Java, Arrays and Functions Recap

CSE260, Computer Science B: Honors
Stony Brook University

http://www.cs.stonybrook.edu/~cse260
Objectives

- Refresh information from CSE160
How Data is Stored?

- What’s binary?
  - a base-2 number system

- What do humans use?
  - base-10

- Why?
  - electronics
    - easier to make hardware that stores and processes binary numbers than decimal numbers
  - more efficient: space & cost

<table>
<thead>
<tr>
<th>Memory address</th>
<th>Memory content</th>
<th>Encoding for character</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>01001010</td>
<td>‘J’</td>
</tr>
<tr>
<td>2001</td>
<td>01100001</td>
<td>‘a’</td>
</tr>
<tr>
<td>2002</td>
<td>01110110</td>
<td>‘v’</td>
</tr>
<tr>
<td>2003</td>
<td>01100001</td>
<td>‘a’</td>
</tr>
<tr>
<td>2004</td>
<td>00000011</td>
<td>Encoding for number 3</td>
</tr>
</tbody>
</table>
Memory: What goes in each memory segment?

- **Stack Segment**
  - temporary variables declared inside methods
  - removed from memory when a method returns

- **Heap Segment**
  - for dynamic data (whenever you use new)
  - data for constructed objects
  - persistent as long as an existing object variable references this region of memory

- **Global Segment**
  - data that can be reserved at compile time
  - global data (like static data)
How objects are stored?

• You must understand that in Java, every object/reference variable stores a memory address

• 32 bit numbers (4 bytes)

OR

• 64 bit numbers (8 bytes)

• These addresses point to memory locations where the objects’ data is stored
So Hardware stores 0s & 1s

- 0101010101010101010101010101 ...

- Data is byte addressable
  - we can access or change any byte (group of 8 bits) independently as needed

**How do we store text?**

- Numerically (using its code)
- Each character is stored in memory as a number
- Standard character sets: ASCII & Unicode
  - ASCII uses 1 byte per character
  - ‘A’ is 65
Anatomy of a Java Program

- Comments
- Reserved words
- Modifiers
- Statements
- Blocks
- Classes
- Methods
- The main method
Reserved Words (Keywords)

- Reserved words or keywords are words that have a specific meaning to the compiler.
- Cannot be used for other purposes in the program.
- Example: `class`
  - the word after class is the name for the class.
Modifiers

Java uses certain reserved words called modifiers that specify the properties of the data, methods, and classes and how they can be used

- Examples: public, static, private, final, abstract, protected
- A public datum, method, or class can be accessed by other programs
- A private datum or method cannot be accessed by other programs
Variable, class, and method names

- What’s an API?
  - Application Programming Interface
  - a library of code to use

- **Names**

- **For Variables, Classes, and Methods**
  - From 2 sources:
    - your own classes, variables, and methods
    - the Oracle/Sun (or someone else’s) API

- Your Identifiers (Names) – Why name them?
  - they are your data and commands
  - you’ll need to reference them elsewhere in your program

```java
int myVariable = 5; // Declaration
myVariable = myVariable + 1; // Using the variable
```
Rules for Identifiers

- Should contain only letters, numbers, & '_'
  - '$' is allowed, but only for special use
- Cannot begin with a digit!
- Uppercase and lowercase letters are considered to be different characters

Examples:
- Legal: `myVariable`, `my_class`, `my4Var`
- Illegal: `4myVariable`, `my class`, `my!Var`, `@#$myClass`
Common Java Naming Conventions

• Variables & Methods start with lower case letters: x, toString
• Classes start with upper case letters: Person
• Variables and Class identifiers should generally be nouns
• Method identifiers should be verbs
• Use Camel notation: myVariable, MyClass
• Although it is legal, do not begin with ‘_’ (underscore).
• Use descriptive names: LinkedList, compareTo

area = PI * radius * radius;
Programming Errors

- Syntax / Compiler Errors
  - Detected by the compiler

- Runtime Errors
  - Causes the program to abort

- Logic Errors
  - Produces incorrect result
public class ShowSyntaxError {
    public static void main(String[] args) {
        int i = 30; // Detected by the compiler
        System.out.println(i + 4);
    }
}
public class ShowRuntimeError {
    public static void main(String[] args) {
        int i = 1 / 0;  // Division with 0
    }
}
public class ShowLogicError {
    // Determine if a number is between 1 and 100 inclusively
    public static void main(String[] args) {
        Scanner input = new Scanner(System.in);
        int number = input.nextInt();
        // Display the result
        System.out.println("The number is between 1 and 100, inclusively: " +
        ((1 < number) && (number < 100)));
        // Wrong result if the entered number is 1 or 100
        System.exit(0);
    }
}
Logic Errors Debugging

- Logic errors are called *bugs*
- The process of finding and correcting errors is called *debugging*

**Methods:**
- hand-trace the program (i.e., catch errors by reading the program),
- insert print statements in order to show the values of the variables
- for a large, complex program, the most effective approach for debugging is to use a **debugger utility**
Debugger is a program that facilitates debugging. You can use a debugger to:

• Execute a single statement at a time.
• Trace into or stepping over a method.
• Set breakpoints.
• Display variables.
• Display call stack.
• Modify variables.
Java’s Primitive Types

- Integers (whole numbers)
  - byte – 1 byte (-128 to 127)
  - short – 2 bytes (-32768 to 32767)
  - int – 4 bytes (-2147483648 to 2147483647)
  - long – 8 bytes (-9223372036854775808 to 9223372036854775807)

- Real Numbers
  - float – 4 bytes
  - double – 8 bytes

- char – 2 bytes
  - stores a single character (Unicode 2)

- boolean – stores true or false (uses 1-bit or byte)
Arithmetic Operators

+  Addition
-  Subtraction
*  Multiplication
/  Division
%  Modulo/Remainder (integer operands only)
++  Increment by one
--  Decrement by one
+=  Increment by specified amount
-=  Decrement by specified amount
*=  Multiply by specified amount
/=  Divide by specified amount
Division

• Integer division:
  • $8/3 = 2$

• Double division:
  • $8.0/3.0 = 2.666666666666667$
  • $8.0/3 = 2.666666666666667$
  • $8/3.0 = 2.666666666666667$
Arithmetic Operators

- Division operator (evaluate full expression first, then assignment):

```c
double average = 100.0/8.0; // 12.5
average = 100.0/8; // 12.5
average = 100/8; // 12.0
int sumGrades = 100/8; // ERROR
sumGrades = (int)100.0/8.0; // ERROR
sumGrades = (int)(100.0/8.0); // 12
int fifty_percent = 50/100; // 0
double fiftyPercent = 50/100; // 0.0
fiftyPercent = 50.0/100.0; // 0.5
```
Increment and Decrement Operators

```java
int i = 10;
int newNum = 10 * i++;
```

Same effect as

```java
int newNum = 10 * i;
i = i + 1;
```

```java
int i = 10;
int newNum = 10 * (i++);
```

Same effect as

```java
i = i + 1;
int newNum = 10 * i;
```
Packages

- To make types easier to find and use, to avoid naming conflicts, and to control access, programmers bundle groups of related types into packages.

