

Building Java Programs

Chapter 8

Classes & Objects

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Classes

Reading

- Building Java Programs, Ch. 8

Learning Outcomes

- Object Oriented programming
- Java class definition
- Class constructors
- Class fields
- Class methods

Classes and objects

- **class**: An abstract template for a program entity. (e.g. a 'car' class) that defines state and behavior.
 - Note - in Java, a class can encapsulate a 'module'
- **object**: A specific instance of a class. (e.g. my Ford Escort is specific instance of a car)
- **object-oriented programming (OOP)**: Programs that use objects to **encapsulate** behavior.

Benefits of encapsulation

- Abstraction between object and clients
- Protects objects from unwanted access
- Allows changing a class implementation without affecting clients that depend on the class
- Can constrain objects' state using **invariants**
 - Example: Only allow `Accounts` with non-negative balance.
 - Example: Only allow `Dates` with a month from 1-12.

Blueprint analogy

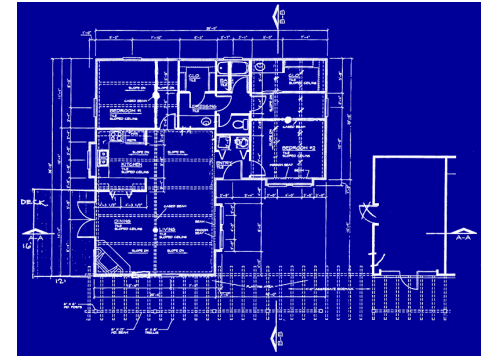
iPod blueprint

state:

current song
volume
battery life

behavior:

power on/off
change station/song
change volume
choose random song



creates

iPod #1

state:

song = "1,000,000 Miles"
volume = 17
battery life = 2.5 hrs

behavior:

power on/off
change station/song
change volume
choose random song



iPod #2

state:

song = "Letting You"
volume = 9
battery life = 3.41 hrs

behavior:

power on/off
change station/song
change volume
choose random song



iPod #3

state:

song = "Discipline"
volume = 24
battery life = 1.8 hrs

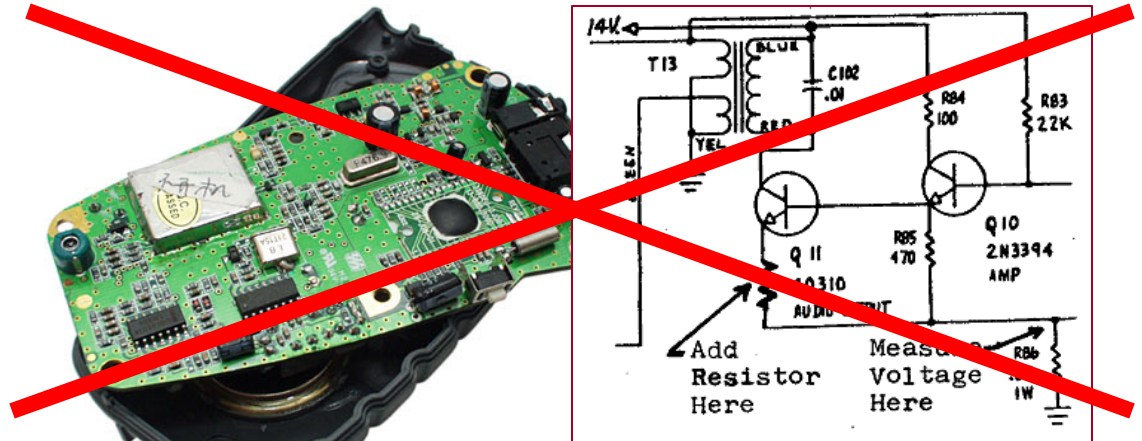
behavior:

power on/off
change station/song
change volume
choose random song



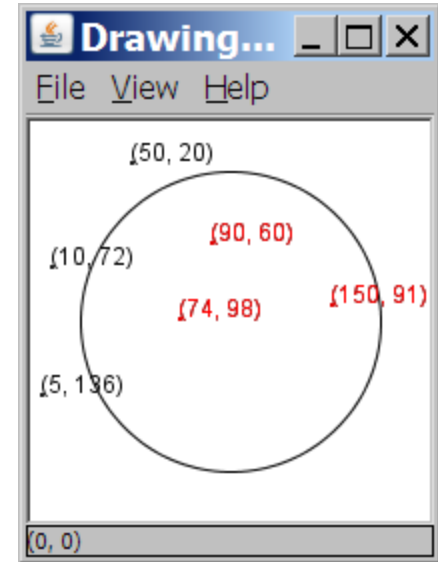
Abstraction

- **abstraction:** A distancing between ideas and details.
 - We can use objects without knowing how they work.
- abstraction in an iPod:
 - You understand its external behavior (buttons, screen).
 - You don't understand its inner details, and you don't need to.



Observations

- The data in this problem is a set of points.
- It would be better stored as `Point` objects.
 - A `Point` would store a city's x/y data.
 - We could compare distances between `Points` to see whether the bomb hit a given city.
 - Each `Point` would know how to draw itself.
 - The overall program would be shorter and cleaner.



Our task

- In the following slides, we will implement a `Point` class as a way of learning about defining classes.
 - We will define a type of objects named `Point`.
 - Each `Point` object will contain x/y data called **fields**.
 - Each `Point` object will contain behavior called **methods**.
 - **Client programs** will use the `Point` objects.

