

Building Java Programs

Chapter 2

Primitive Data and Definite Loops

The `for` loop

Repetition with `for` loops

- So far, repeating a statement is redundant:

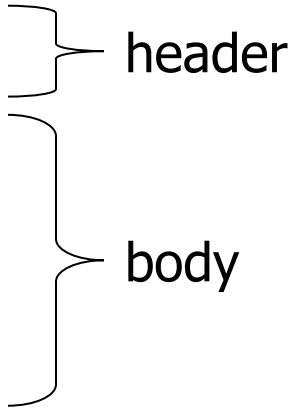
```
System.out.println("Homer says:");  
System.out.println("I am so smart");  
System.out.println("I am so smart");  
System.out.println("I am so smart");  
System.out.println("I am so smart");  
System.out.println("S-M-R-T... I mean S-M-A-R-T");
```

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

```
System.out.println("Homer says:");  
for (int i = 1; i <= 4; i++) {    // repeat 4 times  
    System.out.println("I am so smart");  
}  
System.out.println("S-M-R-T... I mean S-M-A-R-T");
```

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 **statements**.
 - Perform the **update**.

Initialization

```
for (int i = 1; i <= 6; i++) {  
    System.out.println("I am so smart");  
}
```

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

Test

```
for (int i = 1; i <= 6; i++) {  
    System.out.println("I am so smart");  
}
```

- 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

Increment and decrement

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

Shorthand

variable++;

variable--;

```
int x = 2;
```

```
x++;
```

```
double gpa = 2.5;
```

```
gpa--;
```

Equivalent longer version

variable = **variable** + 1;

variable = **variable** - 1;

```
// x = x + 1;
```

```
// x now stores 3
```

```
// gpa = gpa - 1;
```

```
// gpa now stores 1.5
```

Modify-and-assign

shortcuts to modify a variable's value

Shorthand

variable += **value**;
variable -= **value**;
variable *= **value**;
variable /= **value**;
variable %= **value**;

Equivalent longer version

variable = **variable** + **value**;
variable = **variable** - **value**;
variable = **variable** * **value**;
variable = **variable** / **value**;
variable = **variable** % **value**;

x += 3;

gpa -= 0.5;

number *= 2;

// x = x + 3;

// gpa = gpa - 0.5;

// number = number * 2;

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));  
}
```

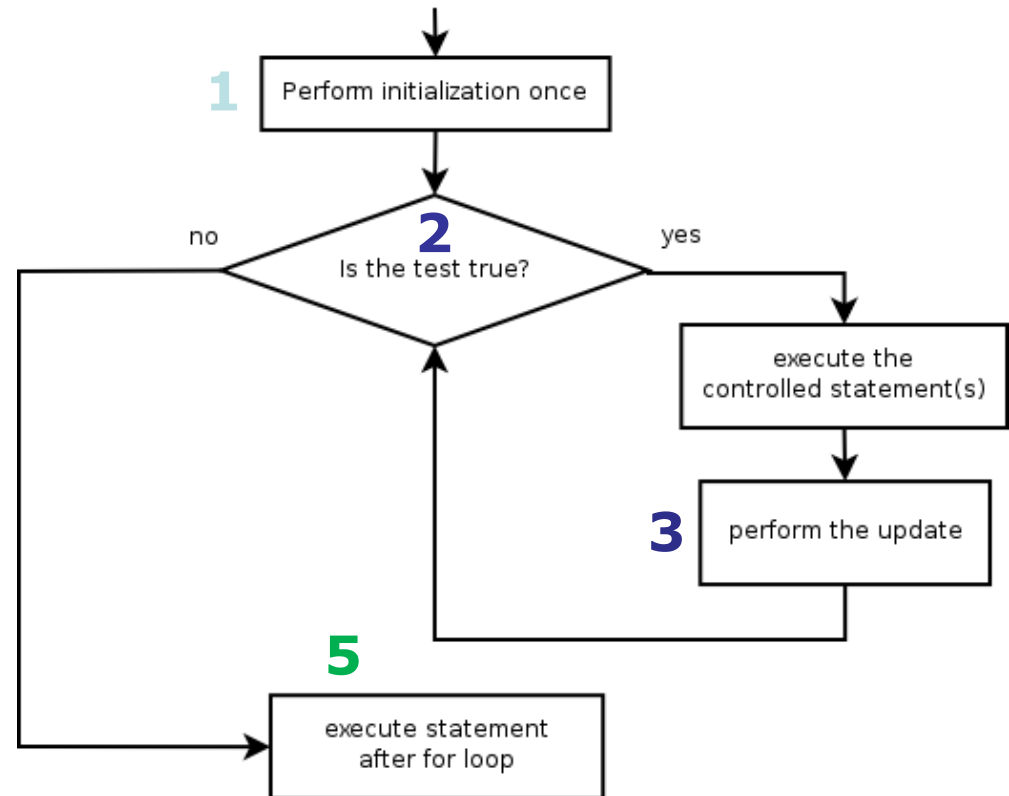
– "For each integer `i` from 1 through 6, print ..."

Loop walkthrough