- The types that are part of the Java platform are members of various packages that bundle classes by function: fundamental classes are in `java.lang`, classes for reading and writing (input and output) are in `java.io`, and so on.

- You can put your types in packages too.
  
  To create a package, you choose a name for the package and put a package statement with that name at the top of every source file that contains the types (e.g., classes, interfaces). In file Circle.java:

```java
package edu.stonybrook.cse160;
public class Circle {
    ...
}
```
To use a public package member from outside its package, you must do one of the following:

- Refer to the member by its fully qualified name
  ```java
to import java.util.Scanner input = new java.util.Scanner(System.in);
```
- Import the package member
  ```java
import java.util.Scanner;
```
- Import the member's entire package
  ```java
import java.util.*;
```
Packages

- Packages appear to be hierarchical, but they are not.
  - Importing `java.awt.*` imports all of the types in the java.awt package, but it does not import `java.awt.color`, `java.awt.font`, or any other `java.awt.xxxx` packages.
  - If you plan to use the classes and other types in `java.awt.color` as well as those in `java.awt`, you must import both packages with all their files:
    ```java
    import java.awt.*;
    import java.awt.color.*;
    ```

Setting the CLASSPATH System Variable

- In Windows: `set CLASSPATH=C:\users\george\java\classes`
- In Unix-based OS:
  ```bash
  %CLASSPATH=/home/george/java/classes;
  export CLASSPATH
  ```
Character Data Type

char letter = 'A';  (ASCII)
char numChar = '4';  (ASCII)
char letter = '\u0041';  (Unicode)
char numChar = '\u0034';  (Unicode)

The increment and decrement operators can also be used on char variables to get the next or preceding Unicode character.

- the following statements display character b:
  
  char ch = 'a';
  System.out.println(++ch);
Java characters use **Unicode UTF-16**

16-bit encoding

Unicode takes two bytes, preceded by \u, expressed in four hexadecimal numbers that run from 'u0000' to 'uFFFF'.

Unicode can represent **65535 + 1 characters**.

Unicode \u03b1 \u03b2 \u03b3 for three Greek letters
The boolean Type and Operators

• Often in a programs you need to compare values:
  \[
  \text{if } x \text{ is greater than } y
  \]

• Java provides six comparison operators (relational operators) to compare two values: \(<\), \(<=\), \(>\), \(>=\), \(==\) and \(!=\)

• The result of the comparison is a Boolean value:
  true or false.

  \[
  \text{boolean } b = (1 > 2);
  \]
One-way if Statements

if (boolean-expression) {
    statement(s);
}

if (radius >= 0) {
    area = radius * radius * PI;
    System.out.println("The area +" for the circle of radius " + radius + " is " + area);
}

(A) (B)

Boolean Expression 

false 

true 

Statement(s) 

(area = radius * radius * PI; 
System.out.println("The area for the circle of " + "radius " + radius + " is " + area); 

true 

false
Two-way if Statement

```java
if (boolean-expression) {
    statement(s)-for-the-true-case;
} else {
    statement(s)-for-the-false-case;
}
```

Diagram:
- If the Boolean expression is true, execute the statement(s) for the true case.
- If the Boolean expression is false, execute the statement(s) for the false case.
<table>
<thead>
<tr>
<th>Operator</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>!</td>
<td>not</td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td>and</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>exclusive or</td>
</tr>
</tbody>
</table>
Determining Leap Year

This program first prompts the user to enter a year as an int value and checks if it is a leap year.

A year is a leap year if it is divisible by 4 but not by 100, or it is divisible by 400.

\[(\text{year} \mod 4 == 0 \land \text{year} \mod 100 \neq 0) \lor \text{year} \mod 400 == 0\]
The unconditional & and | Operators

- The & operator works exactly the same as the && operator, and the | operator works exactly the same as the || operator with one exception:
  - the & and | operators always evaluate both operands
The unconditional & and | Operators

If x is 1, what is x after these expressions:

1. \((x > 1) \land (x++ < 10)\)
2. \((x > 1) \land (x++ < 10)\)

1. \((1 == x) \lor (10 > x++)?\)
2. \((1 == x) \lor (10 > x++)?\)
switch Statements

```java
switch (var) {
    case 0: ...;
        break;
    case 1: ...;
        break;
    case 2: ...;
        break;
    case 3: ...;
    default: ...;
}
```
switch Statement Flow Chart

- var is 0: Compute tax for married file separately
- var is 1: break
- var is 2: break
- var is 3: break
- default: Next Statement
switch Statement Rules

`char`, `byte`, `short`, `int`, `String`

value1, ..., and valueN are constant expressions of the same data type as the value of the `switch`-expression constant = they cannot contain variables in the expression, such as `x+y`

```java
switch (switch-expression) {
    case value1:
        statement(s)1;
        break;
    case value2:
        statement(s)2;
        break;
    ...
    case valueN:
        statement(s)N;
        break;
    default:
        statement(s);
}
```
switch Statement Rules

break is optional, but it terminates the remainder of the switch statement.

default is optional - executed when none of the specified cases matches the switch-expression.

```java
switch (switch-expression) {
    case value1:    statement(s)1;
                    break;
    case value2:    statement(s)2;
                    break;
    ...
    case valueN:    statement(s)N;
                    break;
    default:        statement(s);
}

execution in sequential order
```
Static methods

- What does **static** mean?
  - associates a method with a particular class name
  - any method can call a **static method** either:
    - directly from within same class OR
    - using class name from outside class
The Math Class