Point objects (desired)

```
Point p1 = new Point(5, -2);  
Point p2 = new Point();           // origin, (0, 0)
```

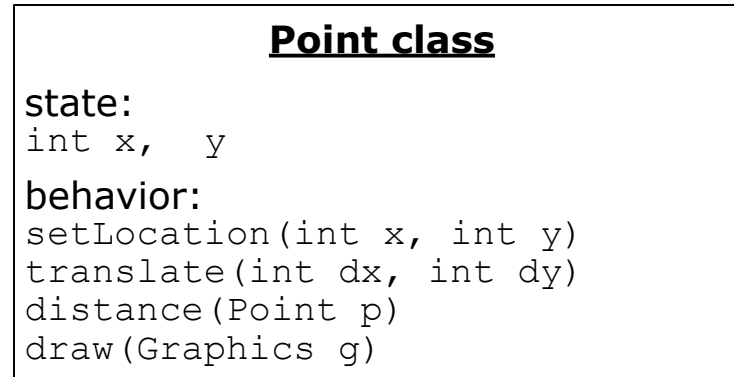
- Data in each `Point` object:

Field name	Description
<code>x</code>	the point's x-coordinate
<code>y</code>	the point's y-coordinate

- Methods in each `Point` object:

Method name	Description
<code>setLocation(x, y)</code>	sets the point's x and y to the given values
<code>translate(dx, dy)</code>	adjusts the point's x and y by the given amounts
<code>distance(p)</code>	how far away the point is from point p
<code>draw(g)</code>	displays the point on a drawing panel

Point class as blueprint



Point object #1

```
state:
x = 5,    y = -2
behavior:
setLocation(int x, int y)
translate(int dx, int dy)
distance(Point p)
draw(Graphics g)
```

Point object #2

```
state:
x = -245,    y = 1897
behavior:
setLocation(int x, int y)
translate(int dx, int dy)
distance(Point p)
draw(Graphics g)
```

Point object #3

```
state:
x = 18,    y = 42
behavior:
setLocation(int x, int y)
translate(int dx, int dy)
distance(Point p)
draw(Graphics g)
```

- The class (blueprint) will describe how to create objects.
- Each object will contain its own data and methods.

Object state: Fields

Point class, version 1

```
public class Point {  
    int x;  
    int y;  
}
```

- Save this code into a file named `Point.java`.
- The above code creates a new type named `Point`.
 - Each `Point` object contains two pieces of data:
 - an `int` named `x`, and
 - an `int` named `y`.
 - `Point` objects do not contain any behavior (yet).

Fields

- **field**: A variable inside an object that is part of its state.
 - Each object has its own copy of each field.

- Declaration syntax:

type name;

- Example:

```
public class Student {  
    String name;    // each Student object has  
a    double gpa;    // name and gpa field  
}
```

Accessing fields

- Other classes can access/modify an object's fields.

- access: **variable.field**
 - modify: **variable.field = value;**

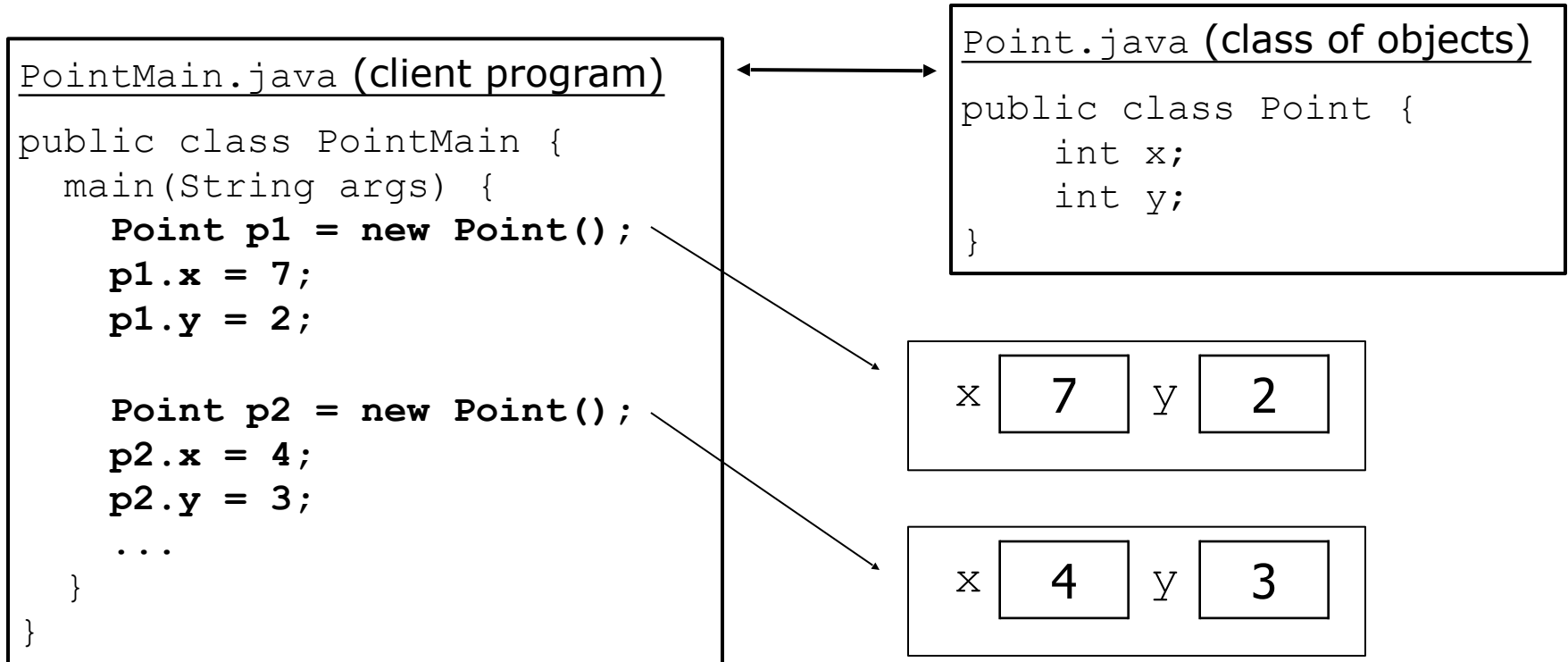
- Example:

```
Point p1 = new Point();  
Point p2 = new Point();  
System.out.println("the x-coord is " + p1.x);  
p2.y = 13;
```

