

Classes and Objects



EECS1022 Sections M & N:
Programming for Mobile Computing
Winter 2021

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It is assumed that you also complete:

- **Java Tutorial Videos:**

- *Weeks 6* [\[link \]](#)
- *Weeks 7* [\[link \]](#)
- *Weeks 8* [\[link \]](#)

- **Written Notes:**

- *Inferring Classes from JUnit Tests* [\[link \]](#)
- *Manipulating Multi-Valued, Reference-Typed Attributes* [\[link \]](#)

Learning Outcomes

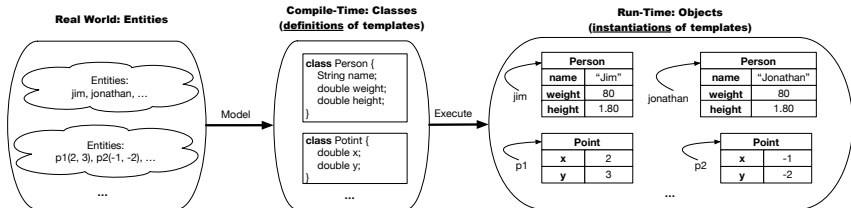
Understand:

- Object Orientation
- Classes as Templates:
 - attributes, constructors, (accessor and mutator) methods
 - use of `this`
- Objects as Instances:
 - use of `new`
 - the dot notation, method invocations
 - reference aliasing
- Reference-Typed Attributes: Single-Valued vs. Multi-Valued
- Non-Static vs. Static Variables
- Helper Methods

Where are we? Where will we go?

- We have developed the Java code within a `main` or utility method.
- In Java:
 - We may define more than one *classes*
 - Each class may contain more than one *methods*
- *object-oriented programming* in Java:
 - Use *classes* to define templates
 - Use *objects* to instantiate classes
 - At *runtime*, *create* objects and *call* methods on objects, to *simulate interactions* between real-life entities.

Object Orientation: Observe, Model, and Execute



- Study this tutorial video that walks you through the idea of **object orientation**.
- We **observe** how real-world *entities* behave.
- We **model** the common *attributes* and *behaviour* of a set of entities in a single *class*.
- We **execute** the program by creating *instances* of classes, which interact in a way analogous to that of real-world *entities*.

Object-Oriented Programming (OOP)

- In real life, lots of **entities** exist and interact with each other.
 - e.g., *People* gain/lose weight, marry/divorce, or get older.
 - e.g., *Cars* move from one point to another.
 - e.g., *Clients* initiate transactions with banks.
- Entities:
 - Possess *attributes*;
 - Exhibit *behaviour*; and
 - Interact with each other.
- Goals: Solve problems *programmatically* by
 - *Classifying* entities of interest
Entities in the same class share *common* attributes and behaviour.
 - *Manipulating* data that represent these entities
Each entity is represented by *specific* values.

OO Thinking: Templates vs. Instances (1.1)

Points on a two-dimensional plane are identified by their signed distances from the X- and Y-axes. A point may move arbitrarily towards any direction on the plane. Given two points, we are often interested in knowing the distance between them.

- A template called `Point` defines the common
 - *attributes* (e.g., `x`, `y`) [≈ nouns]
 - *behaviour* (e.g., `move up`, `get distance from`) [≈ verbs]

OO Thinking: Templates vs. Instances (1.2)

- A **template** (e.g., class `Point`) defines what's shared by a set of related entities (i.e., 2-D points).
 - Common *attributes* (x, y)
 - Common *behaviour* (move left, move up)
- Each template may be **instantiated** as multiple instances, each with *instance-specific* values for attributes x and y :
 - `Point` instance `p1` is located at $(3, 4)$
 - `Point` instance `p2` is located at $(-4, -3)$
- Instances of the same template may exhibit *distinct behaviour*.
 - When `p1` moves up for 1 unit, it will end up being at $(3, 5)$
 - When `p2` moves up for 1 unit, it will end up being at $(-4, -2)$
 - Then, `p1`'s distance from origin:
$$[\sqrt{3^2 + 5^2}]$$
 - Then, `p2`'s distance from origin:
$$[\sqrt{(-4)^2 + (-2)^2}]$$

OO Thinking: Templates vs. Instances (2.1)

A person is a being, such as a human, that has certain attributes and behaviour constituting personhood: a person ages and grows on their heights and weights.

- A template called `Person` defines the common
 - **attributes** (e.g., age, weight, height) [≈ nouns]
 - **behaviour** (e.g., get older, gain weight) [≈ verbs]

OO Thinking: Templates vs. Instances (2.2)

- A **template** (e.g., class `Person`) defines what's shared by a set of related entities (i.e., persons).
 - Common *attributes* (age, weight, height)
 - Common *behaviour* (get older, lose weight, grow taller)
- Each template may be **instantiated** as multiple instances, each with *instance-specific* values for attributes age, weight, and height.
 - `Person` instance `jim` is
50-years old, 1.8-meters tall and 80-kg heavy
 - `Person` instance `jonathan` is
65-years old, 1.73-meters tall and 90-kg heavy
- Instances of the same template may exhibit *distinct behaviour*.
 - When `jim` gets older, he becomes 51
 - When `jonathan` gets older, he becomes 66.
 - `jim's` BMI is based on his own height and weight $\left[\frac{80}{1.8^2} \right]$
 - `jonathan's` BMI is based on his own height and weight $\left[\frac{90}{1.73^2} \right]$

OOP: Classes \approx Templates

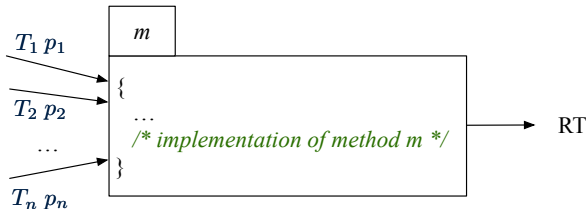
In Java, you use a **class** to define a *template* that enumerates *attributes* that are common to a set of *entities* of interest.

```
public class Person {  
    private int age;  
    private String nationality;  
    private double weight;  
    private double height;  
}
```

```
public class Point {  
    private double x;  
    private double y;  
}
```

OOP: Methods (1.1)

- A **method** is a named block of code, *reusable* via its name.



- The **Header** of a method consists of:
 - Return type [*RT* (which can be void)]
 - Name of method [*m*]
 - Zero or more *parameter names* [*p*₁, *p*₂, ..., *p*_{*n*}]
 - The corresponding *parameter types* [*T*₁, *T*₂, ..., *T*_{*n*}]
- A call to method *m* has the form: $m(a_1, a_2, \dots, a_n)$
 Types of **argument values** a_1, a_2, \dots, a_n must match the the corresponding parameter types T_1, T_2, \dots, T_n .

