Building Java Programs
Chapter 8

Classes

Classes and objects

- **class**: A program entity that represents either:
  1. A program / module, or
  2. **A template for a new type of objects.**

  - The `Fraction` class is a template for creating `Fraction` objects. The `Point` class is a template for creating `Point` objects

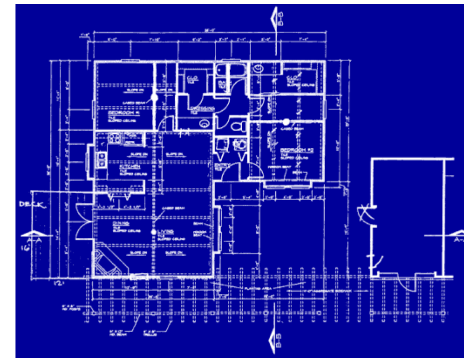
- **object**: An entity that combines state and behavior.
  - **object-oriented programming (OOP)**: Programs that perform their behavior as interactions between objects.

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

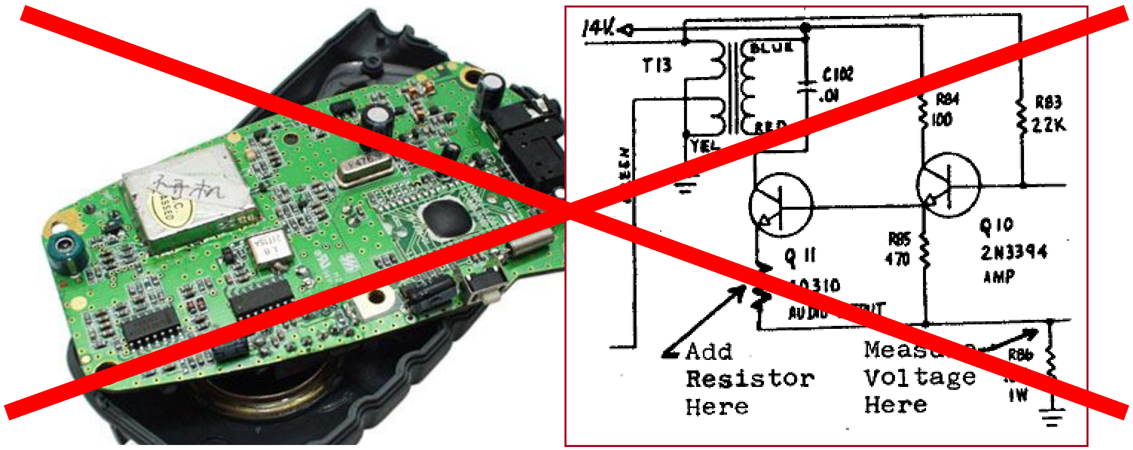
state:
song = "Discipline"
volume = 24
battery life = 1.8 hrs

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.



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
`x`	the point's x-coordinate
`y`	the point's y-coordinate

- Methods in each `Point` object:

Method name	Description
`setLocation(`**x**`, `**y**`)`	sets the point's x and y to the given values
`translate(`**dx**`, `**dy**`)`	adjusts the point's x and y by the given amounts
`distance(`**p**`)`	how far away the point is from point *p*

`Point` class as blueprint

Point class

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

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);    // access
p2.y = 13;                                        // modify
```

A class and its client

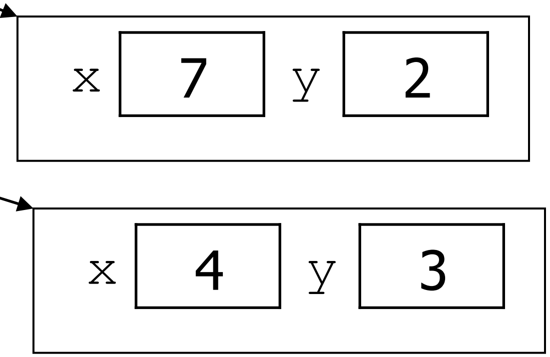
- `Point.java` is not, by itself, a runnable program.
  - A class can be used by **client** programs.

`PointMain.java` (client program)

```
public class PointMain {
  main(String args) {
    Point p1 = new Point();
    p1.x = 7;
    p1.y = 2;

