Building Java Programs

Chapter 2:
Primitive Data and
Definite Loops

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Chapter outline

Lecture 4
- primitive types
- expressions and precedence
- variables: declaration, initialization, assignment
- string concatenation
- modify-and-reassign operators
- `System.out.print`

Lecture 5
- the `for` loop
- nested loops

Lecture 6
- drawing complex figures
- variable scope
- class constants
Primitive data, expressions, and variables

- suggested reading: 2.1 - 2.2
Programs that examine data

- We have already seen that we can print text using `println` and strings:
  ```java
  System.out.println("Hello, world!");
  ```

- Now we will learn how to print and manipulate other kinds of data, such as numbers:
  ```java
  System.out.println(42);
  System.out.println(3 + 5 * 7);
  System.out.println(12.5 / 8.0);
  ```
Data types

- **type**: A category or set of data values.
  - Many languages have a notion of data *types* and ask the programmer to specify what type of data is being manipulated.
  - Example: integer, real number, string

- Internally, the computer stores all data as 0s and 1s.
  - examples: 42 --> 101010
  - "hi" --> 0110100001101001
Java's primitive types

- **primitive types**: Java's built-in simple data types for numbers, text characters, and logic.
  - Java has eight primitive types.
  - Types that are not primitive are called *object* types. (seen later)

- Four primitive types we will use:
  
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>int</td>
<td>integers (whole numbers)</td>
<td>42, -3, 0, 926394</td>
</tr>
<tr>
<td>double</td>
<td>real numbers</td>
<td>3.14, -0.25, 9.4e3</td>
</tr>
<tr>
<td>char</td>
<td>single text characters</td>
<td>'a', 'X', '?', '\n'</td>
</tr>
<tr>
<td>boolean</td>
<td>logical values</td>
<td>true, false</td>
</tr>
</tbody>
</table>
Expressions

**expression**: A data value, or a set of operations that compute a data value.

Example: 1 + 4 * 3

- The simplest expression is a *literal value*.
- A more complex expression can have *operators* and parentheses.
  - The values that an operator applies to are called *operands*.

**Five arithmetic operators we will use**:

+ addition
- subtraction or negation
* multiplication
/ division
% modulus, a.k.a. remainder
Evaluating expressions

- When your Java program executes and encounters a line with an expression, the expression is evaluated (its value is computed).
  - The expression 3 * 4 is evaluated to obtain 12.
  - System.out.println(3 * 4) prints 12, not 3 * 4. (How could we print the text 3 * 4 on the screen?)

- When an expression contains more than one operator of the same kind, it is evaluated left-to-right.
  - Examples: 1 + 2 + 3 is (1 + 2) + 3 which is 6
    1 - 2 - 3 is (1 - 2) - 3 which is -4
When we divide integers, the result is also an integer: the quotient.

Therefore, \(14 \div 4\) evaluates to 3, not 3.5.

\[
\begin{array}{c|c}
3 & 52 \\
4 & 27 & 1425 \\
\hline
14 & 135 & 54 \\
12 & 75 & 21 \\
2 & & \\
\end{array}
\]

Examples:

- \(1425 \div 27\) is 52
- \(35 \div 5\) is 7
- \(84 \div 10\) is 8
- \(156 \div 100\) is 1

Dividing by 0 causes a runtime error in your program.
The % operator computes the remainder from a division of integers.

Example: 14 % 4 is 2
Example: 218 % 5 is 3

What are the results of the following expressions?

45 % 6
2 % 2
8 % 20
11 % 0
Applications of \% operator

- What expression obtains the last digit (units place) of a number?
  - Example: From 230857, obtain the 7.

- How could we obtain the last 4 digits of a Social Security Number?
  - Example: From 658236489, obtain 6489.

- What expression obtains the second-to-last digit (tens place) of a number?
  - Example: From 7342, obtain the 4.