- Class constants:
  - PI
  - E
- Class methods:
  - Trigonometric Methods
  - Exponent Methods
  - Rounding Methods
  - min, max, abs, and random Methods
Trigonometric Methods

- \( \sin(\text{double } a) \)
- \( \cos(\text{double } a) \)
- \( \tan(\text{double } a) \)
- \( \text{acos(\text{double } a)} \)
- \( \text{asin(\text{double } a)} \)
- \( \text{atan(\text{double } a)} \)

Radians

- **Examples:**
  - \( \sin(0) \) returns 0.0
  - \( \sin(\pi / 6) \) returns 0.5
  - \( \sin(\pi / 2) \) returns 1.0
  - \( \cos(0) \) returns 1.0
  - \( \cos(\pi / 6) \) returns 0.866
  - \( \cos(\pi / 2) \) returns 0
Exponent Methods

- \( \text{exp}(\text{double a}) \)
  Returns \( e \) raised to the power of \( a \).
- \( \text{log}(\text{double a}) \)
  Returns the natural logarithm of \( a \).
- \( \text{log10}(\text{double a}) \)
  Returns the 10-based logarithm of \( a \).
- \( \text{pow}(\text{double a, double b}) \)
  Returns \( a \) raised to the power of \( b \).
- \( \text{sqrt}(\text{double a}) \)
  Returns the square root of \( a \).

**Examples:**
- \( \text{Math.exp}(1) \) returns 2.71
- \( \text{Math.log}(2.71) \) returns 1.0
- \( \text{Math.pow}(2, 3) \) returns 8.0
- \( \text{Math.pow}(3, 2) \) returns 9.0
- \( \text{Math.pow}(3.5, 2.5) \) returns 22.91765
- \( \text{Math.sqrt}(4) \) returns 2.0
- \( \text{Math.sqrt}(10.5) \) returns 3.24
Rounding Methods

- **double ceil(double x)**
  x rounded up to its nearest integer. This integer is returned as a double value.

- **double floor(double x)**
  x is rounded down to its nearest integer. This integer is returned as a double value.

- **double rint(double x)**
  x is rounded to its nearest integer. If x is equally close to two integers, the even one is returned as a double.

- **int round(float x)**
  Return (int)Math.floor(x+0.5).

- **long round(double x)**
  Return (long)Math.floor(x+0.5).
Rounding Methods Examples

Math.ceil(2.1) returns 3.0
Math.ceil(2.0) returns 2.0
Math.ceil(-2.0) returns -2.0
Math.ceil(-2.1) returns -2.0
Math.floor(2.1) returns 2.0
Math.floor(2.0) returns 2.0
Math.floor(-2.0) returns -2.0
Math.floor(-2.1) returns -3.0
Math.round(2.6f) returns 3
Math.round(2.0) returns 2
Math.round(-2.0f) returns -2
Math.round(-2.6) returns -3
min, max, and abs

- **max(a, b) and min(a, b)**
  Returns the maximum or minimum of two parameters.

- **abs(a)**
  Returns the absolute value of the parameter.

- **random()**
  Returns a random double value in the range [0.0, 1.0).

### Examples:
- `Math.max(2, 3)` returns 3
- `Math.max(2.5, 3)` returns 3.0
- `Math.min(2.5, 3.6)` returns 2.5
- `Math.abs(-2)` returns 2
- `Math.abs(-2.1)` returns 2.1
The random Method

Generates a random \textbf{double} value greater than or equal to 0.0 and less than 1.0 \((0 \leq \text{Math.random()} < 1.0)\)

Examples:

\[(\text{int})(\text{Math.random()} \times 10)\] Returns a random integer between 0 and 9.

\[50 + (\text{int})(\text{Math.random()} \times 50)\] Returns a random integer between 50 and 99.

In general,

\[a + \text{Math.random()} \times b\] Returns a random number between \(a\) and \(a + b\), excluding \(a + b\).
Generating Random Characters

(char)((int)'a' + Math.random() * ((int)'z' - (int)'a' + 1))

- All numeric operators can be applied to the char operands
- The char operand is cast into a number if the other operand is a number or a character.
- So, the preceding expression can be simplified as follows:

(char)('a' + Math.random() * (char)'z' - char'a' + 1)
if (ch >= 'A' && ch <= 'Z')
    System.out.println(ch + " is an uppercase letter");

if (ch >= 'a' && ch <= 'z')
    System.out.println(ch + " is a lowercase letter");

if (ch >= '0' && ch <= '9')
    System.out.println(ch + " is a numeric character");
The String Type

- The char type only represents one character.
- To represent a string of characters, use the data type called String.

\[
\text{String message = "Welcome to Java";}
\]

- The String type is NOT a primitive type.
  - The String type is a reference type.
    - A String variable is a reference variable, an "address" which points to an object storing the value or actual text.
Strings are immutable!

- There are no methods to change them once they have been created.
- Any new assignment will assign a new String to the old variable.

```java
String word = "Steven";
word = word.substring(0, 5);
```
- The variable `word` is now a reference to a new String that contains "Steve".
Useful String functions

- `charAt`, `equals`, `equalsIgnoreCase`, `compareTo`, `startsWith`, `endsWith`, `indexOf`, `lastIndexOf`, `replace`, `substring`, `toLowerCase`, `toUpperCase`, `trim`

- `s.equals(t)`
  - returns `true` if `s` and `t` have same letters and sequence
  - `false` otherwise
Comparing Strings

- Don’t use ‘==’ to compare Strings
  - it compares their memory addresses and not actual strings (character sequences)
- Instead use the `equals/1` method supplied by the String class
Comparing Strings

String word1 = new String("Hello");
String word2 = new String("Hello");
if (word1 == word2) {
    System.out.println(true);
} else {
    System.out.println(false);
}

Result?
Comparing Strings

```java
String word1 = new String("Hello");
String word2 = new String("Hello");
if (word1 == word2){
    System.out.println(true);
} else {
    System.out.println(false);
}
```

- Two different addresses: false
Comparing Strings

String word1 = new String("Hello");
String word2 = new String("Hello");
if (word1.equals(word2)){
    System.out.println(true);
} else {
    System.out.println(false);
}
Comparing Strings

String word1 = "Hello";
String word2 = "Hello";
if (word1 == word2) {
    System.out.println(true);
} else {
    System.out.println(false);
}

true

- Interned Strings: Only one instance of “Hello” is stored
- word1 and word2 will have the same address
## Comparing Strings