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

`Point.java` (class of objects)

```
public class Point {
    int x;
    int y;
    public Point() {
        x = 0;
        y = 0;
    }
}
```



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
    }
}
```

Object behavior: Methods

Problem with static method

- We are missing a major benefit of objects: code reuse.
  - Every program that uses `Point`s would need their own methods to do things with `Point`s.

- The syntax doesn't match how we're used to using objects.

- The point of classes is to combine state and behavior.
  - The desired behaviors are closely related to a `Point`'s data.
  - The methods belong *inside* each `Point` object.

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

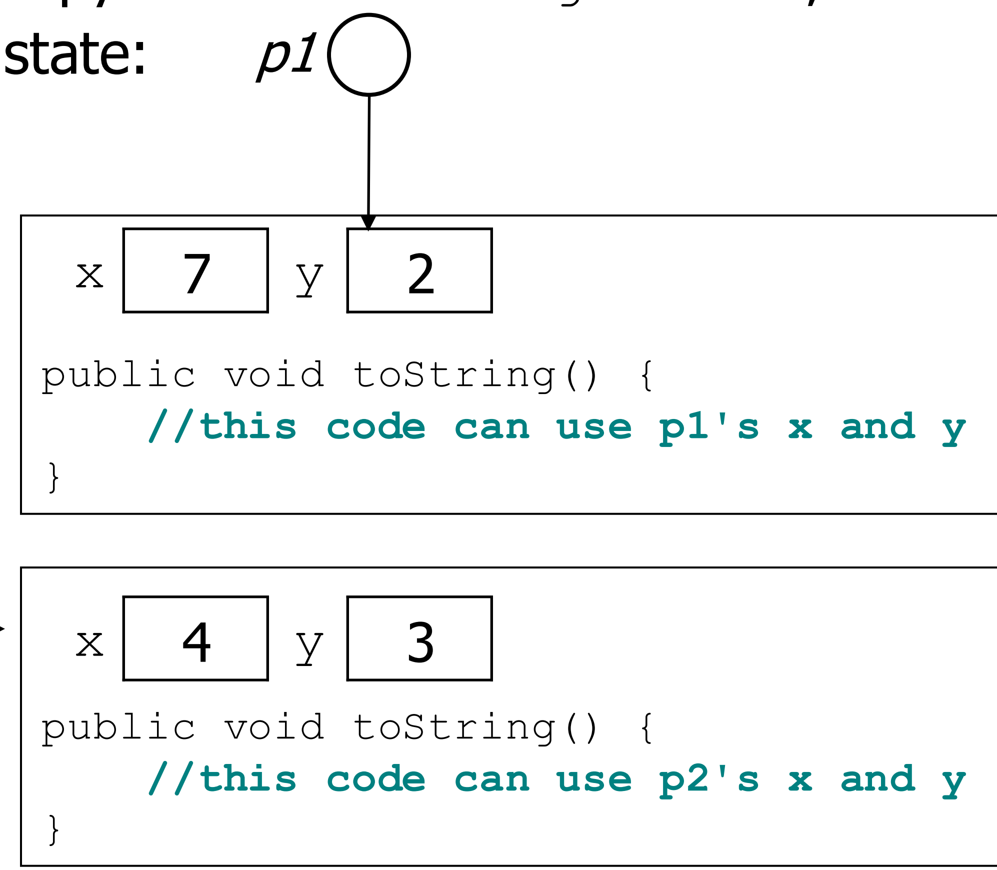
```
public class Point {
    int x;
    int y;

    public Point() {
        x = 0;
        y = 0;
    }

    // Returns a string showing this Point object.
    public String toString() {
        String temp = "";
        temp += "(" + this.x + "," + this.y + ") ";
        return temp;
    }
}
```

- The `toString()` method doesn't have 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 `toString` 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;
```




```
System.out.println(p1.toString());
System.out.println(p2.toString());
```

The implicit parameter

- **implicit parameter**:
  The object on which an instance method is called.

  - During the call `p1.toString();`
    the object referred to by `p1` is the implicit parameter.