- Can the \% operator help us determine whether a number is odd? Can it help us determine whether a number is divisible by, say, 27?
Operator precedence

**precedence**: Order in which operations are computed in an expression.

- Multiplicative operators * / % have a higher level of precedence than additive operators + –.
  
  \[1 + 3 \times 4 \text{ is } 13\]

- Parentheses can be used to force a certain order of evaluation.
  
  \[(1 + 3) \times 4 \text{ is } 16\]

- Spacing does not affect order of evaluation.
  
  \[1+3 \times 4-2 \text{ is } 11\]
Precedence examples

\[
1 \times 2 + 3 \times 5 / 4
\]

\[
2 + 3 \times 5 / 4
\]

\[
2 + 15 / 4
\]

\[
2 + 3
\]

\[
5
\]

\[
1 + 2 / 3 \times 5 - 4
\]

\[
1 + 0 \times 5 - 4
\]

\[
1 + 0 - 4
\]

\[
1 - 4
\]

\[
-3
\]
Precedence questions

What values result from the following expressions?

- 9 / 5
- 695 % 20
- 7 + 6 * 5
- 7 * 6 + 5
- 248 % 100 / 5
- 6 * 3 – 9 / 4
- (5 – 7) * 4
- 6 + (18 % (17 – 12))

Which parentheses above are unnecessary (which do not change the order of evaluation?)
Real numbers (double)

- Java can also manipulate real numbers (type `double`).
  - Examples: 6.022  -15.9997  42.0  2.143e17

- The operators `+ − * / % ( )` all work for real numbers as well.
  - The `/` produces an exact answer when used on real numbers.
    Example: `15.0 / 2.0` is 7.5

- The same rules of precedence that apply to integers also apply to real numbers.
  - `( )` before `* / %` before `+ −`
Real number example

\[ 2.0 \times 2.4 + 2.25 \times 4.0 / 2.0 \]

\[ 4.8 + 2.25 \times 4.0 / 2.0 \]

\[ 4.8 + 9.0 / 2.0 \]

\[ 4.8 + 4.5 \]

\[ 9.3 \]
Real number precision

- The computer internally represents real numbers in an imprecise way.

- Example:

  ```java
  System.out.println(0.1 + 0.2);
  ```

  - The mathematically correct answer should be 0.3
  - Instead, the output is 0.30000000000000004

- Later we will learn some ways to produce a better output for examples like the above.
Mixing integers and reals

- When a Java operator is used on an integer and a real number, the result is a real number.
  - Examples: \(4.2 \times 3\) is 12.6
    \(1 \div 2.0\) is 0.5

- The conversion occurs on a per-operator basis. It affects only its two operands.

  \[
  7 \div 3 \times 1.2 + 3 \div 2
  \]

  \[
  2 \times 1.2 + 3 \div 2
  \]

  \[
  2.4 + 3 \div 2
  \]

  \[
  2.4 + 1
  \]

  \[
  3.4
  \]

- Notice how \(3 \div 2\) is still 1 above, not 1.5.
Mixed types example

\[
2.0 + 10 / 3 \times 2.5 - 6 / 4
\]

\[
2.0 + 3 \times 2.5 - 6 / 4
\]

\[
2.0 + 7.5 - 6 / 4
\]

\[
2.0 + 7.5 - 1
\]

\[
9.5 - 1
\]

\[
8.5
\]
The computer's memory

- Expressions are somewhat like using the computer as a calculator.
  - A good calculator has "memory" keys to store and retrieve a computed value.
  - In what situation(s) is this useful?
  - We'd like the ability to save and restore values in our Java programs, like the memory keys on the calculator.
Variables

- **variable**: A piece of your computer's memory that is given a name and type and can store a value.
  - Usage:
    - compute an expression's result
    - store that result into a variable
    - use that variable later in the program
  - Unlike a calculator, which may only have enough to store a few values, we can declare as many variables as we want.

- Variables are a bit like preset stations on a car stereo:
Declaring variables

- **variable declaration statement**: A Java statement that creates a new variable of a given type.
  - A variable is *declared* by writing a statement that says its type, and then its name.

- Declaration statement syntax:
  
  ```
  <type> <name> ;
  ```
  
  - The `<name>` is an identifier.
  - Examples:    
    ```
    int x;
    double myGPA;
    ```
More on declaring variables

- Declaring a variable sets aside a piece of memory in which you can store a value.

```c
int x;
int y;
```

- Part of the computer's memory:

![Diagram showing part of the computer's memory with x and y variables](image)

(The memory has no value in it yet.)
Assignment statements

- **assignment statement**: A Java statement that stores a value into a variable's memory location.
  - Variables must be declared before they can be assigned a value.