OOP: Methods (1.2)

- In the body of the method, you may
 - Declare new *local variables* (whose **scope** is within that method).
 - Use or change values of *attributes*.
 - Use values of *parameters*, if any.

```
public class Person {  
    private String nationality;  
    public void changeNationality(String newNationality) {  
        nationality = newNationality; } }  
}
```

- *Call* a *method*, with a **context object**, by passing *arguments*.

```
public class PersonTester {  
    public static void main(String[] args) {  
        Person jim = new Person(50, "British");  
        Person jonathan = new Person(60, "Canadian");  
        jim.changeNationality("Korean");  
        jonathan.changeNationality("Korean"); } }  
}
```

OOP: Methods (2)

- Each **class** C defines a list of methods.
 - A **method** m is a named block of code.
- We *reuse* the code of method m by calling it on an **object** obj of class C .
 - For each **method call** $obj.m(\dots)$:
 - obj is the **context object** of type C
 - m is a method defined in class C
 - We intend to apply the **code effect of method** m to object obj .
e.g., `jim.getOlder()` vs. `jonathan.getOlder()`
e.g., `p1.moveUp(3)` vs. `p2.moveUp(3)`
- All objects of class C share *the same definition* of method m .
- However:
 - ∴ Each object may have *distinct attribute values*.
 - ∴ Applying *the same definition* of method m has *distinct effects*.

OOP: Methods (3)

1. *Constructor*

- Same name as the class. No return type. *Initializes* attributes.
- Called with the **new** keyword.
- e.g., `Person jim = new Person(50, "British");`

2. *Mutator*

- *Changes* (re-assigns) attributes
- `void` return type
- Cannot be used when a value is expected
- e.g., `double h = jim.setHeight(78.5)` is illegal!

3. *Accessor*

- *Uses* attributes for computations (without changing their values)
- Any return type other than `void`
- An explicit *return statement* (typically at the end of the method) returns the computation result to where the method is being used.
e.g., `double bmi = jim.getBMI();`
e.g., `println(pl.getDistanceFromOrigin());`

OOP: Class Constructors (1.1)

- The purpose of defining a *class* is to be able to create *instances* out of it.
- To *instantiate* a class, we use one of its **constructors**.
- A constructor
 - declares input *parameters*
 - uses input parameters to *initialize* **some or all** of its *attributes*

OOP: Class Constructors (1.2)

For each *class*, you may define *one or more* **constructors** :

- *Names* of all constructors must match the class name.
- *No return types* need to be specified for constructors.
- Constructor must have *distinct* lists of *parameter types*.
 - `Person(String n), Person(String n, int age)` ✓
 - `Person(String n, int age), Person(int age, String n)` ✓
 - `Person(String fN, int age), Person(String lN, int id)` ✗
- Each *parameter* that is used to initialize an attribute must have a *matching type*.
- The *body* of each constructor specifies how **some or all** *attributes* may be *initialized*.

OOP: Class Constructors (2.1)

```
public class Point {  
    private double x;  
    private double y;  
  
    public Point(double initX, double initY) {  
        x = initX;  
        y = initY;  
    }  
  
    public Point(char axis, double distance) {  
        if (axis == 'x') { x = distance; }  
        else if (axis == 'y') { y = distance; }  
        else { /* Error: invalid axis */ }  
    }  
}
```

OOP: Class Constructors (2.2)

```
public class Person {  
    private int age;  
    private String nationality;  
    private double weight;  
    private double height;  
    public Person(int initAge, String initNat) {  
        age = initAge;  
        nationality = initNat;  
    }  
    public Person (double initW, double initH) {  
        weight = initW;  
        height = initH;  
    }  
    public Person(int initAge, String initNat,  
        double initW, double initH) {  
        ... /* initialize all attributes using the parameters */  
    }  
}
```

Visualizing Objects at Runtime (1)

- To trace a program with sophisticated manipulations of objects, it's critical for you to visualize how objects are:

- Created using *constructors*

```
Person jim = new Person(50, "British", 80, 1.8);
```

- Inquired using *accessor methods*

```
double bmi = jim.getBMI();
```

- Modified using *mutator methods*

```
jim.gainWeightBy(10);
```

- To visualize an object:

- Draw a rectangle box to represent contents of that object:

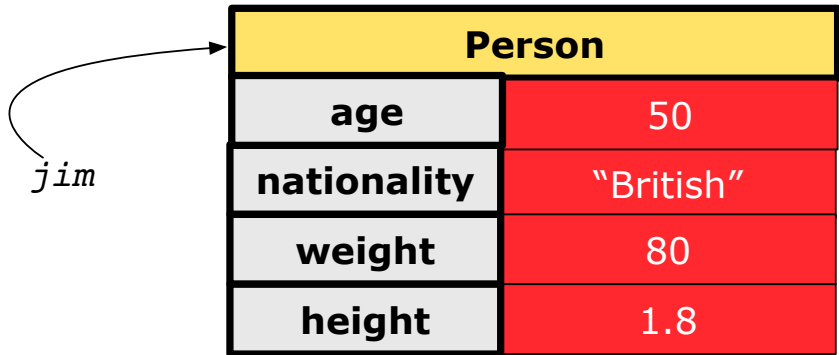
- Title indicates the *name of class* from which the object is instantiated.
- Left column enumerates *names of attributes* of the instantiated class.
- Right column fills in *values* of the corresponding attributes.

- Draw arrow(s) for *variable(s)* that store the object's address.

Visualizing Objects at Runtime (2.1)

After calling a *constructor* to create an object:

```
Person jim = new Person(50, "British", 80, 1.8);
```

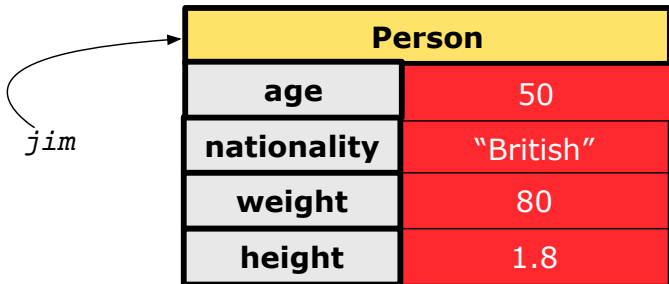


Visualizing Objects at Runtime (2.2)

After calling an *accessor* to inquire about context object *jim*:

```
double bmi = jim.getBMI();
```

- Contents of the object pointed to by *jim* remain intact.
- Returned value $\frac{80}{(1.8)^2}$ of *jim.getBMI()* stored in variable *bmi*.