  - During the call `p2.toString();`
    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.
    - `toString()` 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;
    public Point () {
       x = 0;
       y = 0;
    }

    // Returns a string showing this Point object.
    public String toString {
        String temp = "";
        temp += "(" + this.x + "," + this.y + ") ";
        return temp;
    }
}
```

– Each `Point` object contains a `toString()` 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 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.

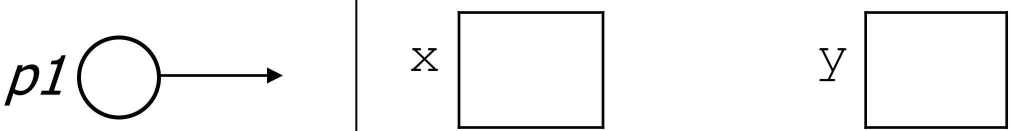
Constructor example

```
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);
```




```
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;
}
```

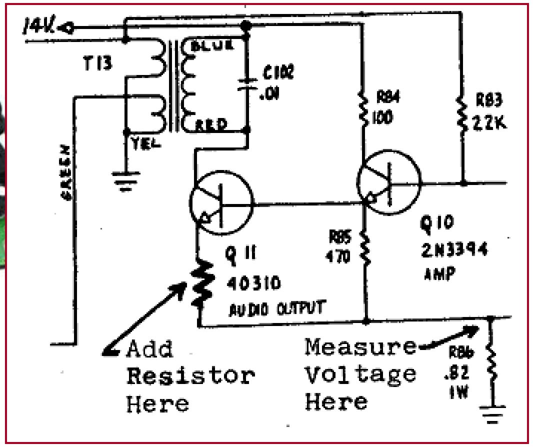
   – This is actually not a constructor, but a method named `Point`

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:

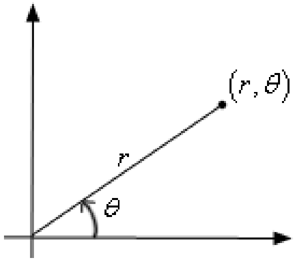
```
System.out.println(p1.getX());
p1.setX(14);
```

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);
    }
}
```

Benefits of encapsulation

- Abstraction between object and clients
- Protects object from unwanted access
  - Example: Can't fraudulently increase an `Account`'s balance.
- Can change the class implementation later
  - Example: `Point` could be rewritten in polar coordinates (r, θ) with the same methods.



- Can constrain objects' state (**invariants**)
  - Example: Only allow `Account`s with non-negative balance.
  - Example: Only allow `Date`s with a month from 1-12.

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

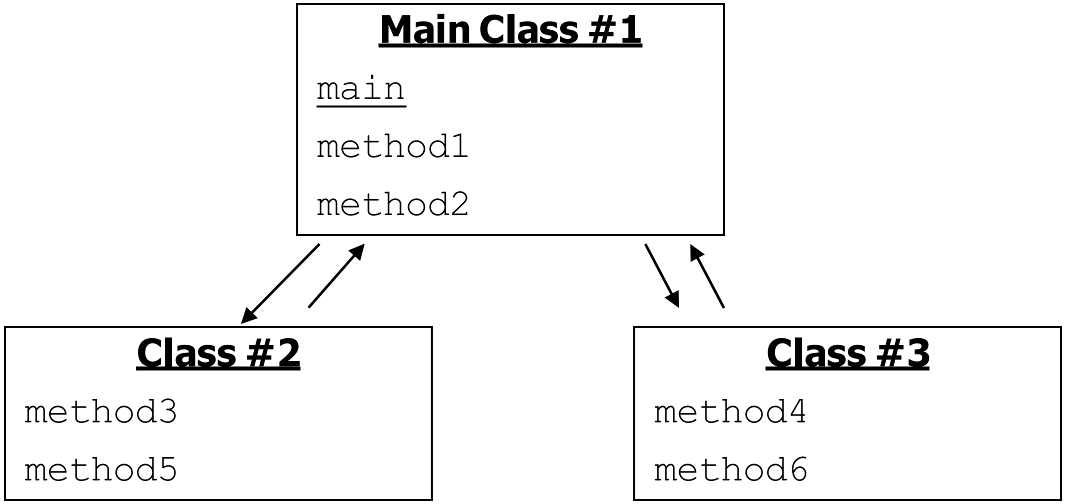
```
public class Point {
    private int x;
    private int y;

    public Point() {
        this(0, 0);      // calls (x, y) constructor
    }

    public Point(int x, int y) {
        this.x = x;
        this.y = y;
    }

    ...
}
```