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>equals(s1)</td>
<td>Returns true if this string is equal to string s1.</td>
</tr>
<tr>
<td>equalsIgnoreCase(s1)</td>
<td>Returns true if this string is equal to string s1; it is case insensitive.</td>
</tr>
<tr>
<td>compareTo(s1)</td>
<td>Returns an integer greater than 0, equal to 0, or less than 0 to indicate whether this string is greater than, equal to, or greater than s1.</td>
</tr>
<tr>
<td>compareToIgnoreCase(s1)</td>
<td>Same as compareTo except that the comparison is case insensitive.</td>
</tr>
<tr>
<td>startsWith(prefix)</td>
<td>Returns true if this string starts with the specified prefix.</td>
</tr>
<tr>
<td>endsWith(suffix)</td>
<td>Returns true if this string ends with the specified suffix.</td>
</tr>
</tbody>
</table>
## Obtaining Substrings

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>substring(beginIndex)</code></td>
<td>Returns this string’s substring that begins with the character at the specified <code>beginIndex</code> and extends to the end of the string, as shown in Figure 4.2.</td>
</tr>
<tr>
<td><code>substring(beginIndex, endIndex)</code></td>
<td>Returns this string’s substring that begins at the specified <code>beginIndex</code> and extends to the character at index <code>endIndex - 1</code>, as shown in Figure 9.6. Note that the character at <code>endIndex</code> is not part of the substring.</td>
</tr>
</tbody>
</table>

### Example

<table>
<thead>
<tr>
<th>Indices</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 10 11 12 13 14</td>
<td>Welcome to Java</td>
</tr>
</tbody>
</table>

- `message.substring(0, 11)`
- `message.substring(11)`
## Finding a Character or a Substring in a String

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>indexOf(ch)</code></td>
<td>Returns the index of the first occurrence of <code>ch</code> in the string. Returns <code>-1</code> if not matched.</td>
</tr>
<tr>
<td><code>indexOf(ch, fromIndex)</code></td>
<td>Returns the index of the first occurrence of <code>ch</code> after <code>fromIndex</code> in the string. Returns <code>-1</code> if not matched.</td>
</tr>
<tr>
<td><code>indexOf(s)</code></td>
<td>Returns the index of the first occurrence of string <code>s</code> in this string. Returns <code>-1</code> if not matched.</td>
</tr>
<tr>
<td><code>indexOf(s, fromIndex)</code></td>
<td>Returns the index of the first occurrence of string <code>s</code> after <code>fromIndex</code>. Returns <code>-1</code> if not matched.</td>
</tr>
<tr>
<td><code>lastIndexOf(ch)</code></td>
<td>Returns the index of the last occurrence of <code>ch</code> in the string. Returns <code>-1</code> if not matched.</td>
</tr>
<tr>
<td><code>lastIndexOf(ch, fromIndex)</code></td>
<td>Returns the index of the last occurrence of <code>ch</code> before <code>fromIndex</code> in this string. Returns <code>-1</code> if not matched.</td>
</tr>
<tr>
<td><code>lastIndexOf(s)</code></td>
<td>Returns the index of the last occurrence of string <code>s</code>. Returns <code>-1</code> if not matched.</td>
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<tr>
<td><code>lastIndexOf(s, fromIndex)</code></td>
<td>Returns the index of the last occurrence of string <code>s</code> before <code>fromIndex</code>. Returns <code>-1</code> if not matched.</td>
</tr>
</tbody>
</table>
Conversion between Strings and Numbers

String intString = "15";
String doubleString = "56.77653";

int intValue =
    Integer.parseInt(intString);

double doubleValue =
    Double.parseDouble(doubleString);

String s2 = "" + intValue;
The printf statement:

```java
System.out.printf(format, items);
```

format is a string that may consist of substrings and format **specifiers**

- A format specifier begins with a percent sign and specifies how an item should be displayed: a numeric value, character, boolean value, or a string
Frequently-Used Specifiers

<table>
<thead>
<tr>
<th>Specifier</th>
<th>Output</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>%b</td>
<td>a boolean value</td>
<td>true or false</td>
</tr>
<tr>
<td>%c</td>
<td>a character</td>
<td>'a'</td>
</tr>
<tr>
<td>%d</td>
<td>a decimal integer</td>
<td>200</td>
</tr>
<tr>
<td>%f</td>
<td>a floating-point number</td>
<td>45.460000</td>
</tr>
<tr>
<td>%e</td>
<td>a number in standard scientific notation</td>
<td>4.5560000e+01</td>
</tr>
<tr>
<td>%s</td>
<td>a string</td>
<td>&quot;Java is cool&quot;</td>
</tr>
</tbody>
</table>

int count = 5;
double amount = 45.5678;
System.out.printf("count is %d and amount is %.2f", count, amount);

Displays: count is 5 and amount is 45.56
Java and iteration

We have 3 types of iterative statements

- a while loop
- a do … while loop
- a for loop

All 3 can be used to do similar things

Which one should you use?

- a matter of individual preference/convenience
while (loop-continuation-condition) {
    // loop-body;
    Statement(s);
}

int count = 0;
while (count < 100) {
    System.out.println("Welcome to Java!");
    count++;
}
Caution: equality for reals

- Don’t use floating-point values for equality checking in a loop control - floating-point values are **approximations** for some values
- Example: the following code for computing $1 + 0.9 + 0.8 + \ldots + 0.1$:

```java
double item = 1; double sum = 0;
while (item != 0) { // No guarantee item will be 0 or 0.0
    sum += item;
    item -= 0.1;
}
System.out.println(sum);
```

- Variable item starts with 1 and is reduced by 0.1 every time the loop body is executed
- The loop should terminate when item becomes 0
- There is no guarantee that item will be exactly 0, because the floating-point arithmetic is approximated
  - 0.1 is not represented exactly: $0.1 = 1/16 + 1/32 + 1/256 + 1/512 + 1/4096 + 1/8192 + \ldots$
- It is actually an infinite loop!
do-while Loop

do {
    // Loop body;
    Statement(s);
} while (loop-continuation-condition);

Flowchart:

- Start
- Statement(s) (loop body)
- Loop Continuation Condition?
  - true: Continue
  - false: End
- End
**for Loops**

```
for (initial-action; 
    loop-continuation-condition; 
    action-after-each-iteration) {
    // loop body;
    Statement(s);
}
```

```java
int i;
for (i = 0; i < 100; i++){
    System.out.println( 
        "Welcome to Java!");
}
```

(A) Initial-Action

(B) i = 0

(i < 100)?

true

System.out.println( 
    "Welcome to Java");

false

i++

Action-After-Each-Iteration

Loop Continuation Condition?

false

Statement(s) (loop body)

true
for loops and counting

• for loops are popular for counting loops
  • through the indices of a string
  • through the indices of an array (later)
  • through iterations of an algorithm
• Good for algorithms that require a known number of iterations
• counter-controlled loops
for loops

The **initial-action** in a **for** loop can be a list of zero or more comma-separated expressions.