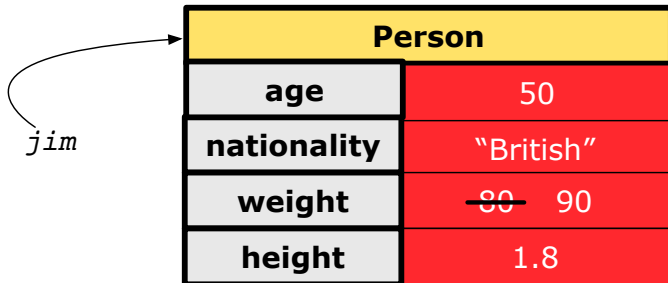


Visualizing Objects at Runtime (2.3)

After calling a *mutator* to modify the state of context object `jim`:

```
jim.gainWeightBy(10);
```

- **Contents** of the object pointed to by `jim` change.
 - **Address** of the object remains unchanged.
- ⇒ `jim` points to the same object!

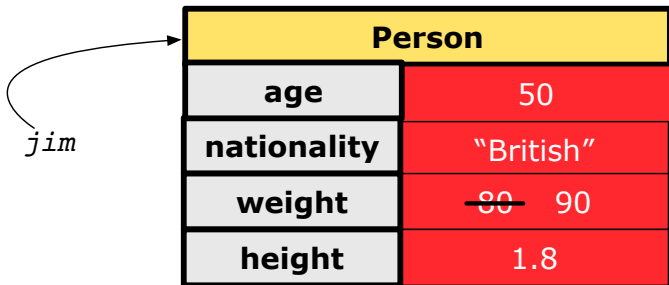


Visualizing Objects at Runtime (2.4)

After calling the same *accessor* to inquire the *modified* state of context object *jim*:

```
bmi = jim.getBMI();
```

- Contents of the object pointed to by *jim* remain intact.
- Returned value $\frac{90}{(1.8)^2}$ of *jim.getBMI()* stored in variable *bmi*.



Person	
age	50
nationality	"British"
weight	80 90
height	1.8

Object Creation (1.1)

```
Point p1 = new Point(2, 4);
```

- RHS (Source) of Assignment:** `new Point(2, 4)` creates a new *Point object* in memory.

Point	
x	2.0
y	4.0

- LHS (Target) of Assignment:** `Point p1` declares a *variable* that is meant to store the *address* of *some Point object*.
- Assignment:** Executing `=` stores new object's address in `p1`.



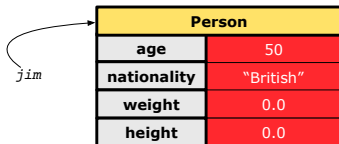
Object Creation (1.2)

```
Person jim = new Person(50, "British");
```

- RHS (Source) of Assignment:** `new Person(50, "British")` creates a new *Person object* in memory.

Person	
age	50
nationality	"British"
weight	0.0
height	0.0

- LHS (Target) of Assignment:** `Point jim` declares a *variable* that is meant to store the *address* of *some Person object*.
- Assignment:** Executing `=` stores new object's address in `jim`.



Object Creation (2)

```
Point p1 = new Point(2, 4);  
System.out.println(p1);
```

```
Point@677327b6
```

By default, the address stored in `p1` gets printed.
Instead, print out attributes separately:

```
System.out.println("(" + p1.getX() + ", " + p1.getY() + ")");
```

```
(2.0, 4.0)
```

OOP: Object Creation (3.1.1)

A constructor may only *initialize* some attributes and leave others *uninitialized*.

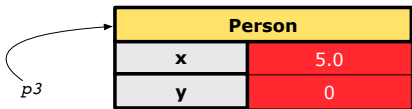
```
public class PointTester {  
    public static void main(String[] args) {  
        Point p1 = new Point(3, 4);  
        Point p2 = new Point(-3 -2);  
        Point p3 = new Point('x', 5);  
        Point p4 = new Point('y', -7);  
    }  
}
```

OOP: Object Creation (3.1.2)

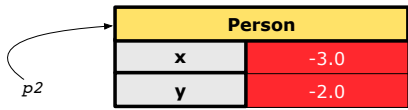
Point p1 = new Point(3, 4)



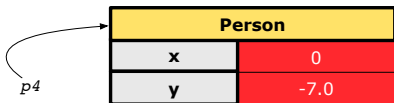
Point p3 = new Point('x', 5)



Point p2 = new Point(-3, -2)



Point p4 = new Point('y', -7)



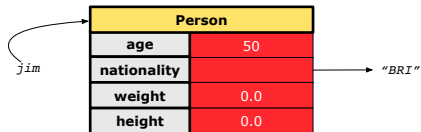
OOP: Object Creation (3.2.1)

A constructor may only *initialize* some attributes and leave others *uninitialized*.

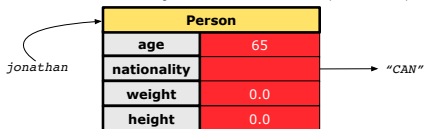
```
public class PersonTester {
    public static void main(String[] args) {
        /* initialize age and nationality only */
        Person jim = new Person(50, "BRI");
        /* initialize age and nationality only */
        Person jonathan = new Person(65, "CAN");
        /* initialize weight and height only */
        Person alan = new Person(75, 1.80);
        /* initialize all attributes of a person */
        Person mark = new Person(40, "CAN", 69, 1.78);
    }
}
```

OOP: Object Creation (3.2.2)

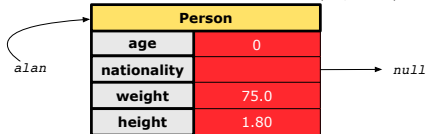
`Person jim = new Person(50, "BRI")`



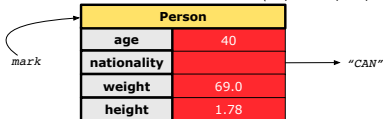
`Person jonathan = new Person(65, "CAN")`



`Person alan = new Person(75, 1.80)`



`Person mark = new Person(40, "CAN", 69, 1.78)`



OOP: Object Creation (4)

- When using the constructor, pass **valid** *argument values*:
 - The type of each argument value must match the corresponding parameter type.
 - e.g., `Person(50, "BRI")` matches
`Person(int initAge, String initNationality)`
 - e.g., `Point(3, 4)` matches
`Point(double initX, double initY)`
- When creating an instance, *uninitialized* attributes implicitly get assigned the **default values**.
 - Set *uninitialized* attributes properly later using **mutator** methods

```
Person jim = new Person(50, "British");  
jim.setWeight(85);  
jim.setHeight(1.81);
```