// access
// modify

A class and its client

- `Point.java` is not, by itself, a runnable program.
 - A class can be used by **client** programs.



PointMain client example

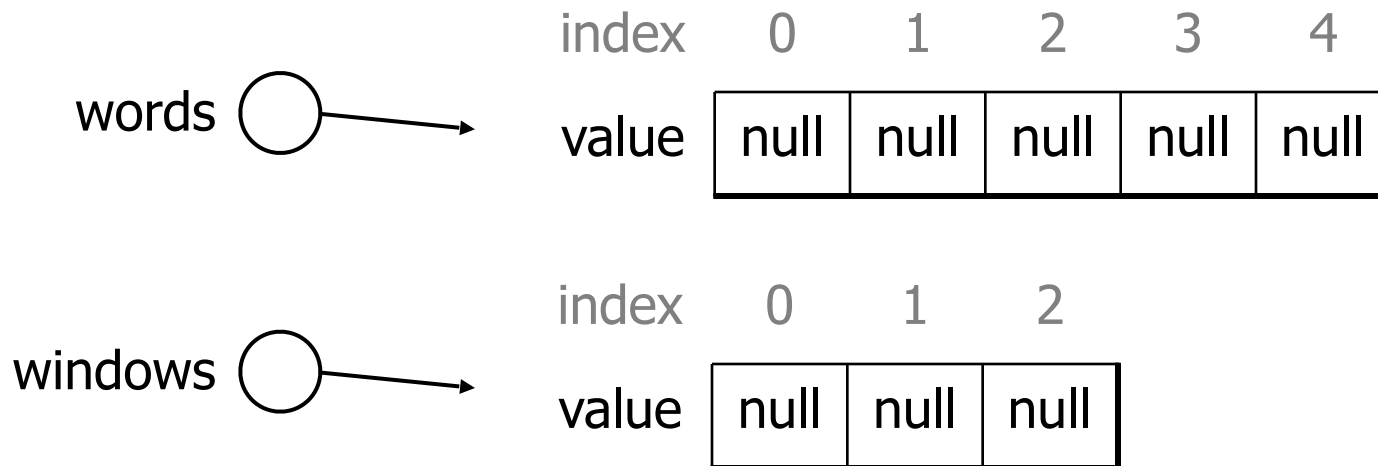
```
public class PointMain {  
    public static void main(String[] args) {  
        // create two Point objects  
        Point p1 = new Point();  
        p1.y = 2;  
        Point p2 = new Point();  
        p2.x = 4;  
  
        System.out.println(p1.x + ", " + p1.y);    // 0, 2  
  
        // move p2 and then print it  
        p2.x += 2;  
        p2.y++;  
        System.out.println(p2.x + ", " + p2.y);    // 6, 1  
    }  
}
```

- Exercise: Modify the Bomb program to use Point objects.

Arrays of objects

- **null** : A value that does not refer to any object.
 - The elements of an array of objects are initialized to `null`.

```
String[] words = new String[5];  
DrawingPanel[] windows = new DrawingPanel[3];
```



Things you can do w/ `null`

- store `null` in a variable or an array element

```
String s = null;  
words[2] = null;
```

- print a `null` reference

```
System.out.println(s);           // null
```

- ask whether a variable or array element is `null`

```
if (words[2] == null) { ...
```

- pass `null` as a parameter to a method

```
System.out.println(null);       // null
```

- return `null` from a method (often to indicate failure)

```
return null;
```

Null pointer exception

- **dereference:** To access data or methods of an object with the dot notation, such as `s.length()`.
 - It is illegal to dereference `null` (causes an exception).
 - `null` is not any object, so it has no methods or data.

```
String[] words = new String[5];  
System.out.println("word is: " + words[0]);  
words[0] = words[0].toUpperCase();    // ERROR
```

Output:

```
word is: null
```

```
Exception in thread "main"  
java.lang.NullPointerException  
    at Example.main(Example.java:8)
```

index	0	1	2	3	4
value	null	null	null	null	null

Looking before you leap

- You can check for `null` before calling an object's methods.

