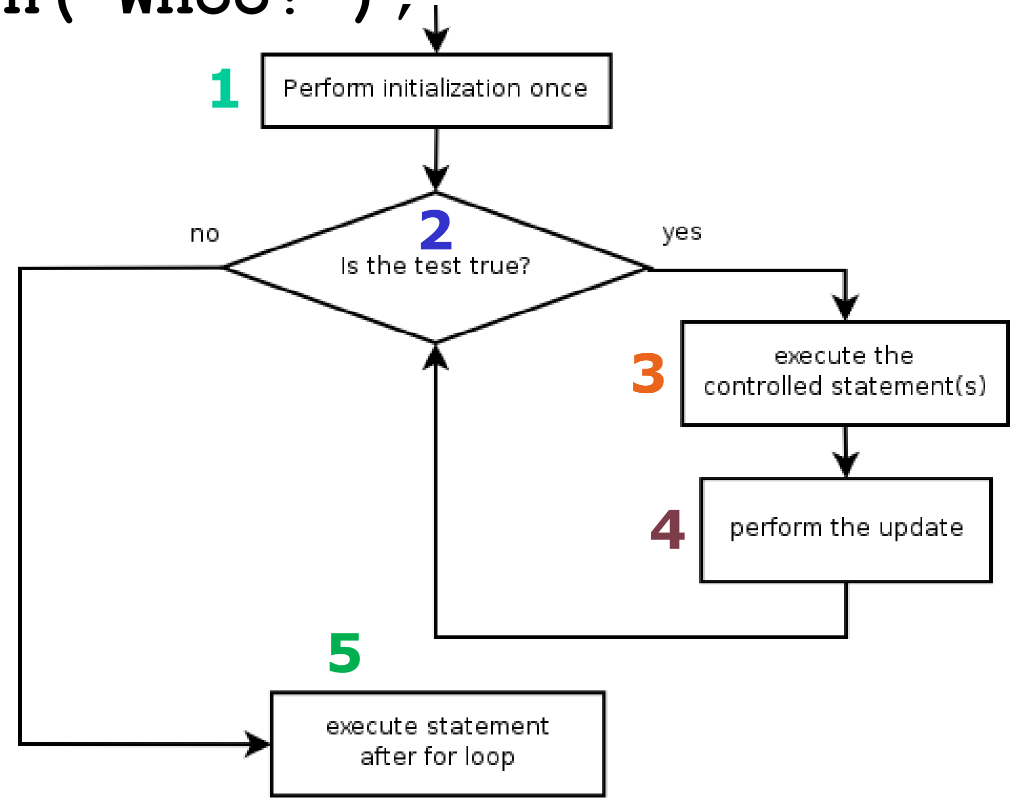
  - "For each integer **i** from 1 through 6, print ..."

Loop walkthrough

```
               1      2      4
  for (int i = 1; i <= 4; i++) {
     3 System.out.println(i + " squared = " + (i * i));
  }
5 System.out.println("Whoo!");
```

Output:

```
1 squared = 1
2 squared = 4
3 squared = 9
4 squared = 16
Whoo!
```


1
Perform initialization once
2
Is the test true?
no
yes
3
execute the controlled statement(s)
4
perform the update
5
execute statement after for loop

Simple Loop Example

- Write a program to calculate and print out the values of N! from 1 to 50 using a for loop
- 0! = 1
- 1! = 1 * 0! = 1 * 1 = 1
- 2! = 2 * 1! = 2 * 1 * 1 = 2
- 3! = 3 * 2! = 3 * 2 * 1 * 1 = 6
- 4! = 4 * 3! = 4 * 3 * 2 * 1 * 1 = 24

Multi-line loop body

```
System.out.println("+-----+");
for (int i = 1; i <= 3; i++) {
    System.out.println("\\    /");
    System.out.println("/    \\");
}
System.out.println("+-----+");
```

Output:

```
+-----+
\     /
/     \
\     /
/     \
\     /
/     \
+-----+
```

Expressions for counter

```
int highTemp = 5;
for (int i = -3; i <= highTemp / 2; i++) {
    System.out.println(i * 1.8 + 32);
}
```

- This computes the Fahrenheit equivalents for -3 degrees Celsius to 2 degrees Celsius.