The **action-after-each-iteration** in a **for** loop can be a list of zero or more comma-separated statements.

```java
for (int i = 1; i < 100; System.out.println(i++));

for (int i = 0, j = 0; (i + j < 10); i++, j++) {
    // Do something
}
```
Infinite loops

If the loop-continuation-condition in a for loop is omitted, it is implicitly true.

\[
\text{for ( ; ; ) } \{ \\
  \text{// Do something} \\
\} \\
\begin{array}{c}
\text{Equivalent} \\
\hline
\text{while (true) } \{ \\
  \text{// Do something} \\
\} \\
\end{array}
\]

(a) 

(b)
Keywords break and continue

• You can also use **break** in a loop to immediately terminate the loop:

```java
public static void main(String[] args) {
    int sum = 0;
    int number = 0;
    while (number < 20) {
        number++;
        sum += number;
        if (sum >= 100) // increments until the sum is
            break;    // greater than 100
    }
    System.out.println("The number is " + number);
    System.out.println("The sum is " + sum);
}
```

The number is 14
The sum is 105
Keywords break and continue

- You can also use `continue` in a loop to **end the current iteration** and program control goes to the end of the loop body (and continues the loop):

```java
public static void main(String[] args) {
    int sum = 0;
    int number = 0;
    while (number < 20) { // adds integers from 1 to 20
        number++;
        if (number == 10 || number == 11)
            continue;
        sum += number;
    }
    System.out.println("The number is " + number);
    System.out.println("The sum is " + sum);
}
```

The number is 20
The sum is 189
A method is a collection of statements that are grouped together to perform an operation.

```java
public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;
}
```

Define a method

Invoke a method

```
int z = max(x, y);
```
Why write methods?

- To shorten your programs
  - avoid writing identical code twice or more
- To modularize your programs
  - fully tested methods can be trusted
- To make your programs more:
  - readable
  - reusable
  - testable
  - debuggable
  - extensible
  - adaptable
Method Signature

- **Method signature** is the combination of the method name and the parameter list.
Formal Parameters

- The variables defined in the method header are known as *formal parameters*.

```
public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;
}
```

```
int z = max(x, y);
```

*Invoke a method*

*Formal Parameters*

- The variables defined in the method header are known as *formal parameters*. 

  - **Modifier**: `public static` 
  - **Return Value Type**: `int` 
  - **Method Name**: `max` 
  - **Parameter List**: `(int num1, int num2)` 

*Invoke a method*

```
int z = max(x, y);
```
Actual Parameters

• When a method is invoked, you pass a value to the parameter: *actual parameter or argument.*

```java
public static int max(int num1, int num2) {
    int result;
    if (num1 > num2) {
        result = num1;
    } else {
        result = num2;
    }
    return result;
}
```

**Define a method**
- **modifier**
- **return value type**
- **method name**
- **formal parameters**
- **return value**

**Invoke a method**

```java
int z = max(x, y);
```
A return statement is required for a value-returning method. The method shown below has a compilation error because the Java compiler thinks it possible that this method does not return any value.

To fix this problem, delete if \((n < 0)\) in (a), so that the compiler will see a return statement to be reached regardless of how the if statement is evaluated.
Call Stacks

Methods are executed using a stack data structure

(a) The main method is invoked.

Space required for the main method
k:  2
j:  5

(b) The max method is invoked.

Space required for
the max method
num2:  2
num1:  5

(c) The max method is being executed.

Space required for
the main method
result:  5
num2:  2
num1:  5

Space required for
the main method
k:  2
j:  5

(d) The max method is finished and the return value is sent to k.

Space required for
the main method
k:  5
j:  2
i:  5

(e) The main method is finished.

Stack is empty

Methods are executed using a stack data structure
public static void main(String[] args) {
    int i = 5;
    int k = max(i, i);
    System.out.println("The maximum between \" + i + \" and \" + i + \" is \" + k);
}

public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;
}
public static void main(String[] args) {
    int i = 5;
    int j = 2;
    int k = max(i, j);
    System.out.println("The maximum between " + i + " and " + i + " is " + k);
}

public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;
}
Trace Call Stack

public static void main(String[] args) {
    int i = 5;
    int j = 2;
    int k = max(i, i);

    System.out.println("The maximum between "+ i + " and " + i + " is " + k);
}

public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;
}
The main method is invoked.

Space required for the main method

\[
\begin{aligned}
&k: \\
j: 2 \\
i: 5 \\
\end{aligned}
\]

Invoke max(i, j)

```java
class MaxExample {
    public static void main(String[] args) {
        int i = 5;
        int j = 2;
        int k = max(i, i);
        System.out.println(
            "The maximum between " + i + 
            " and " + i + " is " + k);
    }

    public static int max(int num1, int num2) {
        int result;
        if (num1 > num2)
            result = num1;
        else
            result = num2;
        return result;
    }
}
```
public static void main(String[] args) {
    int i = 5;
    int j = 2;
    int k = max(i, j);
    System.out.println("The maximum between " + i + " and " + i + " is " + k);
}

public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;
}
The max method is invoked.

result:
num2: 2
num1: 5

Space required for the main method:

k:
j: 2
i: 5

pass the values of i and j to num1 and num2
Trace Call Stack

```
public static void main(String[] args) {
    int i = 5;
    int j = 2;
    int k = max(i, j);

    System.out.println(
        "The maximum between " + i + 
        " and " + j + " is " + k);
}

public static int max(int num1, int num2) {
    int result;

    if (num1 > num2)
        result = num1;
    else
        result = num2;

    return result;
}
```