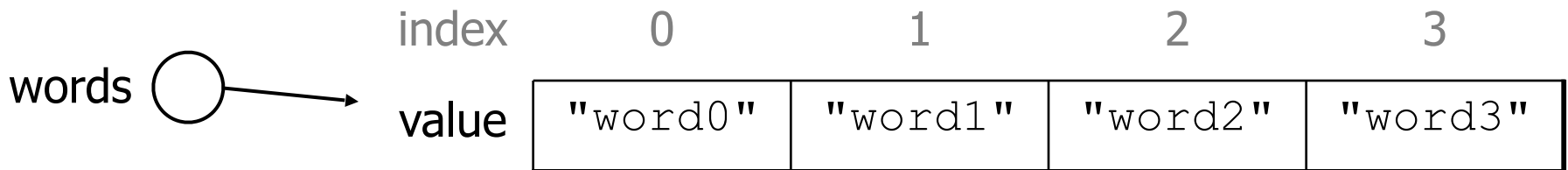
```
String[] words = new String[5];  
words[0] = "hello";  
words[2] = "goodbye";    // words[1], [3], [4] are null  
  
for (int i = 0; i < words.length; i++) {  
    if (words[i] != null) {  
        words[i] = words[i].toUpperCase();  
    }  
}
```



Two-phase initialization

- 1) initialize the array itself (each element is initially `null`)
- 2) initialize each element of the array to be a new object

```
String[] words = new String[4];           // phase 1
for (int i = 0; i < words.length; i++) {  // phase 2
    words[i] = "word" + i;
}
```



Object behavior: Methods

Client code redundancy

- Our client program wants to draw `Point` objects:

```
// draw each city
g.fillOval(cities[i].x, cities[i].y, 3, 3);
g.drawString("(" + cities[i].x + ", " + cities[i].y + ")",
             cities[i].x, cities[i].y);
```

- To draw them in other places, the code must be repeated.
 - We can remove this redundancy using a method.

Eliminating redundancy, v1

- We can eliminate the redundancy with a static method:

```
// Draws the given point on the DrawingPanel.  
public static void draw(Point p, Graphics g) {  
    g.fillOval(p.x, p.y, 3, 3);  
    g.drawString("(" + p.x + ", " + p.y + ")", p.x, p.y);  
}
```

- `main` would call the method as follows:

```
// draw each city  
draw(cities[i], g);
```


Problem with static method

- We are missing a major benefit of objects: code reuse.
 - Every program that draws `Points` would need a `draw` method.
- The syntax doesn't match how we're used to using objects.

```
draw(cities[i], g);    // static (bad)
```

- The point of classes is to combine state and behavior.
 - The `draw` behavior is closely related to a `Point`'s data.
 - The method belongs inside each `Point` object.

```
cities[i].draw(g);    // inside object  
(better)
```

Instance methods

- **instance method** (or **object method**): Exists inside each object of a class and gives behavior to each object.

```
public type name (parameters) {  
    statements;  
}
```

- same syntax as static methods, but without `static` keyword

Example:

```
public void shout() {  
    System.out.println("HELLO THERE!");  
}
```

Instance method example

```
public class Point {  
    int x;  
    int y;  
  
    // Draws this Point object with the given pen.  
    public void draw(Graphics g) {  
        ...  
    }  
}
```

- The `draw` method no longer has a `Point p` parameter.
- How will the method know which point to draw?
 - How will the method access that point's x/y data?

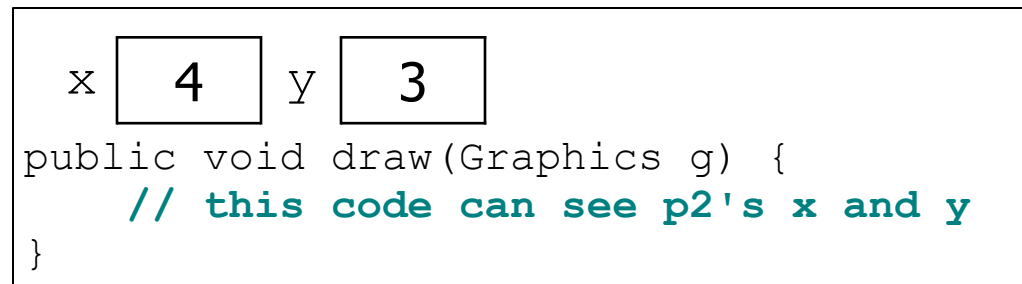
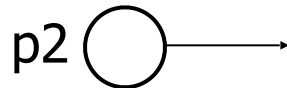
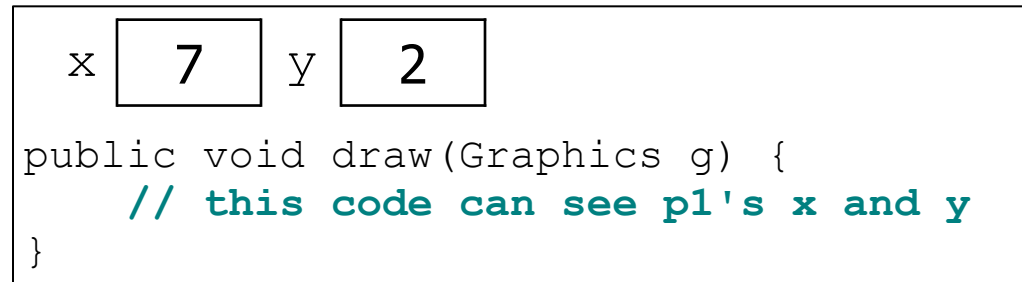
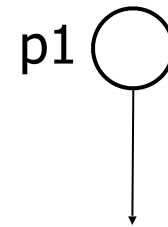
Point objects w/ method

- Each `Point` object has its own copy of the `draw` method, which operates on that object's state:

```
Point p1 = new Point();  
p1.x = 7;  
p1.y = 2;
```

```
Point p2 = new Point();  
p2.x = 4;  
p2.y = 3;
```

```
p1.draw(g);  
p2.draw(g);
```



The implicit parameter

- **implicit parameter:**

The object on which an instance method is called.