Output:

```
26.6
28.4
30.2
32.0
33.8
35.6
```

System.out.print

- Prints without moving to a new line
  - – allows you to print partial messages on the same line

```
int highestTemp = 5;
for (int i = -3; i <= highestTemp / 2; i++) {
    System.out.print((i * 1.8 + 32) + "  ");
}
```

- Output:

```
26.6  28.4  30.2  32.0  33.8  35.6
```

  - Concatenate " " to separate the numbers

Clicker 2

- How many asterisks are output by the following code?

```
for(int i = -2; i <= 13; i++) {
    System.out.print("*");
    System.out.print("**");
}
```

A. 0

B. 15

C. 45

D. 48

E. 68

Counting down

- The ***<update>*** can use -- to make the loop count down.
  - The ***<test>*** must say > instead of < (or logic error)

```
System.out.print("T-minus ");
for (int i = 10; i >= 1; i--) {
     System.out.print(i + ", ");
}
System.out.println("blastoff!");
System.out.println("The end.");
```

Output:

```
T-minus 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, blastoff!
The end.
```

Practice Problem

- Newton's method for approximating square roots adapted from the Dr. Math website

The goal is to find the square root of a number. Let's call it num

1. Choose a rough approximation of the square root of num, call it approx.

    How to choose?

2. Divide num by approx and then average the quotient with approx,

    in other words we want to evaluate the

    expression ((num/approx) + approx) / 2

3. How close are we? In programming we would store the result of the expression back into the variable approx.

4. How do you know if you have the right answer?

Sample of Newton's Method

num	approx	((num/approx)+approx)/2	approx*approx
12	6	(12 / 6 + 6) / 2 = 4	16
12	4	(12 / 4 + 4) / 2 = 3.5	12.25
12	3.5	(12 / 3.5 + 3.5) / 2 = 3.4642857…	12.0012..
12	3.4642857	= 3.46410162…	12.00000003
12	3.46410162	= 3.46410161…	11.999999999

3.4641016151377544 after 5 steps

3.4641016151377545870548926830117 (from calculator)

Nested loops

reading: 2.3

Nested loops

- **nested loop**: A loop placed inside another loop.

```
for (int i = 1; i <= 5; i++) {
    for (int j = 1; j <= 10; j++) {
        System.out.print("*");
    }
    System.out.println();    // to end the line
}
```

- Output:

```
**********
**********
**********
**********
**********
```

- The outer loop repeats 5 times; the inner one 10 times.
  - "sets and reps" exercise analogy

Nested `for` loop exercise

- What is the output of the following nested `for` loops?

```
for (int i = 1; i <= 5; i++) {
    for (int j = 1; j <= i; j++) {
        System.out.print("*");
    }
    System.out.println();
}
```

- Output:

```
*
**
***
****
*****
```

Nested `for` loop exercise

- What is the output of the following nested `for` loops?

```
for (int i = 1; i <= 5; i++) {
    for (int j = 1; j <= i; j++) {
        System.out.print(i);
    }
    System.out.println();
}
```

- Output:

```
1
22
333
4444
55555
```

Clicker 3

- What is output by the following code?

```
int total = 0;
for(int i = 1; i <= 4; i++) {
    for(int j = 1; j <= i; j++) {
        total += i;
    }
}
System.out.println(total);
```