```
for (int i = 1; i <= 4; i++) {  
    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!
```



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);  
}
```

– 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

Counting down

- The **update** can use `--` to make the loop count down.
 - The **test** must say `>` instead of `<`

```
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.
```

Nested for loops

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
```

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 lines

- What nested `for` loops produce the following output?

inner loop (repeated characters on each line)



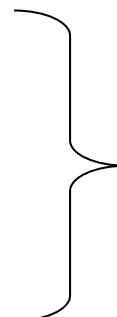
.....1

....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.

<code>count</code>	number to print	<code>5 * count</code>	<code>5 * count - 3</code>
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 ...

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

Nested for loop exercise

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

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

line	# of dots	$-1 * \text{line}$	$-1 * \text{line} + 5$
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....
```

- Answer:

```
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();
}
```

Drawing complex figures

- Use nested `for` loops to produce the following output.
- Why draw ASCII art?
 - Real graphics require a lot of finesse
 - ASCII art has complex patterns
 - Can focus on the algorithms

```
#=====#
|           <><>           |
|           <> . . . . <>   |
|           <> . . . . . . . <> |
| <> . . . . . . . . . . <> |
| <> . . . . . . . . . . <> |
|           <> . . . . . . . <> |
|           <> . . . . <>   |
|           <><>           |
#=====#
```

Development strategy

- Recommendations for managing complexity:
 1. Design the program (think about steps or methods needed).
 - write an English description of steps required
 - use this description to decide the methods
 2. Create a table of patterns of characters
 - use table to write your `for` loops

```
#=====#  
|          <><>          |  
|          <> . . . . <>          |  
|          <> . . . . . . . . <>          |  
| <> . . . . . . . . . . . . <> |  
| <> . . . . . . . . . . . . <> |  
|          <> . . . . . . . . <>          |  
|          <> . . . . <>          |  
|          <><>          |  
#=====#
```

1. Pseudo-code

- **pseudo-code:** An English description of an algorithm.
- Example: Drawing a 12 wide by 7 tall box of stars

```
print 12 stars.  
for (each of 5 lines) {  
    print a star.  
    print 10 spaces.  
    print a star.  
}  
print 12 stars.
```

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

Pseudo-code algorithm

1. Line

- # , 16 =, #

2. Top half

- |
- spaces (decreasing)
- <>
- dots (increasing)
- <>
- spaces (same as above)
- |

3. Bottom half (top half upside-down)

4. Line

- # , 16 =, #

```
#=====#
|          <><>          |
|      <> . . . . <>    |
|  <> . . . . . . . <>  |
|<> . . . . . . . . . <>|
|<> . . . . . . . . . <>|
|  <> . . . . . . . <>  |
|      <> . . . . <>    |
|          <><>          |
#=====#
```


Methods from pseudocode

```
public class Mirror {
    public static void main(String[] args) {
        line();
        topHalf();
        bottomHalf();
        line();
    }

    public static void topHalf() {
        for (int line = 1; line <= 4; line++) {
            // contents of each line
        }
    }

    public static void bottomHalf() {
        for (int line = 1; line <= 4; line++) {
            // contents of each line
        }
    }

    public static void line() {
        // ...
    }
}
```

2. Tables

- A table for the top half:
 - Compute spaces and dots expressions from line number

line	spaces	line * -2 + 8	dots	4 * line - 4
1	6	6	0	0
2	4	4	4	4
3	2	2	8	8
4	0	0	12	12

A 10x10 grid diagram. The top and bottom rows are filled with a dashed line and a '#' symbol at each end. The four corner cells (row 2, col 1; row 2, col 10; row 9, col 1; row 9, col 10) contain a thick blue vertical bar. The remaining cells contain symbols as follows:

- Row 3: Blue double angle brackets <> at columns 4, 5, and 6.
- Row 4: Blue double angle brackets <> at columns 3 and 8, followed by four blue dots at columns 4, 5, 6, and 7.
- Row 5: Blue double angle brackets <> at columns 2 and 9, followed by six blue dots at columns 3, 4, 5, 6, 7, and 8.
- Row 6: Black double angle brackets <> at columns 1 and 10, followed by eight black dots at columns 2, 3, 4, 5, 6, 7, 8, and 9.
- Row 7: Black double angle brackets <> at columns 2 and 9, followed by six black dots at columns 3, 4, 5, 6, 7, and 8.
- Row 8: Black double angle brackets <> at columns 3 and 7, followed by three black dots at columns 4, 5, and 6.
- Row 9: Black double angle brackets <> at columns 4 and 5.