- During the call `p1.draw(g)` ;
the object referred to by `p1` is the implicit parameter.
- During the call `p2.draw(g)` ;
the object referred to by `p2` is the implicit parameter.
- The instance method can refer to that object's fields.
 - We say that it executes in the context of a particular object.
 - `draw` can refer to the `x` and `y` of the object it was called on.

Point class, version 2

```
public class Point {  
    int x;  
    int y;  
    // Changes the location of this Point object.  
    public void draw(Graphics g) {  
        g.fillOval(x, y, 3, 3);  
        g.drawString("(" + x + ", " + y + ")", x, y);  
    }  
}
```

- Each `Point` object contains a `draw` method that draws that point at its current `x/y` position.

Kinds of methods

- **accessor:** A method that lets clients examine object state.
 - Examples: `distance`, `distanceFromOrigin`
 - often has a `non-void` return type
- **mutator:** A method that modifies an object's state.
 - Examples: `setLocation`, `translate`

Mutator method questions

- Write a method `setLocation` that changes a `Point`'s location to the (x, y) values passed.
- Write a method `translate` that changes a `Point`'s location by a given dx, dy amount.
 - Modify the `Point` and client code to use these methods.

Mutator method answers

```
public void setLocation(int newX, int newY) {  
    x = newX;  
    y = newY;  
}
```

```
public void translate(int dx, int dy) {  
    x = x + dx;  
    y = y + dy;  
}
```

```
// alternative solution that utilizes setLocation  
public void translate(int dx, int dy) {  
    setLocation(x + dx, y + dy);  
}
```

Accessor method questions

- Write a method `distance` that computes the distance between a `Point` and another `Point` parameter.

Use the formula: $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$

- Write a method `distanceFromOrigin` that returns the distance between a `Point` and the origin, (0, 0).
 - Modify the client code to use these methods.

Accessor method answers

```
public double distance(Point other) {  
    int dx = x - other.x;  
    int dy = y - other.y;  
    return Math.sqrt(dx * dx + dy * dy);  
}
```

```
public double distanceFromOrigin() {  
    return Math.sqrt(x * x + y * y);  
}
```

// alternative solution that uses distance

```
public double distanceFromOrigin() {  
    Point origin = new Point();  
    return distance(origin);  
}
```

Printing objects

- By default, Java doesn't know how to print objects:

```
Point p = new Point();  
p.x = 10;  
p.y = 7;  
System.out.println("p is " + p);    // p is Point@9e8c34
```

```
// better, but cumbersome;           p is (10, 7)  
System.out.println("p is (" + p.x + ", " + p.y + ")");
```

```
// desired behavior  
System.out.println("p is " + p);    // p is (10, 7)
```

The toString method

tells Java how to convert an object into a *String*

```
Point p1 = new Point(7, 2);  
System.out.println("p1: " + p1);
```

```
// the above code is really calling the following:  
System.out.println("p1: " + p1.toString());
```

- Every class has a `toString`, even if it isn't in your code.
 - Default: class's name @ object's memory address (base 16)

```
Point@9e8c34
```

toString syntax

```
public String toString() {  
    code that returns a String representing this object;  
}
```

- Method name, return, and parameters must match exactly.
- Example:

```
// Returns a String representing this Point.  
public String toString() {  
    return "(" + x + ", " + y + ")";  
}
```

Object initialization: constructors

Initializing objects

- Currently it takes 3 lines to create a `Point` and initialize it:

```
Point p = new Point();  
p.x = 3;  
p.y = 8;                                // tedious
```

- We'd rather specify the fields' initial values at the start:

```
Point p = new Point(3, 8);    // better!
```

- We are able to do this with most types of objects in Java.

Constructors

- **constructor**: Initializes the state of new objects.

```
public type(parameters) {  
    statements;  
}
```

- runs when the client uses the `new` keyword
- no return type is specified;
it implicitly "returns" the new object being created
- If a class has no constructor, Java gives it a default constructor with no parameters that sets all fields to 0.

Constructor example

```
public class Point {  
    int x;  
    int y;  
  
    // Constructs a Point at the given x/y location.  
    public Point(int initialX, int initialY) {  
        x = initialX;  
        y = initialY;  
    }  
  
    public void translate(int dx, int dy) {  
        x = x + dx;  
        y = y + dy;  
    }  
  
    ...  
}
```

Tracing a constructor call

- What happens when the following call is made?

```
Point p1 = new Point(7, 2);
```

p1 ○ →

x

y

```
public Point(int initialX, int initialY) {  
    x = initialX;  
    y = initialY;  
}  
  
public void translate(int dx, int dy) {  
    x += dx;  
    y += dy;  
}
```

Client code, version 3

```
public class PointMain3 {  
    public static void main(String[] args) {  
        // create two Point objects  
        Point p1 = new Point(5, 2);  
        Point p2 = new Point(4, 3);  
  
        // print each point  
        System.out.println("p1: (" + p1.x + ", " + p1.y + ")");  
        System.out.println("p2: (" + p2.x + ", " + p2.y + ")");  
  
        // move p2 and then print it again  
        p2.translate(2, 4);  
        System.out.println("p2: (" + p2.x + ", " + p2.y + ")");  
    }  
}
```

OUTPUT:

```
p1: (5, 2)  
p2: (4, 3)  
p2: (6, 7)
```

Multiple constructors

- A class can have multiple constructors.
 - Each one must accept a unique set of parameters.
- Exercise: Write a `Point` constructor with no parameters that initializes the point to (0, 0).

```
// Constructs a new point at (0, 0).  
public Point() {  
    x = 0;  
    y = 0;  
}
```

Common constructor bugs

1. Re-declaring fields as local variables ("shadowing"):

```
public Point(int initialX, int initialY) {  
    int x = initialX;  
    int y = initialY;  
}
```

- This declares local variables with the same name as the fields, rather than storing values into the fields. The fields remain 0.

