Definite Loops

Computer Science S-111
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Using a Variable for Counting

- Let's say that we're using a variable `i` to count the number of times that something has been done:

```
int i = 0;
```

i | 0

- To increase the count, we can do this:

```
i = i + 1;
    0 + 1
    1
```

i | 1

- To increase the count again, we repeat the same assignment:

```
i = i + 1;
    1 + 1
    2
```

i | 2

Increment and Decrement Operators

- Instead of writing

```
i = i + 1;
```

  we can use a shortcut and just write

```
i++;
```

- `++` is known as the *increment operator*.
  - increment = increase by 1
- Java also provides a *decrement operator* (`--`).
  - decrement = decrease by 1
  - example:

```
i--;
```

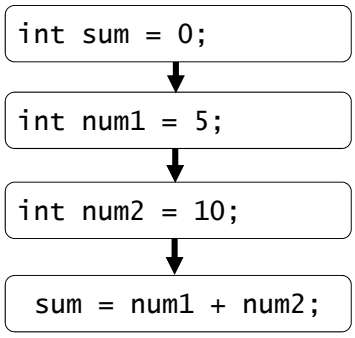
Review: Flow of Control

- Flow of control = the order in which instructions are executed
- By default, instructions are executed in sequential order.

instructions

```
int sum = 0;
int num1 = 5;
int num2 = 10;
sum = num1 + num2;
```

flowchart



- When we make a method call, the flow of control "jumps" to the method, and it "jumps" back when the method completes.

Altering the Flow of Control: Repetition

- To solve many types of problems, we need to be able to modify the order in which instructions are executed.
- One reason for doing this is to allow for *repetition.*
- We saw this in Scratch:

Example of the Need for Repetition

- Here's a method for writing a large block letter L:

```
public static void writeL() {
    System.out.println("|");
    System.out.println("|");
    System.out.println("|");
    System.out.println("|");
    System.out.println("|");
    System.out.println("|");
    System.out.println("|");
    System.out.println("+----------");
}
```

- Rather than duplicating the statement

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

  seven times, we'd like to have this statement appear just once and execute it seven times.

for Loops

- To repeat one or more statements multiple times, we can use a construct known as a *for loop.*
- Here's a revised version of our `writeL` method that uses one:

```
public static void writeL() {
    for (int i = 0; i < 7; i++) {
        System.out.println("|");
    }
    System.out.println("+----------");
}
```

for Loops

- Syntax:

```
for (<initialization>; <continuation test>; <update>) {
    <one or more statements>
}
```

- In our example:

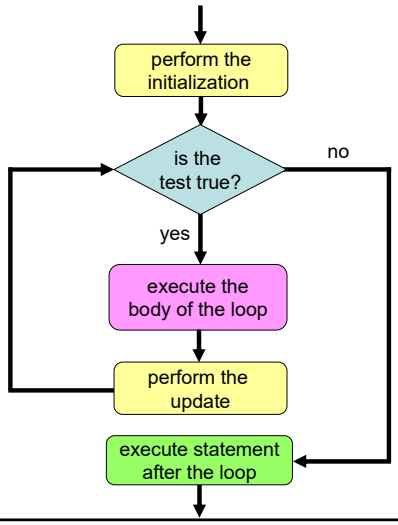
initialization *continuation test* *update*

```
for (int i = 0; i < 7; i++) {
    System.out.println("|");
}
```

- The statements inside the loop are known as the *body* of the loop.
- In our example, we use the variable `i` to count the number of times that the body has been executed.