Assignment statement syntax:

```
<name>  =  <value>  ;
```

- Example:   `x  =  3;`
- Example: `myGPA  =  3.25;`

```
x     3
myGPA  3.25
```
More about assignment

- The `<value>` assigned to a variable can be a complex expression.
  - The expression is evaluated; the variable stores the result.
  - Example: \[ x = (2 + 8) / 3 \times 5; \]

  \[
x = 15
  \]

- A variable can be assigned a value more than once.
  - Example:
    ```java
    int x;
    x = 3;
    System.out.println(x); // 3
    x = 4 + 7;
    System.out.println(x); // 11
    ```
Using variables' values

- Once a variable has been assigned a value, it can be used in an expression, just like a literal value.
  ```java
  int x;
  x = 3;
  System.out.println(x * 5 - 1);
  ```

- The above has output equivalent to:
  ```java
  System.out.println(3 * 5 - 1);
  ```
Assignment and algebra

- Though the assignment statement uses the = character, it is not an algebraic equation.
  - = means, "store the value on the right in the variable on the left"
  - Some people read \( x = 3; \) as, "x becomes 3" or, "x gets 3"
  - We would not say \( 3 = 1 + 2; \) because 3 is not a variable.

- What happens when a variable is used on both sides of an assignment statement?

```c
int x;
x = 3;
x = x + 2;  // what happens?
```
Some errors

- A compiler error will result if you declare a variable twice, or declare two variables with the same name.
  - Example:
    ```java
    int x;
    int x; // ERROR: x already exists
    ```

- A variable that has not been assigned a value cannot be used in an expression or `println` statement.
  - Example:
    ```java
    int x;
    int x;
    System.out.println(x); // ERROR: x has no value
    ```
Assignment and types

- A variable can only store a value of its own type.
  - Example: int x;
    x = 2.5;  // ERROR: x can only store int

- An int value can be stored in a double variable.
  - The value is converted into the equivalent real number.
  - Example: double myGPA;
    myGPA = 2;

myGPA 2.0
What is the output of the following Java code?

```java
int number;
number = 2 + 3 * 4;
System.out.println(number - 1);
number = 16 % 6;
System.out.println(2 * number);
```

What is the output of the following Java code?

```java
double average;
average = (11 + 8) / 2;
System.out.println(average);

average = (5 + average * 2) / 2;
System.out.println(average);
```
A variable can be declared and assigned an initial value in the same statement.

Declaration/initialization statement syntax:

\[ \text{<type> <name> = <value> ;} \]

Examples:
- double myGPA = 3.95;
- int x = (11 % 3) + 12;

same effect as:
- double myGPA;
- myGPA = 3.95;
- int x;
- x = (11 % 3) + 12;
Multiple declaration error

- The compiler will fail if you try to declare-and-initialize a variable twice.
  - Example:
    ```java
    int x = 3;
    System.out.println(x);
    
    int x = 5;       // ERROR: variable x already exists
    System.out.println(x);
    
    This is the same as trying to declare x twice.
    
    How can the code be fixed?
Multiple declarations per line

- It is legal to declare multiple variables on one line:
  
  ```
  <type> <name>, <name>, ..., <name> ;
  ```

  Examples:
  ```
  int a, b, c;
  double x, y;
  ```

- It is also legal to declare/initialize several at once:
  
  ```
  <type> <name> = <value>, ..., <name> = <value> ;
  ```

  Examples:
  ```
  int a = 2, b = 3, c = -4;
  double grade = 3.5, delta = 0.1;
  ```

- The variables must be of the same type.
## Integer or real number?

Categorize each of the following quantities by whether an `int` or `double` variable would best to store it:

<table>
<thead>
<tr>
<th>integer (int)</th>
<th>real number (double)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Temperature in degrees Celsius
2. The population of lemmings
3. Your grade point average
4. A person's age in years
5. A person's weight in pounds
6. A person's height in meters
7. Number of miles traveled
8. Number of dry days in the past month
9. Your locker number
10. Number of seconds left in a game
11. The sum of a group of integers
12. The average of a group of integers

String concatenation

**string concatenation**: Using the + operator between a String and another value to make a longer String.

**Examples**: (Recall: Precedence of + operator is below *, /, %)

- "hello" + 42 is "hello42"
- 1 + "abc" + 2 is "1abc2"
- "abc" + 1 + 2 is "abc12"
- 1 + 2 + "abc" is "3abc"
- "abc" + 9 * 3 is "abc27"
- "1" + 1 is "11"
- 4 - 1 + "abc" is "3abc"