(\texttt{num1} > \texttt{num2}) is true

The max method is invoked.

result: num2: 2
num1: 5

Space required for the main method:

\begin{itemize}
  \item \texttt{k: 5}
  \item \texttt{j: 2}
  \item \texttt{i: 5}
\end{itemize}
public static void main(String[] args) {
    int i = 5;
    int j = 2;
    int k = max(i, j);
    System.out.println("The maximum between " + i + " and " + j + " is " + k);
}

public static int max(int num1, int num2)
    int result:
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;

public static void main(String[] args) {
    int i = 5;
    int j = 2;
    int k = max(i, j);

    System.out.println(
        "The maximum between " + i + 
        " and " + j + " is " + k);
}

public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;

    return result;
}
public static void main(String[] args) {
    int i = 5;
    int j = 2;
    int k = max(i, j);
    System.out.println("The maximum between " + i + " and " + j + " is " + k);
}

public static int max(int num1, int num2) {
    int result;
    if (num1 > num2)
        result = num1;
    else
        result = num2;
    return result;
}
Call-by-value

• Method formal arguments are *copies of the original data*.

• Consequence?
  • methods **cannot** assign ("=") new values to primitive type formal arguments and **affect the original passed variables**.

• Why?
  • changing argument values changes the copy, not the original.
The main method is invoked

The values of num1 and num2 are passed to n1 and n2. Executing swap does not affect num1 and num2.

Space required for the swap method

Space required for the main method

num2: 2
num1: 1

temp: n2: 2
n1: 1

The swap method is invoked

Space required for the main method

num2: 2
num1: 1

The swap method is finished

Stack is empty

The main method is finished
Overloading

- Method overloading is the ability to create multiple methods of the same name with different implementations.

```java
// Overload the name max for different invocations
public static int max(int x, int y){
    return (x>y) ? x : y;
}

public static double max(double x, double y){
    return (x>y) ? x : y;
}

public static void main(String[] args) {
    System.out.println(max(1,2)); // will call max(int,int)
    System.out.println(max(3.5,4.7)); // will call max(double,double)
}
```
Overloading & Ambiguous Invocation

- Sometimes there may be two or more possible matches for an invocation of a method, but the compiler cannot determine the most specific match.
- This is referred to as *ambiguous invocation*.
- Ambiguous invocation is a compilation error.
public class AmbiguousOverloading {
    public static void main(String[] args) {
        System.out.println(max(1, 2));
    }
    public static double max(int num1, double num2) {
        if (num1 > num2)
            return num1;
        else
            return num2;
    }
    public static double max(double num1, int num2) {
        if (num1 > num2)
            return num1;
        else
            return num2;
    }
}
An *array* is a data structure that represents a collection of the same type of data.

```java
double[] myList = new double[10];

myList[0] = 5.6;
...```

<table>
<thead>
<tr>
<th>Element value</th>
<th>Array reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>myList[0]</td>
<td>5.6</td>
</tr>
<tr>
<td>myList[1]</td>
<td>4.5</td>
</tr>
<tr>
<td>myList[2]</td>
<td>3.3</td>
</tr>
<tr>
<td>myList[3]</td>
<td>13.2</td>
</tr>
<tr>
<td>myList[4]</td>
<td>4</td>
</tr>
<tr>
<td>myList[5]</td>
<td>34.33</td>
</tr>
<tr>
<td>myList[6]</td>
<td>34</td>
</tr>
<tr>
<td>myList[7]</td>
<td>45.45</td>
</tr>
<tr>
<td>myList[8]</td>
<td>99.993</td>
</tr>
<tr>
<td>myList[9]</td>
<td>11123</td>
</tr>
</tbody>
</table>
Default Values

- When an array is created, its elements are assigned the default value of 0 for the numeric primitive data types, \u0000 for char types, and false for boolean types.
Indexed Variables

• The array elements are accessed through the index.
• The array indices are 0-based, i.e., it starts from 0 to arrayRefVar.length-1.
• Each element in the array is represented using the following syntax, known as an indexed variable:

```java
arrayRefVar[index];
```
Array Initializers

• Declaring, creating, initializing in one step:

\[
\text{double[]} \ \text{myList} = \{1.9, 2.9, 3.4, 3.5\};
\]

This shorthand syntax must be in one statement.
Enhanced **for** Loop (**for-each loop**)

JDK 1.5 introduced a new for loop that enables you to traverse the complete array sequentially without using an index variable.

- For example, the following code displays all elements in the array `myList`:

  ```java
  for (double value: myList)
      System.out.println(value);
  ```

In general, the syntax is

```java
for (elementType value: arrayRefVar) {
    // Process the value
}
```

Note: You still have to use an index variable if you wish to traverse the array in a different order or change the elements in the array.
Copying Arrays

- Often, in a program, you need to duplicate an array or a part of an array.
- **Using the assignment statement (=), you re-direct the pointer:**
  
  \[
  \text{list2} = \text{list1};
  \]
- **You don’t copy with “=”**!
Using a loop:

```java
int[] sourceArray={2, 3, 1, 5, 10};
int[] targetArray=new int[sourceArray.length];
for (int i = 0; i < sourceArray.length; i++)
    targetArray[i] = sourceArray[i];
```
The \textit{arraycopy} Utility

System.arraycopy(sourceArray, src_pos, targetArray, tar_pos, length);

Example:

System.arraycopy(sourceArray, 0, targetArray, 0, sourceArray.length);
public static void printArray(int[] array) {
    for (int i = 0; i < array.length; i++) {
        System.out.print(array[i] + " ");
    }
}

Invoke the method
int[] list = {3, 1, 2, 6, 4, 2};
printArray(list);

OR

Invoke the method
printArray(new int[]{3, 1, 2, 6, 4, 2});
Pass By Value

Java uses *pass by value* to pass arguments to a method.

- For a parameter of a *primitive* type value, the actual value is passed.
  - Changing the value of the local parameter inside the method does not affect the value of the variable outside the method.

- For a parameter of an *array* type, the value of the parameter contains a reference to an array; this reference is passed to the method.
  - Any changes to the array that occur inside the method body will affect the original array that was passed as the argument.
public class Test {
    public static void main(String[] args) {
        int x = 1; // x represents an int value
        int[] y = new int[10]; // y represents an array of int values
        m(x, y); // Invoke m with arguments x and y
        System.out.println("x is " + x);
        System.out.println("y[0] is " + y[0]);
    }
    public static void m(int number, int[] numbers) {
        number = 1001; // Assign a new value to number
        numbers[0] = 5555; // Assign a new value to numbers[0]
    }
}
The JVM stores the array in an area of memory, called *heap*, which is used for dynamic memory allocation where blocks of memory are allocated and freed in an arbitrary order.
When invoking \( m(x, y) \), the values of \( x \) and \( y \) are passed to \texttt{number} and \texttt{numbers}. Since \( y \) contains the reference value to the array, \texttt{numbers} now contains the same reference value to the same array.
public static int[] reverse(int[] list) {
    int[] result = new int[list.length];
    for (int i = 0, j = result.length - 1; i < list.length; i++, j--) {
        result[j] = list[i];
    }
    return result;
}

int[] list1 = new int[]{1, 2, 3, 4, 5, 6};
int[] list2 = reverse(list1);
Searching Arrays

• Searching is the process of looking for a specific element in an array