OOP: The Dot Notation (1)

- A binary operator:
 - **LHS** an object
 - **RHS** an attribute or a method
- Given a *variable* of some *reference type* that is **not** null:
 - We use a dot to retrieve any of its **attributes**.
Analogous to 's in English
e.g., `jim.nationality` means jim's nationality
 - We use a dot to invoke any of its **mutator methods**, in order to *change* values of its attributes.
e.g., `jim.changeNationality("CAN")` changes the `nationality` attribute of `jim`
 - We use a dot to invoke any of its **accessor methods**, in order to *use* the result of some computation on its attribute values.
e.g., `jim.getBMI()` computes and returns the BMI calculated based on jim's weight and height
 - Return value of an *accessor method* must be stored in a variable.
e.g., `double jimBMI = jim.getBMI()`

The `this` Reference (1)

- Each *class* may be instantiated to multiple *objects* at runtime.

```
public class Point {  
    private double x; private double y;  
    public void moveUp(double units) { y += units; }  
}
```

- Each time when we call a method of some class, using the dot notation, there is a specific *target/context* object.

```
1 Point p1 = new Point(2, 3);  
2 Point p2 = new Point(4, 6);  
3 p1.moveUp(3.5);  
4 p2.moveUp(4.7);
```

- `p1` and `p2` are called the *call targets* or *context objects*.
- **Lines 3 and 4** apply the same definition of the `moveUp` method.
- But how does Java distinguish the change to `p1.y` versus the change to `p2.y`?

The `this` Reference (2)

- In the *method* definition, each *attribute* has an *implicit* `this` which refers to the **context object** in a call to that method.

```
public class Point {
    private double x;
    private double y;
    public Point(double newX, double newY) {
        this.x = newX;
        this.y = newY;
    }
    public void moveUp(double units) {
        this.y = this.y + units;
    }
}
```

- Each time when the *class* definition is used to create a new `Point` *object*, the `this` reference is substituted by the name of the new object.

The this Reference (3)

- After we create `p1` as an instance of `Point`

```
Point p1 = new Point(2, 3);
```

- When invoking `p1.moveUp(3.5)`, a version of `moveUp` that is specific to `p1` will be used:

```
public class Point {  
    private double x;  
    private double y;  
    public Point(double newX, double newY) {  
        p1.x = newX;  
        p1.y = newY;  
    }  
    public void moveUp(double units) {  
        p1.y = p1.y + units;  
    }  
}
```

The this Reference (4)

- After we create `p2` as an instance of `Point`

```
Point p2 = new Point(4, 6);
```

- When invoking `p2.moveUp(4.7)`, a version of `moveUp` that is specific to `p2` will be used:

```
public class Point {  
    private double x;  
    private double y;  
    public Point(double newX, double newY) {  
        p2.x = newX;  
        p2.y = newY;  
    }  
    public void moveUp(double units) {  
        p2.y = p2.y + units;  
    }  
}
```

The `this` Reference (5)

The `this` reference can be used to **disambiguate** when the names of *input parameters* clash with the names of *class attributes*.

```
public class Point {
    private double x;
    private double y;
    public Point(double x, double y) {
        this.x = x;
        this.y = y;
    }
    public void setX(double x) {
        this.x = x;
    }
    public void setY(double y) {
        this.y = y;
    }
}
```

The `this` Reference (6.1): Common Error

The following code fragment compiles but is problematic:

```
1 public class Person {
2     private String name;
3     private int age;
4     public Person(String name, int age) {
5         name = name;
6         age = age;
7     }
8     public void setAge(int age) {
9         age = age;
10    }
11 }
```

- Why? [variable **shadowing**]
Target (LHS) of the assignment (L5) refers to parameter `name` (L4).
- Fix?

The `this` Reference (6.2): Common Error

Always remember to use `this` when *input parameter* names clash with *class attribute* names.

```
public class Person {  
    private String name;  
    private int age;  
    public Person(String name, int age) {  
        this.name = name;  
        this.age = age;  
    }  
    public void setAge(int age) {  
        this.age = age;  
    }  
}
```


OOP: Mutator Methods

- These methods *change* values of attributes.
- We call such methods **mutators** (with `void` return type).

```
public class Person {  
    ...  
    public void gainWeight(double units) {  
        this.weight = this.weight + units;  
    }  
}
```

```
public class Point {  
    ...  
    public void moveUp() {  
        this.y = this.y + 1;  
    }  
}
```

OOP: Accessor Methods

- These methods *return* the result of computation based on attribute values.
- We call such methods **accessors** (with non-void return type).

```
public class Person {  
    ...  
    public double getBMI() {  
        double bmi = this.height / (this.weight * this.weight);  
        return bmi;  
    }  
}
```

```
public class Point {  
    ...  
    public double getDistanceFromOrigin() {  
        double dist =  
            Math.sqrt(this.x * this.x + this.y * this.y);  
        return dist;  
    }  
}
```

OOP: Method Calls

```
1 Point p1 = new Point (3, 4);
2 Point p2 = new Point (-4, -3);
3 System.out.println(p1. getDistanceFromOrigin() );
4 System.out.println(p2. getDistanceFromOrigin() );
5 p1. moveUp (1) ;
6 p2. moveUp (1) ;
7 System.out.println(p1. getDistanceFromOrigin() );
8 System.out.println(p2. getDistanceFromOrigin() );
```

- **Lines 1 and 2** create two different instances of `Point`
- **Lines 3 and 4:** invoking the same accessor method on two different instances returns *distinct* values
- **Lines 5 and 6:** invoking the same mutator method on two different instances results in *independent* changes
- **Lines 3 and 7:** invoking the same accessor method on the same instance *may* return *distinct* values, why?