2. Accidentally giving the constructor a return type:

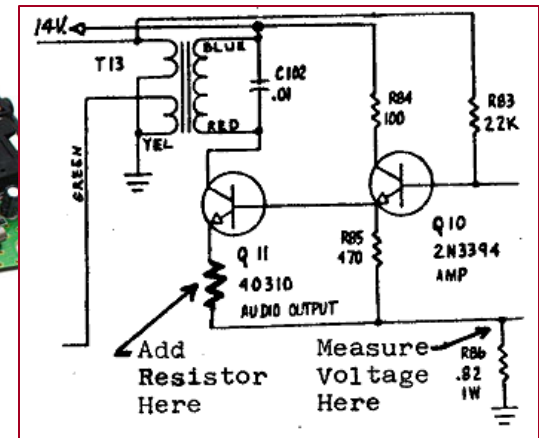
```
public void Point(int initialX, int initialY) {  
    x = initialX;  
    y = initialY;  
}
```

- This is actually not a constructor, but a method named `Point`

Encapsulation

Encapsulation

- **encapsulation**: Hiding implementation details from clients.
 - Encapsulation forces abstraction.
 - separates external view (behavior) from internal view (state)
 - protects the integrity of an object's data



Private fields

A field that cannot be accessed from outside the class

private type name;

– Examples:

```
private int id;  
private String name;
```

- Client code won't compile if it accesses private fields:

```
PointMain.java:11: x has private access in Point  
System.out.println(p1.x) ;  
                        ^
```

Accessing private state

```
// A "read-only" access to the x field ("accessor")
public int getX() {
    return x;
}

// Allows clients to change the x field ("mutator")
public void setX(int newX) {
    x = newX;
}
```

- Client code will look more like this:

```
System.out.println(p1.getX());
p1.setX(14);
```

Point class, version 4

```
// A Point object represents an (x, y) location.
public class Point {
    private int x;
    private int y;
    public Point(int initialX, int initialY) {
        x = initialX;
        y = initialY;
    }
    public int getX() {
        return x;
    }
    public int getY() {
        return y;
    }
    public double distanceFromOrigin() {
        return Math.sqrt(x * x + y * y);
    }
    public void setLocation(int newX, int newY) {
        x = newX;
        y = newY;
    }
    public void translate(int dx, int dy) {
        setLocation(x + dx, y + dy);
    }
}
```

The `this` keyword

- **`this`** : Refers to the implicit parameter inside your class.
(a variable that stores the object on which a method is called)
 - Refer to a field: `this.field`
 - Call a method: `this.method (parameters) ;`
 - One constructor can call another: `this (parameters) ;`

Variable shadowing

- **shadowing**: 2 variables with same name in same scope.
 - Normally illegal, except when one variable is a field.

```
public class Point {  
    private int x;  
    private int y;  
  
    ...  
    // this is legal  
    public void setLocation(int x, int y) {  
        ...  
    }  
}
```

- In most of the class, `x` and `y` refer to the fields.
- In `setLocation`, `x` and `y` refer to the method's parameters.


Fixing shadowing

```
public class Point {  
    private int x;  
    private int y;  
    ...  
    public void setLocation(int x, int  
y) {  
        this.x = x;  
        this.y = y;  
    }  
}
```

- Inside `setLocation`,
 - To refer to the data field `x`, say `this.x`
 - To refer to the parameter `x`, say `x`

Calling another constructor

```
public class Point {  
    private int x;  
    private int y;  
  
    public Point() {  
        this(0, 0);           // calls (x, y) constructor  
    }  
  
    public Point(int x, int y) {  
        this.x = x;  
        this.y = y;  
    }  
  
    ...  
}
```

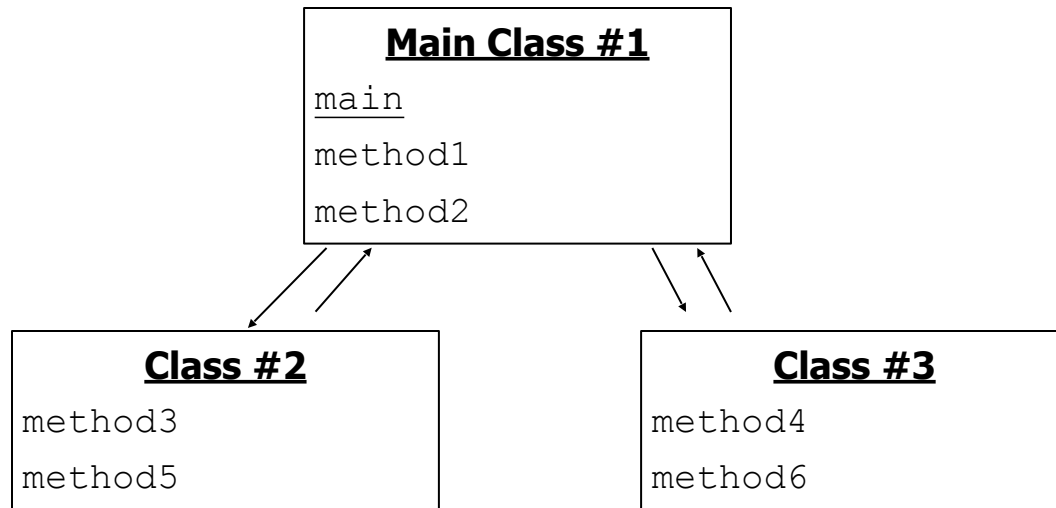
A diagram consisting of a line with an arrowhead pointing from the `this.x = x;` line in the `Point(int x, int y)` constructor to the `this(0, 0);` line in the `Point()` constructor, indicating a call to another constructor.