Executing a `for` Loop

```
for (<initialization>; <continuation test>; <update>) {
    <body of the loop>
}
```



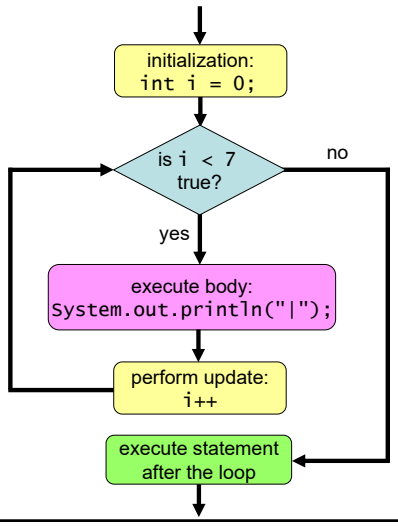
Notes:

- the initialization is only performed once
- the body is only executed if the test is true
- we repeatedly do:
  - test
  - body
  - update

  until the test is false

Executing Our `for` Loop

```
for (int i = 0; i < 7; i++) {
    System.out.println("|");
}
```



i	i < 7	action
0	true	print 1st "|"
1	true	print 2nd "|"
2	true	print 3rd "|"
3	true	print 4th "|"
4	true	print 5th "|"
5	true	print 6th "|"
6	true	print 7th "|"
7	false	execute stmt. after the loop

Definite Loops

- For now, we'll limit ourselves to *definite loops* – which repeat actions a fixed number of times.
- To repeat the body of a loop **<N>** times, we typically take one of the following approaches:

```
for (int i = 0; i < <N>; i++) {
    <body of the loop>
}
```

OR

```
for (int i = 1; i <= <N>; i++) {
    <body of the loop>
}
```

- Each time that the body of a loop is executed is known as an *iteration* of the loop.
  - the loops shown above perform <N> iterations

Other Examples of Definite Loops

- What does this loop do?

```
for (int i = 0; i < 3; i++) {
    System.out.println("Hip! Hip!");
    System.out.println("Hooray!");
}
```

- What does this loop do?

```
for (int i = 0; i < 10; i++) {
    System.out.println(i);
}
```

Using Different Initializations, Tests, and Updates

- The second loop from the previous page would be clearer if we expressed it like this:

```
for (int i = 0; i <= 9; i++) {
    System.out.println(i);
}
```

- Different problems may require different initializations, continuation tests, and updates.

- What does this code fragment do?

```
for (int i = 2; i <= 10; i = i + 2) {
    System.out.println(i * 10);
}
```

Tracing a `for` Loop

- Let's trace through the final code fragment from the last slide:

```
for (int i = 2; i <= 10; i = i + 2) {
    System.out.println(i * 10);
}
```

i	i <= 10	value printed

Common Mistake

- You should not put a semi-colon after the for-loop header:

```
for (int i = 0; i < 7; i++); {
    System.out.println("|");
}
```

- The semi-colon ends the `for` statement.
  - thus, it doesn't repeat anything!
- The println is independent of the `for` statement, and only executes once.

Practice

- Fill in the blanks below to print the integers from 1 to 10:

```
for (_____________; _____________; _____________) {
    System.out.println(i);
}
```

- Fill in the blanks below to print the integers from 10 to 20:

```
for (_____________; _____________; _____________) {
    System.out.println(i);
}
```

- Fill in the blanks below to print the integers from 10 down to 1:

```
for (_____________; _____________; _____________) {
    System.out.println(i);
}
```

Other Java Shortcuts

- Recall this code fragment:

```
for (int i = 2; i <= 10; i = i + 2) {
    System.out.println(i * 10);
}
```

- Instead of writing

```
i = i + 2;
```

  we can use a shortcut and just write

```
i += 2;
```

- In general

```
<variable> += <expression>;
```

  is equivalent to

```
<variable> = <variable> + (<expression>);
```

Java Shortcuts

- Java offers other shortcut operators as well.
- Here's a summary of all of them:

shortcut	equivalent to
`<var>++;`	`<var> = <var> + 1;`
`<var>--;`	`<var> = <var> - 1;`
`<var> += <expr>;`	`<var> = <var> + (<expr>);`
`<var> -= <expr>;`	`<var> = <var> - (<expr>);`
`<var> *= <expr>;`	`<var> = <var> * (<expr>);`
`<var> /= <expr>;`	`<var> = <var> / (<expr>);`
`<var> %= <expr>;`	`<var> = <var> % (<expr>);`

- Important: the = must come *after* the mathematical operator.
  - `+=` is correct
  - `=+` is not!