"abc" + 4 - 1 causes a compiler error... why?
String expressions with `+` are useful so that we can print more complicated messages that involve computed values.

```java
double grade = (95.1 + 71.9 + 82.6) / 3.0;
System.out.println("Your grade was "+grade);

int students = 11 + 17 + 4 + 19 + 14;
System.out.println("There are "+students+
" students in the course.");
```
Example variable exercise

- Write a Java program that stores the following data:
  - Section AA has 17 students.
  - Section AB has 8 students.
  - Section AC has 11 students.
  - Section AD has 23 students.
  - Section AE has 24 students.
  - Section AF has 7 students.
  - The average number of students per section.

and prints the following:

There are 24 students in Section AE.
There are an average of 15 students per section.
Java has several shortcut operators that allow you to quickly modify a variable's value:

<table>
<thead>
<tr>
<th>Shorthand</th>
<th>Equivalent longer version</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;variable&gt; += &lt;value&gt; ;</code></td>
<td><code>&lt;variable&gt; = </code>&lt;variable&gt;<code>+</code>&lt;value&gt; ;`</td>
</tr>
<tr>
<td><code>&lt;variable&gt; -= &lt;value&gt; ;</code></td>
<td><code>&lt;variable&gt; = </code>&lt;variable&gt;<code>-</code>&lt;value&gt; ;`</td>
</tr>
<tr>
<td><code>&lt;variable&gt; *= &lt;value&gt; ;</code></td>
<td><code>&lt;variable&gt; = </code>&lt;variable&gt;<code>*</code>&lt;value&gt; ;`</td>
</tr>
<tr>
<td><code>&lt;variable&gt; /= &lt;value&gt; ;</code></td>
<td><code>&lt;variable&gt; = </code>&lt;variable&gt;<code>/</code>&lt;value&gt; ;`</td>
</tr>
<tr>
<td><code>&lt;variable&gt; %= &lt;value&gt; ;</code></td>
<td><code>&lt;variable&gt; = </code>&lt;variable&gt;<code>%</code>&lt;value&gt; ;`</td>
</tr>
</tbody>
</table>

Examples:

- `x += 3;`  // `x = x + 3;`
- `gpa -= 0.5;`  // `gpa = gpa - 0.5;`
- `number *= 2;`  // `number = number * 2;`
Increment and decrement

- The *increment* and *decrement* operators increase or decrease a variable's value by 1.

**Shorthand**

- `<variable> ++ ;`
- `<variable> -- ;`

**Equivalent longer version**

- `<variable> = <variable> + 1;`
- `<variable> = <variable> - 1;`

**Examples:**

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

double gpa = 2.5;
gpa++;  // gpa = gpa + 1;
        // gpa now stores 3.5
```


System.out.print command

- System.out.println prints a line of output and then advances to a new line.
- Another command named System.out.print prints the given output without moving to the next line.
  - This allows you to print partial messages that can appear on the same line as each other.

Example:

```java
System.out.print("Kind of");
System.out.print("Like a cloud,");
System.out.println("I was up");
System.out.print("Way up in the sky");
```

Output:
Kind ofLike a cloud,I was up
Way up in the sky
Chapter outline

Lecture 4
- primitive types
- expressions and precedence
- variables: declaration, initialization, assignment
- string concatenation
- modify-and-reassign operators
- System.out.print

Lecture 5
- the for loop
- nested loops

Lecture 6
- drawing complex figures
- variable scope
- class constants
The **for** loop

- suggested reading: 2.3
Repetition with for loops

- So far, when we wanted to perform a task multiple times, we have written redundant code:

  ```java
  System.out.println("Building Java Programs");
  System.out.println();  // print 5 blank lines
  System.out.println();
  System.out.println();
  System.out.println();
  System.out.println();
  System.out.println("by Stuart Reges and Marty Stepp");
  ```

- Java has a statement called a for loop statement that instructs the computer to perform a task many times.

  ```java
  System.out.println("Building Java Programs");
  for (int i = 1; i <= 5; i++) {  // print 5 blank lines
      System.out.println();
  }
  System.out.println("by Stuart Reges and Marty Stepp");
  ```
for loop syntax

for loop: A block of Java code that executes a group of statements repeatedly until a given test fails.

- General syntax:
  ```java
  for (<initialization> ; <test> ; <update>) {
    <statement>;
    <statement>;
    ...
    <statement>;
  }
  ```

- Example:
  ```java
  for (int i = 1; i <= 10; i++) {
    System.out.println("His name is Robert Paulson");
  }
  ```
**for loop over range of ints**

We'll write **for** loops over integers in a given range.

- The loop declares a *loop counter* variable that is used in the test, update, and body of the loop.