- Avoids redundancy between constructors
- Only a constructor (not a method) can call another constructor

Static methods/fields

Multi-class systems

- Most large software systems consist of many classes.
 - One main class runs and calls methods of the others.
- Advantages:
 - code reuse
 - splits up the program logic into manageable chunks



Redundant program 1

```
// This program sees whether some interesting numbers are prime.
public class Primes1 {
    public static void main(String[] args) {
        int[] nums = {1234517, 859501, 53, 142};
        for (int i = 0; i < nums.length; i++) {
            if (isPrime(nums[i])) {
                System.out.println(nums[i] + " is prime");
            }
        }
    }

    // Returns the number of factors of the given integer.
    public static int countFactors(int number) {
        int count = 0;
        for (int i = 1; i <= number; i++) {
            if (number % i == 0) {
                count++;    // i is a factor of the number
            }
        }
        return count;
    }

    // Returns true if the given number is prime.
    public static boolean isPrime(int number) {
        return countFactors(number) == 2;
    }
}
```

Redundant program 2

```
// This program prints all prime numbers up to a maximum.
public class Primes2 {
    public static void main(String[] args) {
        Scanner console = new Scanner(System.in);
        System.out.print("Max number? ");
        int max = console.nextInt();
        for (int i = 2; i <= max; i++) {
            if (isPrime(i)) {
                System.out.print(i + " ");
            }
        }
        System.out.println();
    }

    // Returns true if the given number is prime.
    public static boolean isPrime(int number) {
        return countFactors(number) == 2;
    }

    // Returns the number of factors of the given integer.
    public static int countFactors(int number) {
        int count = 0;
        for (int i = 1; i <= number; i++) {
            if (number % i == 0) {
                count++; // i is a factor of the number
            }
        }
        return count;
    }
}
```

Classes as modules

- **module:** A reusable piece of software, stored as a class.
 - Example module classes: Math, Arrays, System

```
// This class is a module that contains useful methods
// related to factors and prime numbers.
public class Factors {
    // Returns the number of factors of the given integer.
    public static int countFactors(int number) {
        int count = 0;
        for (int i = 1; i <= number; i++) {
            if (number % i == 0) {
                count++;    // i is a factor of the number
            }
        }
        return count;
    }
    // Returns true if the given number is prime.
    public static boolean isPrime(int number) {
        return countFactors(number) == 2;
    }
}
```

More about modules

- A module is a partial program, not a complete program.
 - It does not have a `main`. You don't run it directly.
 - Modules are meant to be utilized by other client classes.

- Syntax:

`class.method(parameters) ;`

- Example:

```
int factorsOf24 = Factors.countFactors(24) ;
```

Using a module

```
// This program sees whether some interesting numbers are prime.
public class Primes {
    public static void main(String[] args) {
        int[] nums = {1234517, 859501, 53, 142};
        for (int i = 0; i < nums.length; i++) {
            if (Factors.isPrime(nums[i])) {
                System.out.println(nums[i] + " is prime");
            }
        }
    }
}

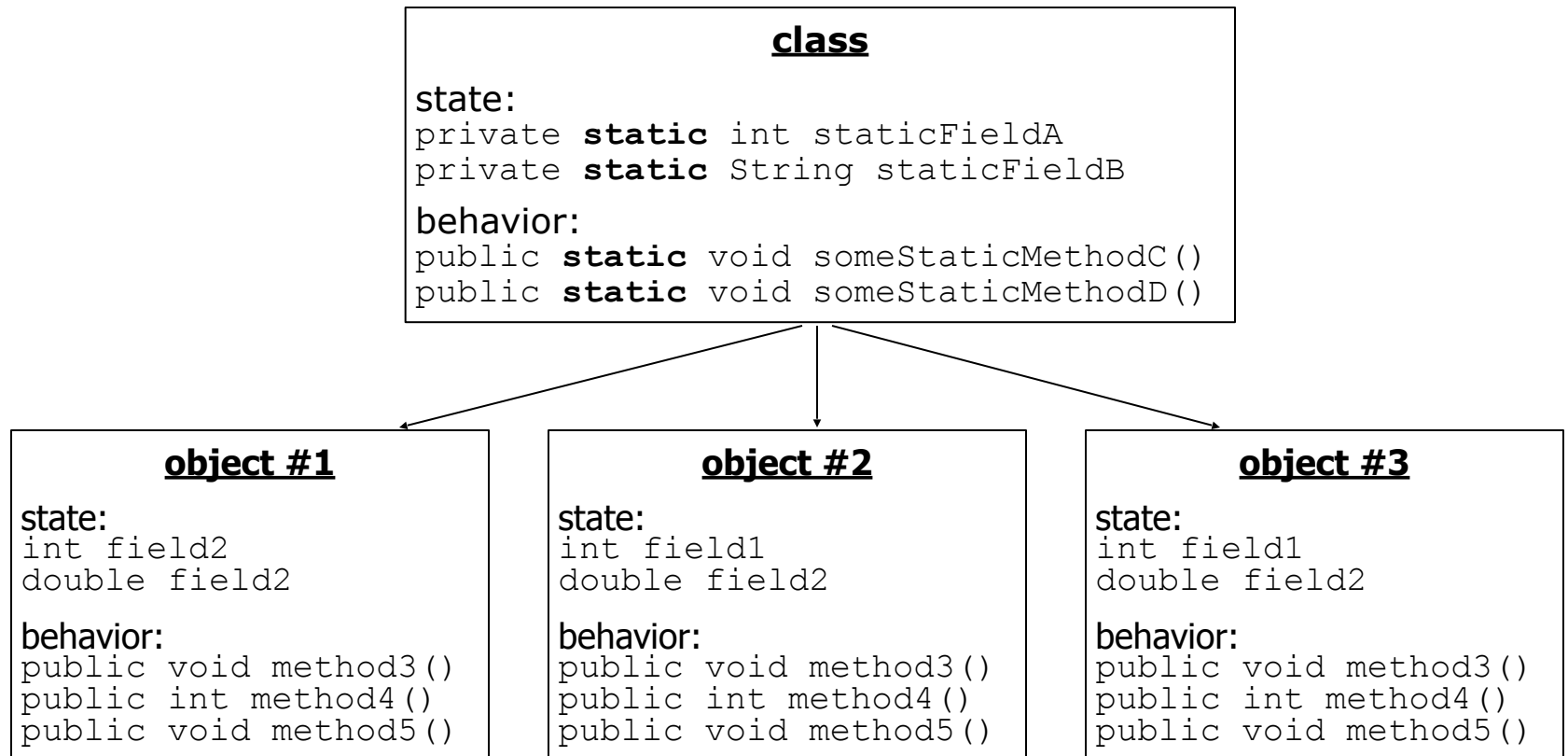
// This program prints all prime numbers up to a given maximum.
public class Primes2 {
    public static void main(String[] args) {
        Scanner console = new Scanner(System.in);
        System.out.print("Max number? ");
        int max = console.nextInt();
        for (int i = 2; i <= max; i++) {
            if (Factors.isPrime(i)) {
                System.out.print(i + " ");
            }
        }
        System.out.println();
    }
}
```