Line 5

OOP: Use of Mutator vs. Accessor Methods

- Calls to **mutator methods** *cannot* be used as values.
 - e.g., `System.out.println(jim.setWeight(78.5));` ×
 - e.g., `double w = jim.setWeight(78.5);` ×
 - e.g., `jim.setWeight(78.5);` ✓
- Calls to **accessor methods** *should* be used as values.
 - e.g., `jim.getBMI();` ×
 - e.g., `System.out.println(jim.getBMI());` ✓
 - e.g., `double w = jim.getBMI();` ✓

OOP: Method Parameters

- **Principle 1:** A **constructor** needs an *input parameter* for every attribute that you wish to initialize.

e.g., `Person(double w, double h)` vs.
`Person(String fName, String lName)`

- **Principle 2:** A **mutator** method needs an *input parameter* for every attribute that you wish to modify.

e.g., `In Point, void moveToXAxis()` vs.
`void moveUpBy(double unit)`

- **Principle 3:** An **accessor method** needs *input parameters* if the attributes alone are not sufficient for the intended computation to complete.

e.g., `In Point, double getDistFromOrigin()` vs.
`double getDistFrom(Point other)`

OOP: Reference Aliasing (1)

```
1 int i = 3;
2 int j = i; System.out.println(i == j); /*true*/
3 int k = 3; System.out.println(k == i && k == j); /*true*/
```

- **Line 2** copies the number stored in `i` to `j`.
- After **Line 4**, `i`, `j`, `k` refer to three separate integer placeholder, which happen to store the same value 3.

```
1 Point p1 = new Point(2, 3);
2 Point p2 = p1; System.out.println(p1 == p2); /*true*/
3 Point p3 = new Point(2, 3);
4 System.out.println(p3 == p1 || p3 == p2); /*false*/
5 System.out.println(p3.x == p1.x && p3.y == p1.y); /*true*/
6 System.out.println(p3.x == p2.x && p3.y == p2.y); /*true*/
```

- **Line 2** copies the *address* stored in `p1` to `p2`.
- Both `p1` and `p2` refer to the same object in memory!
- `p3`, whose *contents* are same as `p1` and `p2`, refer to a different object in memory.

OOP: Reference Aliasing (2.1)

Problem: Consider assignments to *primitive* variables:

```
1  int i1 = 1;
2  int i2 = 2;
3  int i3 = 3;
4  int[] numbers1 = {i1, i2, i3};
5  int[] numbers2 = new int[numbers1.length];
6  for(int i = 0; i < numbers1.length; i++) {
7      numbers2[i] = numbers1[i];
8  }
9  numbers1[0] = 4;
10 System.out.println(numbers1[0]);
11 System.out.println(numbers2[0]);
```

OOP: Reference Aliasing (2.2)

Problem: Consider assignments to *reference* variables:

```
1  Person alan = new Person("Alan");
2  Person mark = new Person("Mark");
3  Person tom = new Person("Tom");
4  Person jim = new Person("Jim");
5  Person[] persons1 = {alan, mark, tom};
6  Person[] persons2 = new Person[persons1.length];
7  for(int i = 0; i < persons1.length; i++) {
8      persons2[i] = persons1[i]; }
9  persons1[0].setAge(70);
10 System.out.println(jim.getAge());
11 System.out.println(alan.getAge());
12 System.out.println(persons2[0].getAge());
13 persons1[0] = jim;
14 persons1[0].setAge(75);
15 System.out.println(jim.getAge());
16 System.out.println(alan.getAge());
17 System.out.println(persons2[0].getAge());
```


Java Data Types (1)

A (data) type denotes a set of related *runtime values*.

1. Primitive Types

- o *Integer* Type
 - `int` [set of 32-bit integers]
 - `long` [set of 64-bit integers]
- o *Floating-Point Number* Type
 - `double` [set of 64-bit FP numbers]
- o *Character* Type
 - `char` [set of single characters]
- o *Boolean* Type
 - `boolean` [set of `true` and `false`]

2. Reference Type: *Complex Type with Attributes and Methods*

- o *String* [set of references to character sequences]
- o *Person* [set of references to Person objects]
- o *Point* [set of references to Point objects]
- o *Scanner* [set of references to Scanner objects]

Java Data Types (2)

- A variable that is declared with a *type* but *uninitialized* is implicitly assigned with its **default value**.
 - **Primitive Type**
 - `int i;` [`0` is implicitly assigned to `i`]
 - `double d;` [`0.0` is implicitly assigned to `d`]
 - `boolean b;` [`false` is implicitly assigned to `b`]
 - **Reference Type**
 - `String s;` [`null` is implicitly assigned to `s`]
 - `Person jim;` [`null` is implicitly assigned to `jim`]
 - `Point p1;` [`null` is implicitly assigned to `p1`]
 - `Scanner input;` [`null` is implicitly assigned to `input`]
- You *can* use a primitive variable that is *uninitialized*.
Make sure the **default value** is what you want!
- Calling a method on a *uninitialized* reference variable crashes your program. [`NullPointerException`]
Always initialize reference variables!

Java Data Types (3.1)

- An **attribute** may store the reference to another object.

```
public class Person { private Person spouse; }
```

- Methods may take as **parameters** references to other objects.

```
public class Person {  
    public void marry(Person other) { ... }  
}
```

- **Return values** from methods may be references to objects.

```
public class Point {  
    public void moveUpBy(int i) { y = y + i; }  
    Point movedUpBy(int i) {  
        Point np = new Point(x, y);  
        np.moveUpBy(i);  
        return np;  
    }  
}
```

Java Data Types (3.2.1)

An attribute may be *multi*-valued, *reference*-typed
e.g., of type `Point[]`, storing references to `Point` objects.

```
1 public class PointCollector {
2     private Point[] points; private int nop; /* number of points */
3     public PointCollector() { this.points = new Point[100]; }
4     public void addPoint(double x, double y) {
5         this.points[this.nop] = new Point(x, y); this.nop++; }
6     public Point[] getPointsInQuadrantI() {
7         Point[] ps = new Point[this.nop];
8         int count = 0; /* number of points in Quadrant I */
9         for(int i = 0; i < this.nop; i++) {
10            Point p = this.points[i];
11            if(p.x > 0 && p.y > 0) { ps[count] = p; count++; } }
12        Point[] qlPoints = new Point[count];
13        /* ps contains null if count < nop */
14        for(int i = 0; i < count; i++) { qlPoints[i] = ps[i] }
15        return qlPoints;
16    } }
```

Required Reading: Point and PointCollector

Java Data Types (3.2.2)

```
1 public class PointCollectorTester {
2     public static void main(String[] args) {
3         PointCollector pc = new PointCollector();
4         System.out.println(pc.getNumberOfPoints()); /* 0 */
5         pc.addPoint(3, 4);
6         System.out.println(pc.getNumberOfPoints()); /* 1 */
7         pc.addPoint(-3, 4);
8         System.out.println(pc.getNumberOfPoints()); /* 2 */
9         pc.addPoint(-3, -4);
10        System.out.println(pc.getNumberOfPoints()); /* 3 */
11        pc.addPoint(3, -4);
12        System.out.println(pc.getNumberOfPoints()); /* 4 */
13        Point[] ps = pc.getPointsInQuadrantI();
14        System.out.println(ps.length); /* 1 */
15        System.out.println("(" +
16            ps[0].getX() + ", " + ps[0].getY() + ")"); /* (3, 4) */
17    }
18 }
```