```java
for (int <name> = 1; <name> <= <value>; <name>++)
```

- Example:

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

- Possible interpretation: "For each int i from 1 through 6, ..."

- **Output:**
  
  1 squared is 1
  2 squared is 4
  3 squared is 9
  4 squared is 16
  5 squared is 25
  6 squared is 36
for loop flow diagram

- Behavior of the for loop:
  - Start out by performing the <initialization> once.
  - Repeatedly execute the <statement(s)> followed by the <update> as long as the <test> is still a true statement.

```plaintext
Perform initialization once

Is the test true?

no

execute statement after for loop

yes

execute the controlled statement(s)

perform the update
```
Loop walkthrough

Let's walk through the following for loop:

```java
for (int i = 1; i <= 3; i++) {
    System.out.println(i + " squared is " + (i * i));
}
```

**Output**
1 squared is 1
2 squared is 4
3 squared is 9
Another example for loop

Example:

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

Output:

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

+-----+
Some for loop variations

- The initial and final values for the loop counter variable can be arbitrary numbers or expressions:

  - Example:
    ```java
    for (int i = -3; i <= 2; i++) {
        System.out.println(i);
    }
    ```
    Output:
    -3
    -2
    -1
    0
    1
    2

  - Example:
    ```java
    for (int i = 1 + 3 * 4; i <= 5248 % 100; i++) {
        System.out.println(i + " squared is " + (i * i));
    }
    ```
Downward-counting for loop

- The update can also be a -- or other operator, to make the loop count down instead of up.
  - This also requires changing the test to say >= instead of <=.

```java
System.out.print("T-minus ");
for (int i = 5; i >= 1; i--) {
    System.out.print(i + " ");
}
System.out.println("Blastoff!");
```

Output:
T-minus 5 4 3 2 1 Blastoff!
Single-line for loop

- When a for loop only has one statement in its body, the 
  
  ```java
  for (int i = 1; i <= 6; i++)
      System.out.println(i + " squared is " + (i * i));
  ```

- However, this can lead to mistakes where a line appears to be inside a loop, but is not:
  
  ```java
  for (int i = 1; i <= 3; i++)
      System.out.println("This is printed 3 times");
      System.out.println("So is this... or is it?");
  ```

Output:
- This is printed 3 times
- This is printed 3 times
- This is printed 3 times
- So is this... or is it?
Write a loop that produces the following output.

On day #1 of Christmas, my true love sent to me
On day #2 of Christmas, my true love sent to me
On day #3 of Christmas, my true love sent to me
On day #4 of Christmas, my true love sent to me
On day #5 of Christmas, my true love sent to me
...
On day #12 of Christmas, my true love sent to me

Write a loop that produces the following output.

2 4 6 8
Who do we appreciate
Mapping loops to numbers

- Suppose that we have the following loop:
  
  ```java
  for (int count = 1; count <= 5; count++) {
      ...
  }
  ```

- What statement could we write in the body of the loop that would make the loop print the following output?

  3 6 9 12 15

- Answer:

  ```java
  for (int count = 1; count <= 5; count++) {
      System.out.print(3 * count + " ");
  }
  ```
Mapping loops to numbers 2

- Now consider another loop of the same style:
  ```java
  for (int count = 1; count <= 5; count++) {
      ...
  }
  ```

- What statement could we write in the body of the loop that would make the loop print the following output?
  4 7 10 13 16

- Answer:
  ```java
  for (int count = 1; count <= 5; count++) {
      System.out.print(3 * count + 1 + " ");
  }
  ```
Loop number tables

- What statement could we write in the body of the loop that would make the loop print the following output?
  2 7 12 17 22

- To find the pattern, it can help to make a table of the count and the number to print.
  - Each time count goes up by 1, the number should go up by 5.
  - But count * 5 is too great by 3, so we must subtract 3.

<table>
<thead>
<tr>
<th>count</th>
<th>number to print</th>
<th>count * 5</th>
<th>count * 5 - 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>25</td>
<td>22</td>
</tr>
</tbody>
</table>
Loop table question

- What statement could we write in the body of the loop that would make the loop print the following output? 
  17 13 9 5 1

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

<table>
<thead>
<tr>
<th>count</th>
<th>number to print</th>
<th>count * -4</th>
<th>count * -4 + 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>-4</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>-8</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>-12</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>-16</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>-20</td>
<td>1</td>
</tr>
</tbody>
</table>
Degenerate loops

- Some loops execute 0 times, because of the nature of their test and update.