Modules in Java libraries

```
// Java's built in Math class is a module
public class Math {
    public static final double PI = 3.14159265358979323846;
    ...
    public static int abs(int a) {
        if (a >= 0) {
            return a;
        } else {
            return -a;
        }
    }
    public static double toDegrees(double radians) {
        return radians * 180 / PI;
    }
}
```

Static members

- **static:** Part of a class, rather than part of an object.
 - Object classes can have static methods and fields.
 - Not copied into each object; shared by all objects of that class.



Static fields

```
private static type name;
```

or,

```
private static type name = value;
```

- Example:

```
private static int theAnswer = 42;
```

- **static field**: Stored in the class instead of each object.

- A "shared" global field that all objects can access and modify.
- Like a class constant, except that its value can be changed.

Accessing static fields

- From inside the class where the field was declared:

```
fieldName                                // get the  
value  
fieldName = value;                      // set the value
```

- From another class (if the field is `public`):

```
ClassName.fieldName                      // get the value  
ClassName.fieldName = value;             // set the value
```

– generally static fields are not `public` unless they are `final`

- Exercise: Modify the `BankAccount` class shown previously so that each account is automatically given a unique ID.
- Exercise: Write the working version of `FratGuy`.

BankAccount solution

```
public class BankAccount {  
    // static count of how many accounts are created  
    // (only one count shared for the whole class)  
    private static int objectCount = 0;  
  
    // fields (replicated for each object)  
    private String name;  
    private int id;  
  
    public BankAccount() {  
        objectCount++; // advance the id, and  
        id = objectCount; // give number to account  
    }  
    ...  
    public int getID() { // return this account's id  
        return id;  
    }  
}
```

Static methods

// the same syntax you've already used for methods

```
public static type name(parameters) {  
    statements;  
}
```

- **static method:** Stored in a class, not in an object.
 - Shared by all objects of the class, not replicated.
 - Does not have any implicit parameter, `this`;
therefore, cannot access any particular object's fields.
- **Exercise:** Make it so that clients can find out how many total `BankAccount` objects have ever been created.

BankAccount solution

```
public class BankAccount {  
    // static count of how many accounts are created  
    // (only one count shared for the whole class)  
    private static int objectCount = 0;  
  
    // clients can call this to find out # accounts created  
    public static int getNumAccounts() {  
        return objectCount;  
    }  
  
    // fields (replicated for each object)  
    private String name;  
    private int id;  
  
    public BankAccount() {  
        objectCount++;  
        id = objectCount;    // advance the id, and  
                             // give number to account  
    }  
  
    ...  
    public int getID() {    // return this account's id  
        return id;  
    }  
}
```

Summary of Java classes

- A class is used for any of the following in a large program:
 - a program : Has a main and perhaps other static methods.
 - example: `GuessingGame`, `Birthday`, `MadLibs`, `CritterMain`
 - does not usually declare any static fields (except `final`)
 - an object class : Defines a new type of objects.
 - example: `Point`, `BankAccount`, `Date`, `Critter`, `FratGuy`
 - declares object fields, constructor(s), and methods
 - might declare static fields or methods, but these are less of a focus
 - should be encapsulated (all fields and static fields `private`)
 - a module : Utility code implemented as static methods.
 - example: `Math`