A. 4 B. 10 C. 16 D. 24 E. 30

Common errors

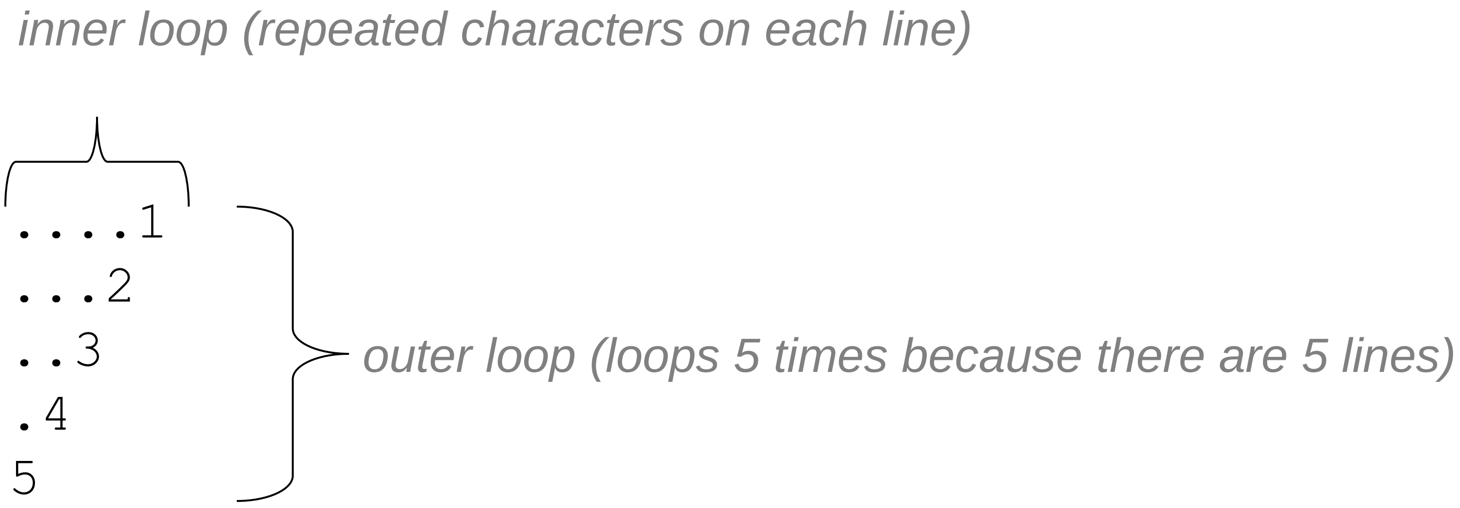
- Both of the following sets of code produce *infinite loops*:

```
for (int i = 1; i <= 5; i++) {
    for (int j = 1; i <= 10; j++) {
        System.out.print("*");
    }
    System.out.println();
}

for (int i = 1; i <= 5; i++) {
    for (int j = 1; j <= 10; i++) {
        System.out.print("*");
    }
    System.out.println();
}
```

Complex output

- Write a nested `for` loop to produce the following output.



inner loop (repeated characters on each line)

```
....1
...2
..3
.4
5
```

outer loop (loops 5 times because there are 5 lines)

- We must build multiple complex lines of output using:
  - an *outer "vertical" loop* for each of the lines
  - *inner "horizontal" loop(s)* for the patterns within each line

Outer and inner loop

- First write the outer loop, from 1 to the number of lines.

```
for (int line = 1; line <= 5; line++) {
        ...
}
```

- Now look at the line contents. Each line has a pattern:
  - some dots (0 dots on the last line), then a number

```
....1
...2
..3
.4
5
```

  - Observation: the number of dots is related to the line number.

Mapping loops to numbers

```
for (int count = 1; count <= 5;
  count++) {
    System.out.print( … );
}
```

- What statement in the body would cause the loop to print:

  4 7 10 13 16

```
for (int count = 1; count <= 5; count++) {
    System.out.print(3 * count + 1 + " ");
}
```

Loop tables

- What statement in the body would cause the loop to print:

```
2 7 12 17 22
```

- To see patterns, make a table of `count` and the numbers.
  - Each time count goes up by 1, the number should go up by 5.
  - But `count * 5` is too great by 3, so we subtract 3.

`count`	number to print	`5 * count`	`5 * count - 3`
1	2	5	2
2	7	10	7
3	12	15	12
4	17	20	17
5	22	25	22

Loop tables question

- What statement in the body would cause the loop to print:

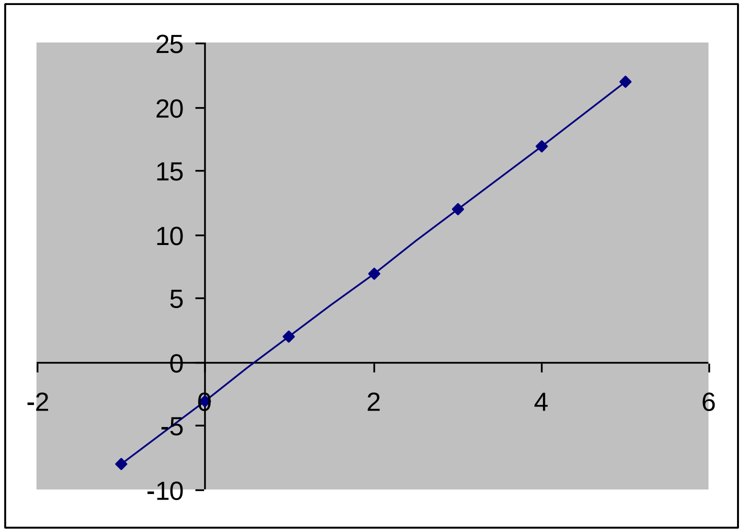
```
17 13 9 5 1
```

- Let's create the loop table together.
  - Each time `count` goes up 1, the number printed should ...
  - But this multiple is off by a margin of ...

`count`	number to print	`-4 * count`	`-4 * count + 21`
1	17	-4	17
2	13	-8	13
3	9	-12	9
4	5	-16	5
5	1	-20	1

Another view: Slope-intercept

- The next three slides present the mathematical basis for the loop tables.



`count (x)`	number to print (`y`)
1	2
2	7
3	12
4	17
5	22

Another view: Slope-intercept

- *Caution*: This is algebra, not assignment!
- Recall: slope-intercept form (`y = mx + b`)
- Slope is defined as “rise over run” (i.e. rise / run). Since the “run” is always `1` (we increment along `x` by 1), we just need to look at the “rise”. The rise is the difference between the `y` values. Thus, the slope (`m`) is the difference between `y` values; in this case, it is `+5`.
- To compute the y-intercept (`b`), plug in the value of `y` at `x = 1` and solve for `b`. In this case, `y = 2`.

```
y = m * x + b
2 = 5 * 1 + b
```

Then `b = -3`

- So the equation is

```
y = m * x + b
y = 5 * x - 3
y = 5 * count - 3
```

count (x)	number to print (y)
1	2
2	7
3	12
4	17
5	22

Another view: Slope-intercept

- Algebraically, if we always take the value of y at $x = 1$, then we can solve for b as follows:

$$y = m * x + b$$
$$y_1 = m * 1 + b$$
$$y_1 = m + b$$
$$b = y_1 - m$$

- In other words, to get the y-intercept, just subtract the slope from the first y value ($b = 2 - 5 = -3$)
  - This gets us the equation

$$y = m * x + b$$
$$y = 5 * x - 3$$
$$y = 5 * \mathrm{count} - 3$$

(which is exactly the equation from the previous slides)

Nested `for` loop exercise

- Make a table to represent any patterns on each line.

```
....1
...2
..3
.4
5
```

`line`	# of dots	`-1 * line`	`-1 * line + 5`
1	4	-1	4
2	3	-2	3
3	2	-3	2
4	1	-4	1
5	0	-5	0

- To print a character multiple times, use a `for` loop.

```
for (int j = 1; j <= 4; j++) {
    System.out.print(".");           // 4 dots
}
```

Nested `for` loop solution

- Answer:

```
for (int line = 1; line <= 5; line++) {
    for (int j = 1; j <= (-1 * line + 5); j++) {
        System.out.print(".");
    }
    System.out.println(line);
}
```

- Output:

```
....1
...2
..3
.4
5
```

Nested `for` loop exercise

- What is the output of the following nested `for` loops?

```
for (int line = 1; line <= 5; line++) {
    for (int j = 1; j <= (-1 * line + 5); j++) {
        System.out.print(".");
    }
    for (int k = 1; k <= line; k++) {
        System.out.print(line);
    }
    System.out.println();
}
```

- Answer:

```
....1
...22
..333
.4444
55555
```

Nested `for` loop exercise

- Modify the previous code to produce this output:

```
....1
...2.
..3..
.4...
5....
```

```
for (int line = 1; line <= 5; line++) {
    for (int j = 1; j <= (-1 * line + 5); j++) {
        System.out.print(".");
    }
    System.out.print(line);
    for (int j = 1; j <= (line - 1); j++) {
        System.out.print(".");
    }
    System.out.println();
}
```