3. Writing the code

- Useful questions about the top half:
 - What methods? (think structure and redundancy)
 - Number of (nested) loops per line?

```
#=====#  
|          <><>          |  
|          <> . . . . <>          |  
|      <> . . . . . . . . <>      |  
| <> . . . . . . . . . . . . <> |  
| <> . . . . . . . . . . . . <> |  
|      <> . . . . . . . . <>      |  
|          <> . . . . <>          |  
|          <><>          |  
#=====#
```

Partial solution

// Prints the expanding pattern of <> for the top half of the figure.

```
public static void topHalf() {  
    for (int line = 1; line <= 4; line++) {  
        System.out.print("|");  
  
        for (int space = 1; space <= (line * -2 + 8); space++) {  
            System.out.print(" ");  
        }  
  
        System.out.print("<>");  
  
        for (int dot = 1; dot <= (line * 4 - 4); dot++) {  
            System.out.print(".");  
        }  
  
        System.out.print("<>");  
  
        for (int space = 1; space <= (line * -2 + 8); space++) {  
            System.out.print(" ");  
        }  
  
        System.out.println("|");  
    }  
}
```

Class constants and scope

Scaling the mirror

- Let's modify our Mirror program so that it can scale.
 - The current mirror (left) is at size 4; the right is at size 3.
- We'd like to structure the code so we can scale the figure by changing the code in just one place.

```
#=====#
|          <><>          |
|      <> . . . . <>      |
|  <> . . . . . . . <>  |
|<> . . . . . . . . . <>|
|<> . . . . . . . . . <>|
|  <> . . . . . . . <>  |
|      <> . . . . <>      |
|      <> . . . . <>      |
|          <><>          |
#=====#
```

```
#=====#
|          <><>          |
|      <> . . . . <>      |
|<> . . . . . . . <>  |
|<> . . . . . . . <>  |
|      <> . . . . <>      |
|          <><>          |
#=====#
```

Limitations of variables

- Idea: Make a variable to represent the size.
 - Use the variable's value in the methods.
- Problem: A variable in one method can't be seen in others.

```
public static void main(String[] args) {  
    int size = 4;  
    topHalf();  
    printBottom();  
}  
  
public static void topHalf() {  
    for (int i = 1; i <= size; i++) {        // ERROR: size not found  
        ...  
    }  
}  
  
public static void bottomHalf() {  
    for (int i = size; i >= 1; i--) {        // ERROR: size not found  
        ...  
    }  
}
```

Scope

- **scope:** The part of a program where a variable exists.
 - From its declaration to the end of the { } braces
 - A variable declared in a `for` loop exists only in that loop.
 - A variable declared in a method exists only in that method.

```
i's scope { public static void example() {  
            int x = 3;  
            for (int i = 1; i <= 10; i++) {  
                System.out.println(x);  
            }  
            // i no longer exists here  
        } // x ceases to exist here
```

x's scope

Scope implications

- Variables without overlapping scope can have same name.

```
for (int i = 1; i <= 100; i++) {  
    System.out.print("/");  
}  
for (int i = 1; i <= 100; i++) {    // OK  
    System.out.print("\\");  
}  
int i = 5;                        // OK: outside of loop's scope
```

- A variable can't be declared twice or used out of its scope.

```
for (int i = 1; i <= 100 * line; i++) {  
    int i = 2;                        // ERROR: overlapping scope  
    System.out.print("/");  
}  
i = 4;                              // ERROR: outside scope
```

Class constants

- **class constant:** A fixed value visible to the whole program.
 - value can be set only at declaration; cannot be reassigned

- **Syntax:**

```
public static final type name = value;
```

- name is usually in ALL_UPPER_CASE

- **Examples:**

```
public static final int DAYS_IN_WEEK = 7;  
public static final double INTEREST_RATE = 3.5;  
public static final int SSN = 658234569;
```

Constants and figures

- Consider the task of drawing the following scalable figure:

Multiples of 5 occur many times

$$\begin{array}{ccccccc} + & / & \backslash & / & \backslash & / & \backslash & + \\ | & & & & & & & | \\ | & & & & & & & | \\ + & / & \backslash & / & \backslash & / & \backslash & + \end{array}$$