- 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

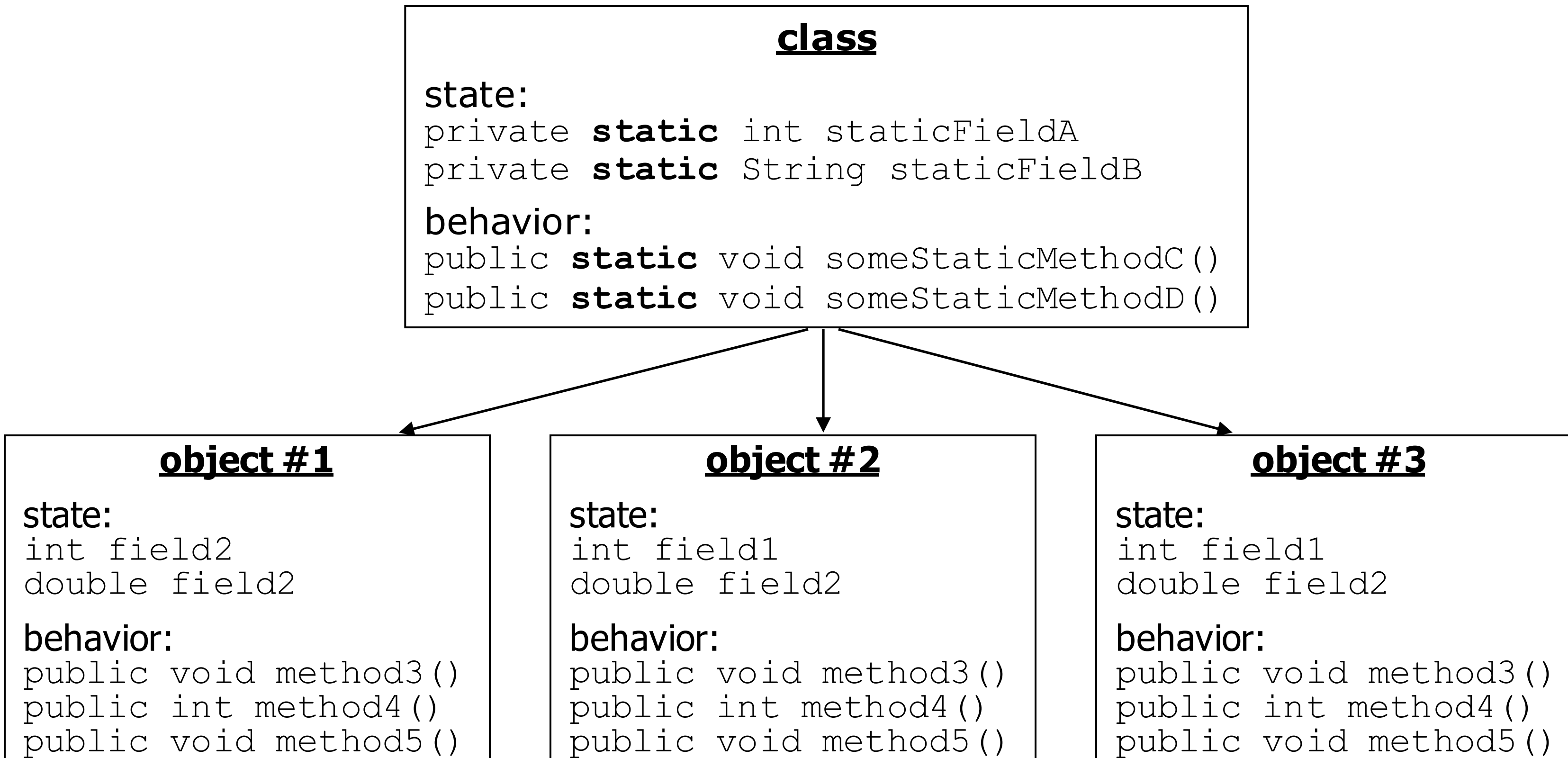
```
// This program sees whether some interesting numbers are prime.
public class Primes {
    public static void main(String[] args) {
        int[] nums = {1234517, 859501, 53, 142};
        for (int i = 0; i < nums.length; i++) {
            if (Factors.isPrime(nums[i])) {
                System.out.println(nums[i]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

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`