```java
// a degenerate loop
for (int i = 10; i < 5; i++) {
    System.out.println("How many times do I print?");
}
```

- Some loops execute endlessly (or far too many times), because the loop test never fails. A loop that never terminates is called an infinite loop.

```java
for (int i = 10; i >= 1; i++) {
    System.out.println("Runaway Java program!!!");
}
```
Nested loops

- **nested loop**: Loops placed inside one another.
  - The inner loop's counter variable should have a different name so that it will not conflict with the variable from the outer loop.

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

**Output:**

```
i = 1
  j = 1
  j = 2

i = 2
  j = 1
  j = 2

i = 3
  j = 1
  j = 2
```
More nested loops

In this example, all of the statements in the outer loop's body are executed 5 times.

- The inner loop prints 10 numbers each of those 5 times, for a total of 50 numbers printed.

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

Output:
```
1 2 3 4 5 6 7 8 9 10
2 4 6 8 10 12 14 16 18 20
3 6 9 12 15 18 21 24 27 30
4 8 12 16 20 24 28 32 36 40
5 10 15 20 25 30 35 40 45 50
```
Nested for loop exercise

What is the output of the following nested for loops?

```java
for (int i = 1; i <= 6; i++) {
    for (int j = 1; j <= 10; j++) {
        System.out.print("*");
    }
    System.out.println();
}
```

Output:

```
***********
***********
***********
***********
***********
***********
```
Nested for loop exercise

What is the output of the following nested for loops?

```java
for (int i = 1; i <= 6; 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?

```java
for (int i = 1; i <= 6; i++) {
    for (int j = 1; j <= i; j++) {
        System.out.print(i);
    }
    System.out.println();
}
```

Output:
1
22
333
4444
55555
666666
Nested for loop exercise

- What nested for loops produce the following output?

1, 1
2, 1
3, 1
1, 2
2, 2
3, 2

- Answer:

```java
for (int y = 1; y <= 2; y++) {
    for (int x = 1; x <= 3; x++) {
        System.out.println(x + "", " + y);
    }
}
```
Nested for loop exercise

- What nested for loops produce the following output?

  inner loop (repeated characters on each line)

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

- This is an example of a nested loop problem where we build multiple complex lines of output:
  - outer "vertical" loop for each of the lines
  - inner "horizontal" loop(s) for the patterns within each line
Nested for loop exercise

- First we write the outer loop, which always goes from 1 to the number of lines desired:

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

- We notice that each line has the following pattern:
  - some number of dots (0 dots on the last line)
  - a number

  ```plaintext
  ....1
  ...2
  ..3
  .4
  5
  ```
Nested for loop exercise

Next we make a table to represent any necessary patterns on that line:

<table>
<thead>
<tr>
<th>line</th>
<th># of dots</th>
<th>value displayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Answer:

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

- A **for** loop can have more than one loop nested in it. What is the output of the following nested **for** loops?

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

- **Answer:**
  
  1
  22
  333
  4444
  55555
Common nested loop bugs

- It is easy to accidentally type the wrong loop counter variable.

  What is the output of the following nested loops?

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

  What is the output of the following nested loops?

  ```java
  for (int i = 1; i <= 10; i++) {
      for (int j = 1; j <= 5; i++) {
          System.out.print(j);
      }
      System.out.println();
  }
  ```
How to comment: for loops

- Place a comment on complex loops explaining *what* they do from a conceptual standpoint, not the mechanics of the syntax.