The same figure at size 2

Repetitive figure code

```
public class Sign {

    public static void main(String[] args) {
        drawLine();
        drawBody();
        drawLine();
    }

    public static void drawLine() {
        System.out.print("+");
        for (int i = 1; i <= 10; i++) {
            System.out.print("/\\");
        }
        System.out.println("+");
    }

    public static void drawBody() {
        for (int line = 1; line <= 5; line++) {
            System.out.print("|");
            for (int spaces = 1; spaces <= 20; spaces++) {
                System.out.print(" ");
            }
            System.out.println("|");
        }
    }
}
```

Adding a constant

```
public class Sign {
    public static final int HEIGHT = 5;

    public static void main(String[] args) {
        drawLine();
        drawBody();
        drawLine();
    }

    public static void drawLine() {
        System.out.print("+");
        for (int i = 1; i <= HEIGHT * 2; i++) {
            System.out.print("/\\");
        }
        System.out.println("+");
    }

    public static void drawBody() {
        for (int line = 1; line <= HEIGHT; line++) {
            System.out.print("|");
            for (int spaces = 1; spaces <= HEIGHT * 4; spaces++) {
                System.out.print(" ");
            }
            System.out.println("|");
        }
    }
}
```

Complex figure w/ constant

- Modify the Mirror code to be resizable using a constant.

A mirror of size 4:

```
#=====#  
|          <><>          |  
|      <> . . . . <>      |  
|  <> . . . . . . . . <>  |  
| <> . . . . . . . . . . <> |  
| <> . . . . . . . . . . <> |  
|  <> . . . . . . . . <>  |  
|      <> . . . . <>      |  
|          <><>          |  
#=====#
```

A mirror of size 3:

```
#=====#  
|          <><>          |  
|      <> . . . . <>      |  
| <> . . . . . . . . <> |  
| <> . . . . . . . . <> |  
|      <> . . . . <>      |  
|          <><>          |  
#=====#
```

Using a constant

- Constant allows many methods to refer to same value:

```
public static final int SIZE = 4;

public static void main(String[] args) {
    topHalf();
    printBottom();
}

public static void topHalf() {
    for (int i = 1; i <= SIZE; i++) {        // OK
        ...
    }
}

public static void bottomHalf() {
    for (int i = SIZE; i >= 1; i--) {        // OK
        ...
    }
}
```

Loop tables and constant

- Let's modify our loop table to use `SIZE`
 - This can change the amount added in the loop expression

SIZE	line	spaces	$-2*\text{line} + (2*SIZE)$	dots	$4*\text{line} - 4$
4	1,2,3,4	6,4,2,0	$-2*\text{line} + 8$	0,4,8,12	$4*\text{line} - 4$
3	1,2,3	4,2,0	$-2*\text{line} + 6$	0,4,8	$4*\text{line} - 4$

```
#=====#
|           |
|      <><>  |
|   <> . . . <> |
|  <> . . . . . <> |
| <> . . . . . . . <> |
| <> . . . . . . . <> |
|  <> . . . . . <> |
|   <> . . . . <> |
|      <> . . . <> |
|           |
|      <><>  |
|           |
#=====#
```

```
#=====#
|           |
|      <><>  |
|   <> . . . <> |
|  <> . . . . . <> |
|  <> . . . . . <> |
|   <> . . . . <> |
|      <><>  |
|           |
#=====#
```


Partial solution

```
public static final int SIZE = 4;

// Prints the expanding pattern of <> for the top half of the figure.
public static void topHalf() {
    for (int line = 1; line <= SIZE; line++) {
        System.out.print("|");

        for (int space = 1; space <= (line * -2 + (2*SIZE)); space++) {
            System.out.print(" ");
        }

        System.out.print("<>");

        for (int dot = 1; dot <= (line * 4 - 4); dot++) {
            System.out.print(".");
        }

        System.out.print("<>");

        for (int space = 1; space <= (line * -2 + (2*SIZE)); space++) {
            System.out.print(" ");
        }

        System.out.println("|");
    }
}
```

Observations about constant

- The constant can change the "intercept" in an expression.
 - Usually the "slope" is unchanged.

```
public static final int SIZE = 4;

for (int space = 1; space <= (line * -2 + (2 * SIZE));
    space++) {
    System.out.print(" ");
}
```

- It doesn't replace *every* occurrence of the original value.

```
for (int dot = 1; dot <= (line * 4 - 4); dot++) {
    System.out.print(".");
}
```