More Practice

- Fill in the blanks below to print the even integers in reverse order from 20 down to 6:

```
for (_____________; _____________; _____________) {
    System.out.println(i);
}
```

Find the Error

- Let's say that we want to print the numbers from 1 to n.
- Where is the error in the following code?

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

- This is an example of an *off-by-one error*. Beware of these when writing your loop conditions!

Example Problem: Printing a Pattern, version 1

- Ask the user for a positive integer (call it n), and print a pattern containing n asterisks.
  - example:

```
Enter a positive integer: 3
***
```

- Let's use a `for` loop to do this:

```
// code to read n goes here...

for ( ____________________________________ ) {
    System.out.print("*");
}
System.out.println();
```

Example Problem: Printing a Pattern, version 2

- Print a pattern containing n lines of n asterisks.
  - example:

```
Enter a positive integer: 3
***
***
***
```

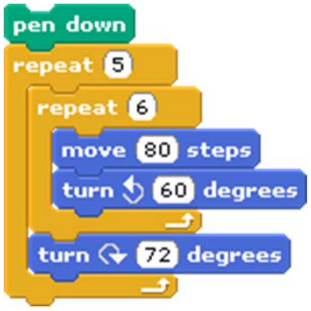
- One way to do this is to use a *nested loop* – one loop inside another:

```
// code to read in n goes here...

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

- This makes it easier to create a similar box of a different size.

Nested Loops

- When you have a nested loop, the inner loop is executed to completion for every iteration of the outer loop.
- Recall our Scratch drawing program:



- How many times is the *move* statement executed?

Nested Loops (cont.)

- How many times is the `println` statement executed below?

```
for (int i = 0; i < 5; i++) {
    for (int j = 0; j < 7; j++) {
        System.out.println(i + " " + j);
    }
}
```

- How many times is the `println` statement executed below?

```
for (int i = 0; i < 5; i++) {
    for (int j = 0; j < i; j++) {
        System.out.println(i + " " + j);
    }
}
```

Tracing a Nested `for` Loop

```
for (int i = 0; i < 5; i++) {
    for (int j = 0; j < i; j++) {
        System.out.println(i + " " + j);
    }
}
```

i	i < 5	j	j < i	value printed

Recall: Variable Scope

- The *scope* of a variable is the portion of a program in which the variable can be used.
- By default, the scope of a variable in Java:
  - begins at the point at which it is declared
  - ends at the end of the innermost block that encloses the declaration

```
public class MyProgram2 {
    public static void main(String[] args) {
        System.out.println("Welcome!");
        System.out.println("Let's do some math!");
        int j = 10;
        System.out.println(j / 5);
    }
}
```

scope of j

Special Case: `for` Loops and Variable Scope

- When a variable is declared in the initialization clause of a `for` loop, its scope is limited to the loop.
- Example:

```
public static void myMethod() {
    for (int i = 0; i < 5; i++) {
        int j = i * 3;
        System.out.println(j);
    }
    // the following line won't compile
    System.out.print(i);
    System.out.println(" values were printed.");
}
```

scope of `i`

Special Case: `for` Loops and Variable Scope (cont.)

- To allow `i` to be used outside the loop, we need to declare it outside the loop:
- Example:

```
public static void myMethod() {
    int i;
    for (i = 0; i < 5; i++) {
        int j = i * 3;
        System.out.println(j);
    }
    // now this will compile
    System.out.print(i);
    System.out.println(" values were printed.");
}
```

scope of `i`

Special Case: `for` Loops and Variable Scope (cont.)

- Limiting the scope of a loop variable allows us to use the standard loop templates multiple times in the same method.
- Example:

```
public static void myMethod() {
    for (int i = 0; i < 5; i++) {
        int j = i * 3;
        System.out.println(j);
    }

    for (int i = 0; i < 7; i++) {
        System.out.println("Go Crimson!");
    }
}
```

scope of first `i`

scope of second `i`

Review: Simple Repetition Loops

- Recall our two templates for performing **<N>** repetitions:

```
for (int i = 0; i < <N>; i++) {
    // code to be repeated
}

for (int i = 1; i <= <N>; i++) {
    // code to be repeated
}
```

- How may repetitions will each of the following perform?