- **Bad:**
  ```java
  // This loop repeats 10 times, with i from 1 to 10.
  for (int i = 1; i <= 10; i++) {
      for (int j = 1; j <= 5; j++) {
          // loop goes 5 times
          System.out.print(j);
          // print the j
      }
      System.out.println();
  }
  ```

- **Better:**
  ```java
  // Prints 12345 ten times on ten separate lines.
  for (int i = 1; i <= 10; i++) {
      for (int j = 1; j <= 5; j++) {
          System.out.print(j);
      }
      System.out.println(); // end the line of output
  }
  ```
Chapter outline

Lecture 4

- primitive types
- expressions and precedence
- variables: declaration, initialization, assignment
- string concatenation
- modify-and-reassign operators
- System.out.print

Lecture 5

- the for loop
- nested loops

Lecture 6

- drawing complex figures
- variable scope
- class constants
Drawing complex figures

- suggested reading: 2.4 - 2.5
Drawing complex figures

- Write a Java program that produces the following figure as its output.
- Write nested `for` loops to capture the repetition.

```
#================#
   <><>      
   <> .... <> 
   <> ....... <>
   <> ........ <>
   <> ........ <>
   <> .... <>  
   <> .... <>  
   <><>      
#================#
```
Drawing complex figures

When the task is as complicated as this one, it may help to write down some steps on paper before we write our code:

1. A *pseudo-code* description of the algorithm (written in English)
2. A table of each line's contents, to help see the pattern in the input
Pseudo-code

**pseudo-code**: A written English description of an algorithm to solve a programming problem.

Example: Suppose we are trying to draw a box of stars on the screen which is 12 characters wide and 7 tall.
- A possible pseudo-code for this algorithm:

```
print 12 stars.
for each of 5 lines,
    print a star.
    print 10 spaces.
    print a star.
print 12 stars.
```

************  *
*          *
*          *
*          *
*          *
*          *
************
A pseudo-code algorithm

A possible pseudo-code for our complex figure task:

1. Draw top line with #, 16 =, then #
2. Draw the top half with the following on each line:
   some spaces (decreasing in number as we go downward)
   <>
   some dots (decreasing in number as we go downward)
   <>
   more spaces (same number as above)
3. Draw the bottom half, which is the same as the top half but upside-down
4. Draw bottom line with #, 16 =, then #

Our pseudo-code suggests that we should write a table to learn the pattern in the top and bottom halves of the figure.
Tables to examine output

- A table of the contents of the lines in the "top half" of the figure:
- What expressions connect each line with its number of spaces and dots?

<table>
<thead>
<tr>
<th>line</th>
<th>spaces</th>
<th>line * -2 + 8</th>
<th>dots</th>
<th>4 * line - 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

#================#
Implementing the figure

Let's implement the code for this figure together.

Some questions we should ask ourselves:

- How many loops do we need on each line of the top half of the output?
- Which loops are nested inside which other loops?
- How should we use static methods to represent the structure and redundancy of the output?
Partial solution

// Prints the expanding pattern of <> for the top half of the figure.
public static void drawTopHalf() {
    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("|");
    }
}

Scope and class constants

- suggested reading: 2.4
Variable scope

- **scope**: The portion of a program where a given variable exists.
  - A variable's scope is from its declaration to the end of the `{ }` braces in which it was declared.
    - If a variable is declared in a `for` loop, it exists only in that loop.
    - If a variable is declared in a method, it exists only in that method.

```java
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
```
Scope and using variables

- It is illegal to try to use a variable outside of its scope.

```java
public static void main(String[] args) {
    example();
    System.out.println(x);  // illegal

    for (int i = 1; i <= 10; i++) {
        int y = 5;
        System.out.println(y);
    }
    System.out.println(y);  // illegal
}

public static void example() {
    int x = 3;
    System.out.println(x);
}
```
Overlapping scope

- It is legal to declare variables with the same name, as long as their scopes do not overlap:

```java
public static void main(String[] args) {
    int x = 2;

    for (int i = 1; i <= 5; i++) {
        int y = 5;
        System.out.println(y);
    }
    for (int i = 3; i <= 5; i++) {
        int y = 2;
        int x = 4; // illegal
        System.out.println(y);
    }
}

public static void anotherMethod() {
    int i = 6;
    int y = 3;
    System.out.println(i + " , " + y);
}
```
Problem: redundant values

- Sometimes we have values (called *magic numbers*) that are used throughout the program.
- A normal variable cannot be used to fix the magic number problem, because it is out of scope.

```java
public static void main(String[] args) {
    int max = 3;
    printTop();
    printBottom();
}

public static void printTop() {
    for (int i = 1; i <= max; i++) {
        for (int j = 1; j <= i; j++) {
            System.out.print(j);
        }
        System.out.println();
    }
}

public static void printBottom() {
    for (int i = max; i >= 1; i--) {
        for (int j = i; j >= 1; j--) {
            System.out.print(max);
        }
        System.out.println();
    }
}
```
class constant: A special kind of variable that can be seen throughout the program.
- The value of a constant can only be set when it is declared. It can not be changed while the program is running.