```java
public static int linearSearch(int[] list, int key)
```

- list
- key
  - Compare key with list[i] for i = 0, 1, …
Linear Search Example

Key | List
---|---
3 | 6 4 1 9 7 3 2 8
3 | 6 4 1 9 7 3 2 8
3 | 6 4 1 9 7 3 2 8
3 | 6 4 1 9 7 3 2 8
3 | 6 4 1 9 7 3 2 8
public static int linearSearch(int[] list, int key) {
    for (int i = 0; i < list.length; i++)
        if (key == list[i])
            return i;
    return -1;
}

int[] list = {6,4,1,9,7,3,2,8};
int i = linearSearch(list, 3);  // returns 5
int j = linearSearch(list, -4); // returns -1
int k = linearSearch(list, 4); // returns 1
Binary Search

• If an array is already ordered, then it is cheaper to find an element
  
• Assume that the array is in ascending order. e.g., 1, 2, 3, 4, 6, 7, 8, 9

The binary search first compares the key (e.g., 8) with the element in the middle of the array.
Binary Search

Consider the following three cases:

- If the key is less than the middle element, you only need to search the key in the first half of the array.
- If the key is equal to the middle element, the search ends with a match.
- If the key is greater than the middle element, you only need to search the key in the second half of the array.
Binary Search

Key | List
---|---
8

1 2 3 4 6 7 8 9

8

1 2 3 4 6 7 8 9

8

1 2 3 4 6 7 8 9
/** Use binary search to find the key in the list */
public static int binarySearch(int[] list, int key) {
    int low = 0;
    int high = list.length - 1;
    while (high >= low) {
        int mid = (low + high) / 2;
        if (key < list[mid])
            high = mid - 1;
        else if (key == list[mid])
            return mid;
        else
            low = mid + 1;
    }
    return -1 - low;
}
Binary Search

<table>
<thead>
<tr>
<th>low</th>
<th>mid</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0]</td>
<td>[1]</td>
<td>[2]</td>
</tr>
<tr>
<td>[6]</td>
<td>[7]</td>
<td>[8]</td>
</tr>
<tr>
<td>[9]</td>
<td>[10]</td>
<td>[11]</td>
</tr>
<tr>
<td>[12]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Key is 11
Key < 50

List: 2 4 7 10 11 45 50 59 60 66 69 70 79

Key > 7

List: 2 4 7 10 11 45

Key == 11

List: 10 11 45
Binary Search

key is 54

key > 50

list

<table>
<thead>
<tr>
<th>low</th>
<th>mid</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0]</td>
<td>[1]</td>
<td>[2]</td>
</tr>
<tr>
<td>[6]</td>
<td>[7]</td>
<td>[8]</td>
</tr>
<tr>
<td>[9]</td>
<td>[10]</td>
<td>[11]</td>
</tr>
<tr>
<td>[12]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

key < 66

list

<table>
<thead>
<tr>
<th>low</th>
<th>mid</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0]</td>
<td>[1]</td>
<td>[2]</td>
</tr>
<tr>
<td>[6]</td>
<td>[7]</td>
<td>[8]</td>
</tr>
<tr>
<td>[9]</td>
<td>[10]</td>
<td>[11]</td>
</tr>
<tr>
<td>[12]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

key < 59

list

<table>
<thead>
<tr>
<th>low</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>[6]</td>
<td>[7]</td>
</tr>
<tr>
<td>[8]</td>
<td></td>
</tr>
</tbody>
</table>

59   60
Java provides several overloaded `binarySearch` methods for searching a key in an array of `int`, `double`, `char`, `short`, `long`, and `float` in the `java.util.Arrays` class.

```java
int[] list = {1, 2, 3, 4, 6, 7, 8, 9};
System.out.println("Index is "+java.util.Arrays.binarySearch(list, 11));
```

Return is 4
Selection sort finds the smallest number in the list and places it first. It then finds the smallest number in the remaining list and places it second, and so on until the list contains only a single number. Sort the list \{2, 9, 5, 4, 8, 1, 6\} using selection sort would be:

1. Select 1 (the smallest) and swap it with 2 (the first) in the list:
   \[2 \quad 9 \quad 5 \quad 4 \quad 8 \quad 1 \quad 6\]

2. Select 2 (the smallest) and swap it with 9 (the first) in the remaining list:
   \[1 \quad 9 \quad 5 \quad 4 \quad 8 \quad 6\]

3. Select 4 (the smallest) and swap it with 5 (the first) in the remaining list:
   \[1 \quad 2 \quad 5 \quad 4 \quad 8 \quad 9\]

4. Select 6 (the smallest) and swap it with 8 (the first) in the remaining list:
   \[1 \quad 2 \quad 4 \quad 5 \quad 8 \quad 9\]

5. Select 8 (the smallest) and swap it with 9 (the first) in the remaining list:
   \[1 \quad 2 \quad 4 \quad 5 \quad 6 \quad 8\]

Since there is only one element remaining in the list, sort is completed:

\[1 \quad 2 \quad 4 \quad 5 \quad 6 \quad 8 \quad 9\]
for (int i = 0; i < list.length; i++) {
    select the smallest element in list[i..listSize-1];
    swap the smallest with list[i], if necessary;
    // list[i] is in its correct position.
    // The next iteration apply on list[i+1..listSize-1]
}
for (int i = 0; i < list.length; i++) {
  select the smallest element in list[i..listSize-1];
  swap the smallest with list[i], if necessary;
  // list[i] is in its correct position.
  // The next iteration apply on list[i+1..listSize-1]
}

double currentMin = list[i];
int currentMinIndex = i;
for (int j = i+1; j < list.length; j++) {
  if (currentMin > list[j]) {
    currentMin = list[j];
    currentMinIndex = j;
  }
}
Wrap it in a Method

/** The method for sorting numbers */
public static void selectionSort(double[] list) {
    for (int i = 0; i < list.length; i++) {
        // Find the minimum in the list[i..list.length-1]
        double currentMin = list[i];
        int currentMinIndex = i;
        for (int j = i + 1; j < list.length; j++) {
            if (currentMin > list[j]) {
                currentMin = list[j];
                currentMinIndex = j;
            }
        }
        // Swap list[i] with list[currentMinIndex] if necessary;
        if (currentMinIndex != i) {
            list[currentMinIndex] = list[i];
            list[i] = currentMin;
        }
    }
}
(c) Paul Fodor (CS Stony Brook) & Pearson
The insertion sort algorithm sorts a list of values by repeatedly inserting an unsorted element into a sorted sublist until the whole list is sorted.