Java Data Types (3.3.1)

An attribute may be of type `ArrayList<Point>`, storing references to `Point` objects.

```
1 class PointCollector {
2     ArrayList<Point> points;
3     PointCollector() { points = new ArrayList<>(); }
4     void addPoint(Point p) {
5         points.add(p); }
6     void addPoint(double x, double y) {
7         points.add(new Point(x, y)); }
8     ArrayList<Point> getPointsInQuadrantI() {
9         ArrayList<Point> q1Points = new ArrayList<>();
10        for(int i = 0; i < points.size(); i++) {
11            Point p = points.get(i);
12            if(p.x > 0 && p.y > 0) { q1Points.add(p); } }
13        return q1Points;
14    } }
```

L8 & L9 may be replaced by:

```
for(Point p : points) { q1Points.add(p); }
```

Java Data Types (3.3.2)

```
1 class PointCollectorTester {
2     public static void main(String[] args) {
3         PointCollector pc = new PointCollector();
4         System.out.println(pc.points.size()); /* 0 */
5         pc.addPoint(3, 4);
6         System.out.println(pc.points.size()); /* 1 */
7         pc.addPoint(-3, 4);
8         System.out.println(pc.points.size()); /* 2 */
9         pc.addPoint(-3, -4);
10        System.out.println(pc.points.size()); /* 3 */
11        pc.addPoint(3, -4);
12        System.out.println(pc.points.size()); /* 4 */
13        ArrayList<Point> ps = pc.getPointsInQuadrantI();
14        System.out.println(ps.length); /* 1 */
15        System.out.println("(" + ps[0].x + ", " + ps[0].y + ")");
16        /* (3, 4) */
17    }
18 }
```

Anonymous Objects (1)

- What's the difference between these two fragments of code?

```

1 double square(double x) {
2     double sqr = x * x;
3     return sqr; }
  
```

```

1 double square(double x) {
2     return x * x; }
  
```

After **L2**, the result of $x * x$:

- LHS: it can be reused (without recalculating) via the name `sqr`.
 - RHS: it is not stored anywhere and returned right away.
- Same principles applies to objects:

```

1 Person getP(String n) {
2     Person p = new Person(n);
3     return p; }
  
```

```

1 Person getP(String n) {
2     return new Person(n); }
  
```

`new Person(n)` is an object whose address is not stored in a variable.

- LHS: **L2** stores the address of this anonymous object in `p`.
- RHS: **L2** returns the address of this anonymous object directly.

Anonymous Objects (2.1)

Anonymous objects can also be used as *assignment sources* or *argument values*:

```
class Member {
    private Order[] orders;
    private int noo;
    /* constructor omitted */
    public void addOrder(Order o) {
        this.orders[this.noo] = o;
        this.noo++;
    }
    public void addOrder(String n, double p, double q) {
        this.addOrder(new Order(n, p, q));
        /* Equivalent implementation:
        * this.orders[this.noo] = new Order(n, p, q); noo ++;
        */
    }
}
```

Anonymous Objects (2.2)

One more example on using anonymous objects:

```
public class MemberTester {  
    public static void main(String[] args) {  
        Member m = new Member("Alan");  
        Order o = new Order("Americano", 4.7, 3);  
        m.addOrder(o);  
        m.addOrder(new Order("Cafe Latte", 5.1, 4));  
    }  
}
```

The `this` Reference (7.1): Exercise

Consider the `Person` class

```
public class Person {  
    private String name;  
    private Person spouse;  
    public Person(String name) {  
        this.name = name;  
    }  
}
```

How do you implement a mutator method `marry` which marries the current `Person` object to an input `Person` object?

The `this` Reference (7.2): Exercise

```
public void marry(Person other) {  
    if(this.spouse != null || other.spouse != null) {  
        /* Error: both must be single */  
    }  
    else { this.spouse = other; other.spouse = this; }  
}
```

When we call `jim.marry(elsa)`: `this` is substituted by the **context object** `jim`, and `other` by the **argument** `elsa`.

```
public void marry(Person other elsa) {  
    ...  
    jim.spouse = elsa;  
    elsa.spouse = jim;  
    ...  
}
```

OOP: The Dot Notation (2)

- LHS of dot *can be more complicated than a variable* :
 - It can be a *path* that brings you to an object

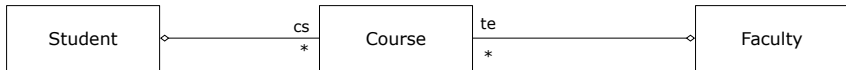
```
public class Person {
    private String name; /* public accessor: name() */
    private Person spouse; /* public accessor: spouse() */
}
```

- Say we have `Person jim = new Person("Jim Davies")`
- Inquire about jim's name? `[jim.name()]`
- Inquire about jim's spouse's name? `[jim.spouse().name()]`
- But what if jim is single (i.e., `jim.spouse() == null`)?
 Calling `jim.spouse().name()` will cause *NullPointerException!!*
- **Question.** Assuming that:
 - jim is not single. `[jim.spouse() != null]`
 - The marriage is mutual. `[jim.spouse().spouse() != null]`
 What does `jim.spouse().spouse().name()` mean?

Answer. `jim.name()`

OOP: The Dot Notation (3.1)

In real life, the relationships among classes are sophisticated.



```

class Student {
    String id;
    Course[] cs;
}
  
```

```

class Course {
    String title;
    Faculty prof;
}
  
```

```

class Faculty {
    String name;
    Course[] te;
}
  
```

- Assume: All attributes are **private** with the corresponding **public** accessor methods.
- In the context of class `Student`:
 - Writing **cs** denotes the array of registered courses.
 - Writing **cs[i]** (where *i* is a valid index) navigates to the class `Course`, which changes the context to class `Course`.