```
for (int i = 1; i <= 15; i++) {
    System.out.println("Hello");
    System.out.println("How are you?");
}

for (int i = 0; i < 2*j; i++) {
    …
}
```

More Practice: Tracing a Nested `for` Loop

```
for (int i = 1; i <= 3; i++) {
    for (int j = 0; j < 2*i + 1; j++) {
        System.out.print("*");
    }
    System.out.println();
}
```

i	i <= 3	j	j < 2*i + 1

output

Case Study: Drawing a Complex Figure

- Here's the figure:

```
   ()
  (())
 ((()))
(((())))
========
|::::::|
 |::::|
  |::|
  |::|
  |::|
  |::|
  +==+
```

- To begin with, we'll focus on creating this exact figure.
- Then we'll modify our code so that the size of the figure can easily be changed.
  - we'll use `for` loops to allow for this

Problem Decomposition

- We begin by breaking the problem into subproblems, looking for groups of lines that follow the same pattern:

```
   ()
  (())
 ((()))
(((())))
```
← flame

```
========
```
← rim of torch

```
|::::::|
 |::::|
```
← top of torch

```
  |::|
  |::|
  |::|
  |::|
```
← handle of torch

```
  +--+
```
← bottom of torch

Problem Decomposition (cont.)

- This gives us the following initial pseudocode:

```
   ()
  (())
 ((()))
(((())))

========

|::::::|
 |::::|

  |::|
  |::|
  |::|
  |::|

  +--+
```

```
draw the flame
draw the rim of the torch
draw the top of the torch
draw the handle of the torch
draw the bottom of the torch
```

- This is a high-level description of what needs to be done.
- We'll gradually expand the pseudocode into more and more detailed instructions – until we're able to implement them in Java.

Drawing the Flame

- Let's begin by refining our specification for drawing the flame.

```
   ()
  (())
 ((()))
(((())))
```

- Here's our initial pseudocode for this task:

```
for (each of 4 lines) {
    print some spaces (possibly 0)
    print some left parentheses
    print some right parentheses
    go to a new line
}
```

- We need formulas for how many spaces and parens should be printed on a given line.

Finding the Formulas

- To begin with, we:
  - number the lines in the flame
  - form a table of the number of spaces and parentheses on each line:

```
1   ()
2  (())
3 ((()))
4(((())))
```

line	spaces	parens (each type)
1	3	1
2	2	2
3	1	3
4	0	4

- Then we find the formulas.
  - assume the formulas are *linear functions* of the line number:

    `c1*line + c2`

    where `c1` and `c2` are constants
  - parens = ?
  - spaces = ?

Refining the Pseudocode

- Given these formulas, we can refine our pseudocode:

```
for (each of 4 lines) {
    print some spaces (possibly 0)
    print some left parentheses
    print some right parentheses
    go to a new line
}
```

```
for (line going from 1 to 4) {
    print 4 - line spaces
    print line left parentheses
    print line right parentheses
    go to a new line
}
```

Implementing the Pseudocode in Java

- We use nested `for` loops:

```
for (line going from 1 to 4) {
    print 4 - line spaces
    print line left parentheses
    print line right parentheses
    go to a new line
}
```

```
for (int line = 1; line <= 4; line++) {
    for (int i = 0; i < 4 - line; i++) {
        System.out.print(" ");
    }
    for (int i = 0; i < line; i++) {
        System.out.print("(");
    }
    for (int i = 0; i < line; i++) {
        System.out.print(")");
    }
    System.out.println();
}
```

A Method for Drawing the Flame

- We put the code in its own static method, and add some explanatory comments:

```
public static void drawFlame() {
    for (int line = 1; line <= 4; line++) {
        // spaces to the left of the current line
        for (int i = 0; i < 4 - line; i++) {
            System.out.print(" ");
        }

        // left and right parens on the current line
        for (int i = 0; i < line; i++) {
            System.out.print("(");
        }
        for (int i = 0; i < line; i++) {
            System.out.print(")");
        }

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

Drawing the Top of the Torch

- What's the initial pseudocode for this task?

```
for (each of 2 lines) {




}
```

```
1|:::::::|
2 |:::::|
```

- Here's a table for the number of spaces and number of colons:

line	spaces	colons
1	0	6
2	1	4

  - spaces = ?
  - colons decreases by 2 as line increases by 1
    ➔ colons = -2*line + c2 for some number c2
  - try different values, and eventually get: colons = ?