```java
int[] myList = {2, 9, 5, 4, 8, 1, 6}; // Unsorted
```

Step 1: Initially, the sorted sublist contains the first element in the list. Insert 9 to the sublist.

Step 2: The sorted sublist is \(\{2, 9\}\). Insert 5 to the sublist.

Step 3: The sorted sublist is \(\{2, 5, 9\}\). Insert 4 to the sublist.

Step 4: The sorted sublist is \(\{2, 4, 5, 9\}\). Insert 8 to the sublist.

Step 5: The sorted sublist is \(\{2, 4, 5, 8, 9\}\). Insert 1 to the sublist.

Step 6: The sorted sublist is \(\{1, 2, 4, 5, 8, 9\}\). Insert 6 to the sublist.

Step 7: The entire list is now sorted.
The insertion sort algorithm sorts a list of values by repeatedly inserting an unsorted element into a sorted sublist until the whole list is sorted.

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Step 1: Save 4 to a temporary variable currentElement

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Step 2: Move list[2] to list[3]

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Step 3: Move list[1] to list[2]

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</table>

Step 4: Assign currentElement to list[1]
for (int i = 1; i < list.length; i++) {
    insert list[i] into a sorted sublist list[0..i-1] so that
    list[0..i] is sorted
}
public static void insertionSort(double[] list)
{
    for(int i=1; i<list.length; i++)
    {
        //insert list[i] in the sorted sublist list[0,i-1]
        // find the position
        int pos;
        for(pos=0; pos<i; pos++)
            if(list[pos]>list[i])
                break;
        double temp = list[i];
        // shift right elements from pos to i-1
        for(int j=i; j>pos; j--)
            list[j] = list[j-1];
        list[pos] = temp;
    }
}

public static void main(String[] args) {
    double[] list1 = new double[]{8, 2, 3, 4};
    insertionSort(list1);
    print(list1);
}

public static void print(double[] list){
    for(double x:list) System.out.print(x + " ");
}
The Arrays.sort Method

Since sorting is frequently used in programming, Java provides several overloaded sort methods for sorting an array of int, double, char, short, long, and float in the java.util.Arrays class. For example, the following code sorts an array of numbers and an array of characters.

```java
double[] numbers = {6.0, 4.4, 1.9, 2.9, 3.4, 3.5};
java.util.Arrays.sort(numbers);

char[] chars = {'a', 'A', '4', 'F', 'D', 'P'};
java.util.Arrays.sort(chars);
```
Declaring Variables of Two-dimensional Arrays and Creating Two-dimensional Arrays

```java
int[][] matrix = new int[10][10];
or
int matrix[][] = new int[10][10];
```

- **Indexed variables:**
  ```java
  matrix[0][0] = 3;
  ```

- **Length:**
  ```java
  for (int i = 0; i < matrix.length; i++)
      for (int j = 0; j < matrix[i].length; j++)
          matrix[i][j] = (int)(Math.random() * 1000);
  ```
Two-dimensional Array Lengths

```
0 1 2 3 4
0
1
2
3
4

matrix = new int[5][5];

matrix[2][1] = 7;
```

```
0 1 2 3 4
0
1
2
3
4

int[][] array = {
{1, 2, 3},
{4, 5, 6},
{7, 8, 9},
{10, 11, 12} 
};
```

```
0   1   2
0   1   2   3   4
0   1   2   3   4
0   1   2   3   4
0   1   2   3   4
```

```
0   1   2
1   4   5   6
2   7   8   9
3   10  11  12
```

```
matrix.length?  5
matrix[0].length?  5
```

```
array.length?  4
array[0].length?  3
```
Lengths of Two-dimensional Arrays

```java
int[][] x = new int[3][4];
```

- `x.length` is 3
- `x[0].length` is 4
- `x[1].length` is 4
- `x[2].length` is 4
You can also use an array initializer to declare, create and initialize a two-dimensional array. For example,

```java
int[][] array = {
    {1, 2, 3},
    {4, 5, 6},
    {7, 8, 9},
    {10, 11, 12}
};
```

Same as

```java
int[][] array = new int[4][3];
array[0][0] = 1; array[0][1] = 2; array[0][2] = 3;
array[1][0] = 4; array[1][1] = 5; array[1][2] = 6;
array[2][0] = 7; array[2][1] = 8; array[2][2] = 9;
array[3][0] = 10; array[3][1] = 11; array[3][2] = 12;
```
Ragged Arrays

• A ragged array is an array where rows can have different lengths:

```java
int[][] matrix = {
    {1, 2, 3, 4, 5},
    {2, 3, 4, 5},
    {3, 4, 5},
    {4, 5},
    {5}
};
```

- matrix.length is 5
- matrix[0].length is 5
- matrix[1].length is 4
- matrix[2].length is 3
- matrix[3].length is 2
- matrix[4].length is 1
Ragged Arrays

Storing a ragged array:

```java
int[][] triangleArray = {
    {1, 2, 3, 4, 5},
    {1, 2, 3, 4},
    {1, 2},
    {1}
};
```