Class constant syntax:
```java
public static final <type> <name> = <value> ;
```
- Constants' names are usually written in ALL_UPPER_CASE.
- Examples:
  ```java
  public static final int DAYS_IN_WEEK = 7;
  public static final double INTEREST_RATE = 3.5;
  public static final int SSN = 658234569;
  ```
Making the 3 a class constant removes the redundancy:

```java
public static final int MAX_VALUE = 3;

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

public static void printTop() {
    for (int i = 1; i <= MAX_VALUE; i++) {
        for (int j = 1; j <= i; j++) {
            System.out.print(j);
        }
        System.out.println();
    }
}

public static void printBottom() {
    for (int i = MAX_VALUE; i >= 1; i--) {
        for (int j = i; j >= 1; j--) {
            System.out.print(MAX_VALUE);
        }
        System.out.println();
    }
}
Constants and figures

Consider the task of drawing the following figures:

```
+\///\///\///\///\///+
|                |
+\///\///\///\///\///+
|                |
+\///\///\///\///\///+
```

Each figure is strongly tied to the number 5 (or a multiple of 5, such as 10 ...)

Let's use a class constant so that these figures will be easily resizable.
Repetitive figure code

- Note the repetition of numbers based on 5 in the code:

```java
public static void drawFigure1() {
    drawPlusLine();
    drawBarLine();
    drawPlusLine();
}

public static void drawPlusLine() {
    System.out.print("+/\/");
    for (int i = 1; i <= 5; i++) {
        System.out.print("/\/");
    }
    System.out.println("+");
}

public static void drawBarLine() {
    System.out.print("| ");
    for (int i = 1; i <= 10; i++) {
        System.out.print(" ");
    }
    System.out.println("|");
}
```

- It would be cumbersome to resize the figure.
Fixing our code with constant

A class constant will fix the "magic number" problem:

```java
public static final int FIGURE_WIDTH = 5;

public static void drawFigure1() {
    drawPlusLine();
    drawBarLine();
    drawPlusLine();
}

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

public static void drawBarLine() {
    System.out.print("|");
    for (int i = 1; i <= 2 * FIGURE_WIDTH; i++) {
        System.out.print(" ");
    }
    System.out.println("|");
}
```

Output:
```
+/
+/
```
Modify your code from the previous slides to use a constant so that it can show figures of different sizes.

The figure originally shown has a size of 4.

A figure of size 3:
public static final int SIZE = 4;

// Prints the expanding pattern of <> for the top half of the figure.
public static void drawTopHalf() {
    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.println("<>");
        for (int dot = 1; dot <= (line * 4 - 4); dot++) {
            System.out.print(".");
        }
    }
    System.out.println("<>");
    for (int space = 1; space <= (line * -2 + (2 * SIZE)); space++) {
        System.out.print(" ");
    }
    System.out.println("|");
}
Observations about constant

- Adding a constant often changes the amount that is added to a loop expression, but usually the multiplier (slope) is unchanged.
  ```java
  public static final int SIZE = 4;
  for (int space = 1; space <= (line * -2 + (2 * SIZE)); space++) {
    System.out.print(" ");
  }
  ```

- A constant doesn't always replace every occurrence of the original value.
  ```java
  for (int dot = 1; dot <= (line * 4 - 4); dot++) {
    System.out.print(".");
  }
  ```
Another complex figure

- Write a Java program that produces the following figure as its output.
  - Write nested `for` loops to capture the repetition.
  - Use static methods to capture structure and redundancy.

```
====+==== #   |   # #   |   # #   |   # ====+==== #   |   # #   |   # #   |   #
#     #     # #     # #     # #     # #     # #     #
====+==== #   |   # #   |   # #   |   # #######
#     #     # #     # #     # #     # #     # #     #
#     #     # #     # #     # #     # #     # #     #
#     #     # #     # #     # #     # #     # #     #
#     #     # #     # #     # #     # #     # #     #
```

- After implementing the program, add a constant so that the figure can be resized.