OOP: The Dot Notation (3.2)

```
class Student {  
    String id;  
    Course[] cs;  
}
```

```
class Course {  
    String title;  
    Faculty prof;  
}
```

```
class Faculty {  
    String name;  
    Course[] te;  
}
```

```
class Student {  
    ... /* attributes */  
    /* Get the student's id */  
    String getID() { return this.id; }  
    /* Get the title of the ith course */  
    String getTitle(int i) {  
        return this.cs[i].getTitle();  
    }  
    /* Get the instructor's name of the ith course */  
    String getName(int i) {  
        return this.cs[i].getProf.getName();  
    }  
}
```

OOP: The Dot Notation (3.3)

```
class Student {  
    String id;  
    Course[] cs;  
}
```

```
class Course {  
    String title;  
    Faculty prof;  
}
```

```
class Faculty {  
    String name;  
    Course[] te;  
}
```

```
class Course {  
    ... /* attributes */  
    /* Get the course's title */  
    String getTitle() { return this.title; }  
    /* Get the instructor's name */  
    String getName() {  
        return this.prof.getName();  
    }  
    /* Get title of ith teaching course of the instructor */  
    String getTitle(int i) {  
        return this.prof.getTE()[i].getTitle();  
    }  
}
```


OOP: The Dot Notation (3.4)

```
class Student {  
    String id;  
    Course[] cs;  
}
```

```
class Course {  
    String title;  
    Faculty prof;  
}
```

```
class Faculty {  
    String name;  
    Course[] te;  
}
```

```
class Faculty {  
    ... /* attributes */  
    /* Get the instructor's name */  
    String getName() {  
        return this.name;  
    }  
    /* Get the title of ith teaching course */  
    String getTitle(int i) {  
        return this.te[i].getTitle();  
    }  
}
```

OOP: Equality (1)

```
Point p1 = new Point(2, 3);  
Point p2 = new Point(2, 3);  
boolean sameLoc = ( p1 == p2 );  
System.out.println("p1 and p2 same location?" + sameLoc);
```

```
p1 and p2 same location? false
```

OOP: Equality (2)

- Recall that
 - A **primitive** variable stores a primitive *value*
e.g., `double d1 = 7.5; double d2 = 7.5;`
 - A **reference** variable stores the *address* to some object (rather than storing the object itself)
e.g., `Point p1 = new Point(2, 3)` assigns to `p1` the address of the new `Point` object
e.g., `Point p2 = new Point(2, 3)` assigns to `p2` the address of *another* new `Point` object
- The binary operator `==` may be applied to compare:
 - **Primitive** variables: their *contents* are compared
e.g., `d1 == d2` evaluates to *true*
 - **Reference** variables: the *addresses* they store are compared (rather than comparing contents of the objects they refer to)
e.g., `p1 == p2` evaluates to *false* because `p1` and `p2` are addresses of *different* objects, even if their contents are *identical*.

Static Variables (1)

```
public class Account {  
    private int id;  
    private String owner;  
    public int getID() { return this.id; }  
    public Account(int id, String owner) {  
        this.id = id;  
        this.owner = owner;  
    }  
}
```

```
class AccountTester {  
    Account acc1 = new Account(1, "Jim");  
    Account acc2 = new Account(2, "Jeremy");  
    System.out.println(acc1.getID() != acc2.getID());  
}
```

But, managing the unique id's *manually* is **error-prone**!

Static Variables (2)

```
class Account {  
    private static int globalCounter = 1;  
    private int id; String owner;  
    public Account(String owner) {  
        this.id = globalCounter;  
        globalCounter++;  
        this.owner = owner; } }  
}
```

```
class AccountTester {  
    Account acc1 = new Account("Jim");  
    Account acc2 = new Account("Jeremy");  
    System.out.println(acc1.getID() != acc2.getID()); }  
}
```

- Each instance of a class (e.g., acc1, acc2) has a *local* copy of each attribute or instance variable (e.g., id).
 - Changing acc1.id does not affect acc2.id.
- A **static** variable (e.g., globalCounter) belongs to the class.
 - All instances of the class share a *single* copy of the **static** variable.
 - Change to globalCounter via acc1 is also visible to acc2.

Static Variables (3)

```
public class Account {  
    private static int globalCounter = 1;  
    private int id; private String owner;  
    public Account(String owner) {  
        this.id = globalCounter;  
        globalCounter ++;  
        this.owner = owner;  
    }  
}
```

- **Static** variable `globalCounter` is not instance-specific like **instance** variable (i.e., attribute) `id` is.
- To access a **static** variable:
 - **No** context object is needed.
 - Use of the class name suffices, e.g., `Account.globalCounter`.
- Each time `Account`'s constructor is called to create a new instance, the increment effect is **visible to all existing objects** of `Account`.

Static Variables (4.1): Common Error

```
public class Client {  
    private Account[] accounts;  
    private static int numberOfAccounts = 0;  
    public void addAccount(Account acc) {  
        accounts[this.numberOfAccounts] = acc;  
        this.numberOfAccounts ++;  
    }  
}
```

```
public class ClientTester {  
    Client bill = new Client("Bill");  
    Client steve = new Client("Steve");  
    Account acc1 = new Account();  
    Account acc2 = new Account();  
    bill.addAccount(acc1);  
    /* correctly added to bill.getAccounts()[0] */  
    steve.addAccount(acc2);  
    /* mistakenly added to steve.getAccounts()[1]! */  
}
```

Static Variables (4.2): Common Error

- Attribute `numberOfAccounts` should **not** be declared as `static` as its value should be specific to the client object.
- If it were declared as `static`, then every time the `addAccount` method is called, although on different objects, the increment effect of `numberOfAccounts` will be visible to all `Client` objects.
- Here is the correct version:

```
public class Client {  
    private Account[] accounts;  
    private int numberOfAccounts;  
    public void addAccount(Account acc) {  
        accounts[this.numberOfAccounts] = acc;  
        this.numberOfAccounts ++;  
    }  
}
```


Static Variables (5.1): Common Error

```
1 public class Bank {  
2     private string branchName;  
3     public String getBrachName() { return this.branchName; }  
4     private static int nextAccountNumber = 0;  
5     public static String getInfo() {  
6         nextAccountNumber++;  
7         return this.branchName + nextAccountNumber;  
8     }  
9 }
```

- *Non-static method cannot be referenced from a static context*
- **Line 4** declares that we **can** call the method `getInfo` without instantiating an object of the class `Bank`.
- However, in **Line 7**, the *static* method references a *non-static* attribute, for which we **must** instantiate a `Bank` object.

Static Variables (5.2): Common Error

```
1 public class Bank {  
2     private String branchName;  
3     public String getBrachName() { return this.branchName; }  
4     private static int nextAccountNumber = 0;  
5     public static String getInfo() {  
6         nextAccountNumber++;  
7         return this.branchName + nextAccountNumber;  
8     }  
9 }
```

- To call `getInfo()`, no instances of `Bank` are required:

```
Bank.getInfo();
```

- **Contradictorily**, to access `branchName`, a *context object* is required:

```
Bank b = new Bank(); b.setBranch("Songdo IBK");  
System.out.println(b.getBranchName());
```

Static Variables (5.3): Common Error

There are two possible ways to fix:

1. Remove all uses of *non-static* variables (i.e., `branchName`) in the *static* method (i.e., `useAccountNumber`).
2. Declare `branchName` as a *static* variable.
 - This does not make sense.
 - ∴ `branchName` should be a value specific to each `Bank` instance.