Refining the Pseudocode

- Once again, we use the formulas to refine our pseudocode:

```
for (each of 2 lines) {
    print some spaces (possibly 0)
    print a single vertical bar
    print some colons
    print a single vertical bar
    go to a new line
}
```

```
for (line going from 1 to 2) {
    print line - 1 spaces
    print a single vertical bar
    print -2*line + 8 colons
    print a single vertical bar
    go to a new line
}
```

A Method for Drawing the Top of the Torch

```
public static void drawTop() {
    for (int line = 1; line <= 2; line++) {
        // spaces to the left of the current line
        for (int i = 0; i < line - 1; i++) {
            System.out.print(" ");
        }

        // bars and colons on the current line
        System.out.print("|");
        for (int i = 0; i < -2*line + 8; i++) {
            System.out.print(":");
        }
        System.out.print("|");

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

Drawing the Rim

- This always has only one line, so we *don't* need *nested* loops.

```
========
```

- However, we still need a single loop, because we want to be able to scale the size of the figure.
- What should the code look like?

```
for (            ;            ;            ) {


}
```

- This code also goes in its own method, called `drawRim()`

Incremental Development

- We take similar steps to implement methods for the remaining subtasks.
- After completing a given method, we test and debug it.
- The `main` method just calls the methods for the subtasks:

```
public static void main(String[] args) {
    drawFlame();
    drawRim();
    drawTop();
    drawHandle();
    drawBottom();
}
```

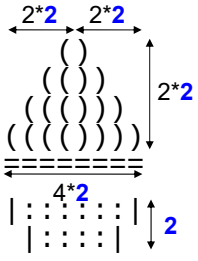
- See the example program `DrawTorch.java`

Using Class Constants

- To make the torch larger or smaller, we'd need to make many changes.
  - the size of the figure is hard-coded into most methods
- To make the program more flexible, we can store info. about the figure's dimensions in one or more *class constants*.
  - like variables, but their values are fixed
  - can be used throughout the program

Using Class Constants (cont.)

- We only need one constant for the torch.
  - for the default size, it equals 2
  - its connection to some of the dimensions is shown at right



- We declare it at the very start of the class:

```
public class DrawTorch2 {
    public static final int SCALE_FACTOR = 2;
    ...
```

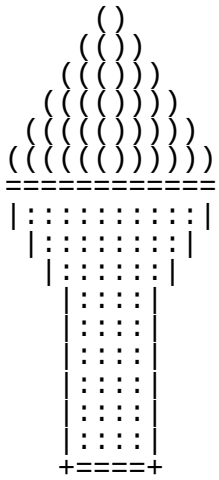
- General syntax:

```
public static final <type> <name> = <expression>;
```

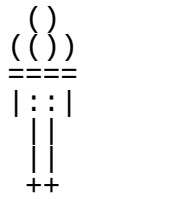
  - conventions:
    - capitalize all letters in the name
    - put an underscore ('_') between multiple words

Scaling the Figure

- Here are some other versions of the figure:



SCALE_FACTOR = 3

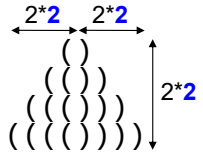


SCALE_FACTOR = 1

Revised Method for Drawing the Flame

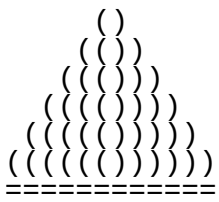
- We replace the two 4s with 2*SCALE_FACTOR:

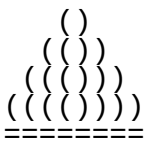
```
public static void drawFlame() {
    for (int line = 1; line <= 2*SCALE_FACTOR; line++) {
        // spaces to the left of the flame
        for (int i = 0; i < 2*SCALE_FACTOR - line; i++) {
            System.out.print(" ");
        }

        // the flame itself, both left and right halves
        for (int i = 0; i < line; i++) {
            System.out.print("(");
        }
        for (int i = 0; i < line; i++) {
            System.out.print(")");
        }

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



Making the Rim Scaleable

- How does the width of the rim depend on SCALE_FACTOR?





- Use a table!

SCALE_FACTOR	width of rim
1	4
2	8
3	12

width of rim = ?

Revised Method for Drawing the Rim

- Original version (for the default size):

```
public static void drawRim() {
    for (int i = 0; i < 8; i++) {
        System.out.print("=");
    }
    System.out.println();
}
```

- Scaleable version:

```
public static void drawRim() {
    for (int i = 0; i < 4*SCALE_FACTOR; i++) {
        System.out.print("=");
    }
    System.out.println();
}
```

Making the Top of the Torch Scaleable

- For SCALE_FACTOR = 2, we got:

  number of lines = 2
  spaces = line – 1
  colons = -2 * line + 8

```
1|:::::::|
2 |:::::|
```

- What about SCALE_FACTOR = 3?

line	spaces	colons
1	0	10
2	1	8
3	2	6

```
1|::::::::::|
2 |::::::::|
3  |::::::|
```

  number of lines = 3
  spaces = ?
  colons = ?

- in general, number of lines = ?

Making the Top of the Torch Scaleable (cont.)

- Compare the two sets of formulas:

SCALE_FACTOR = 2	SCALE_FACTOR = 3
spaces = line – 1	spaces = line – 1
colons = -2 * line + 8	colons = -2 * line + 12

- There's no change in:
  - the formula for spaces
  - the first constant in the formula for colons

- Use a table for the second constant:

SCALE_FACTOR	constant
2	8
3	12

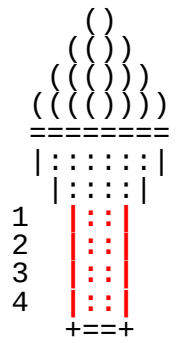
  constant = ?

- Scaleable formulas: spaces = line – 1
  colons = ?

Revised Method for Drawing the Top of the Torch

```
public static void drawTop() {
    for (int line = 1; line <= SCALE_FACTOR; line++) {
        // spaces to the left of the current line
        for (int i = 0; i < line - 1; i++) {
            System.out.print(" ");
        }

        // bars and colons on the current line
        System.out.print("|");
        for (int i = 0; i < -2*line + 4*SCALE_FACTOR; i++) {
            System.out.print(":");
        }
        System.out.print("|");

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

Practice: The Torch Handle



- Pseudocode for default size:

- Java code for default size:

```
public static void drawHandle() {




}
```

Practice: Making the Handle Scaleable

- We again compare two different sizes.

SCALE_FACTOR	# lines	spaces	colons
2	4	2	2
3	6	3	4

- number of lines = ?
  spaces = ?
  colons = ?

```
  |:::::::|
   |:::::|
1   |:::|
2   |:::|
3   |:::|
4   |:::|
```

```
  |:::::::::::|
   |:::::::::|
    |:::::::|
1    |:::::|
2    |:::::|
3    |:::::|
4    |:::::|
5    |:::::|
6    |:::::|
```

Revised Method for Drawing the Handle

- What changes do we need to make?

```
public static void drawHandle() {
    for (int line = 1; line <= 4; line++) {
        for (int i = 0; i < 2; i++) {
            System.out.print(" ");
        }
        System.out.print("|");
        for (int i = 0; i < 2; i++) {
            System.out.print(":");
        }
        System.out.println("|");
    }
}
```

Extra Practice: Printing a Pattern, version 3

- Print a triangular pattern with lines containing n, n – 1, …, 1 asterisks.
  - example:

```
Enter a positive integer: 3
***
**
*
```

- How would we use a nested loop to do this?

```
for ( ____________________________________ ) {
    for ( ____________________________________ ) {
        System.out.print("*");
    }
    System.out.println();
}
```