OOP: Helper Methods (1)

- After you complete and test your program, feeling confident that it is *correct*, you may find that there are lots of *repetitions*.
- When similar fragments of code appear in your program, we say that your code “*smells*”!
- We may eliminate *repetitions* of your code by:
 - **Factoring out** recurring code fragments into a new method.
 - This new method is called a **helper method** :
 - You can replace every occurrence of the recurring code fragment by a **call** to this helper method, with appropriate argument values.
 - That is, we **reuse** the body implementation, rather than repeating it over and over again, of this helper method via calls to it.
- This process is called **refactoring** of your code:
Modify the code structure **without** compromising *correctness*.

OOP: Helper (Accessor) Methods (2.1)

```
public class PersonCollector {
    private Person[] ps;
    private final int MAX = 100; /* max # of persons to store */
    private int nop; /* number of persons */
    public PersonCollector() {
        this.ps = new Person[MAX];
    }
    public void addPerson(Person p) {
        this.ps[this.nop] = p;
        this.nop++;
    }
    /* Tasks:
     * 1. An accessor: boolean personExists(String n)
     * 2. A mutator: void changeWeightOf(String n, double w)
     * 3. A mutator: void changeHeightOf(String n, double h)
     */
}
```

OOP: Helper (Accessor) Methods (2.2.1)

```
public class PersonCollector {
    /* ps, MAX, nop, PersonCollector(), addPerson */
    public boolean personExists(String n) {
        boolean found = false;
        for(int i = 0; i < nop; i++) {
            if(ps[i].getName().equals(n)) { found = true; } }
        return found;
    }
    public void changeWeightOf(String n, double w) {
        for(int i = 0; i < nop; i++) {
            if(ps[i].getName().equals(n)) { ps[i].setWeight(w); } }
    }
    public void changeHeightOf(String n, double h) {
        for(int i = 0; i < nop; i++) {
            if(ps[i].getName().equals(n)) { ps[i].setHeight(h); } }
    }
}
```

OOP: Helper (Accessor) Methods (2.2.2)

```
public class PersonCollector {/* code smells:repetitions! */
    /* ps, MAX, nop, PersonCollector(), addPerson */
    public boolean personExists(String n) {
        boolean found = false;
        for(int i = 0; i < nop; i++) {
            if(ps[i].getName().equals(n)) { found = true; } }
        return found;
    }
    public void changeWeightOf(String n, double w) {
        for(int i = 0; i < nop; i++) {
            if(ps[i].getName().equals(n)) { ps[i].setWeight(w); } }
    }
    public void changeHeightOf(String n, double h) {
        for(int i = 0; i < nop; i++) {
            if(ps[i].getName().equals(n)) { ps[i].setHeight(h); } }
    }
}
```

OOP: Helper (Accessor) Methods (2.3)

```
public class PersonCollector { /* Code Smell Eliminated */
    /* ps, MAX, nop, PersonCollector(), addPerson */
    private int indexOf(String n) { /* Helper Methods */
        int i = -1;
        for(int j = 0; j < nop; j++) {
            if(ps[j].getName().equals(n)) { i = j; }
        }
        return i; /* -1 if not found; >= 0 if found. */
    }
    public boolean personExists(String n) {
        return this.indexOf(n) >= 0; }
    public void changeWeightOf(String n, double w) {
        int i = indexOf(n); if(i >= 0) { ps[i].setWeight(w); }
    }
    public void changeHeightOf(String n, double h) {
        int i = indexOf(n); if(i >= 0) { ps[i].setHeight(h); }
    }
}
```


OOP: Helper (Accessor) Methods (3.1)

Problems:

- A `Point` class with `x` and `y` coordinate values.
- Accessor `double getDistanceFromOrigin()`.
`p.getDistanceFromOrigin()` returns the distance between `p` and `(0, 0)`.
- Accessor `double getDistancesTo(Point p1, Point p2)`.
`p.getDistancesTo(p1, p2)` returns the sum of distances between `p` and `p1`, and between `p` and `p2`.
- Accessor `double getTriDistances(Point p1, Point p2)`.
`p.getDistancesTo(p1, p2)` returns the sum of distances between `p` and `p1`, between `p` and `p2`, and between `p1` and `p2`.

OOP: Helper (Accessor) Methods (3.2)

```
class Point { /* code smells:repetitions! */
    double x; double y;

    double getDistanceFromOrigin() {
        return Math.sqrt(Math.pow(this.x - 0, 2) + Math.pow(this.y - 0, 2));
    }

    double getDistancesTo(Point p1, Point p2) {
        return
            Math.sqrt(Math.pow(this.x - p1.x, 2) + Math.pow(y - p1.y, 2))
            +
            Math.sqrt(Math.pow(this.x - p2.x, 2) + Math.pow(y - p2.y, 2));
    }

    double getTriDistances(Point p1, Point p2) {
        return
            Math.sqrt(Math.pow(this.x - p1.x, 2) + Math.pow(y - p1.y, 2))
            +
            Math.sqrt(Math.pow(this.x - p2.x, 2) + Math.pow(y - p2.y, 2))
            +
            Math.sqrt(Math.pow(p1.x - p2.x, 2) + Math.pow(p1.y - p2.y, 2));
    }
}
```

OOP: Helper (Accessor) Methods (3.3)

- The code pattern

```
Math.sqrt(Math.pow(... - ..., 2) + Math.pow(... - ..., 2))
```

is written down explicitly every time we need to use it.

- Create a **helper method** out of it, with the right *parameter* and *return* types:

```
double getDistanceFrom(double otherX, double otherY) {  
    return Math.sqrt(  
        Math.pow(otherX - this.x, 2)  
        +  
        Math.pow(otherY - this.y, 2));  
}
```

OOP: Helper (Accessor) Methods (3.4)

```
public class Point { /* Code Smell Eliminated */
    private double x; private double y;
    double getDistanceFrom(double otherX, double otherY) {
        return Math.sqrt(Math.pow(otherX - this.x, 2) +
            Math.pow(otherY - this.y, 2));
    }
    double getDistanceFromOrigin() {
        return this.getDistanceFrom(0, 0);
    }
    double getDistancesTo(Point p1, Point p2) {
        return this.getDistanceFrom(p1.x, p1.y) +
            this.getDistanceFrom(p2.x, p2.y);
    }
    double getTriDistances(Point p1, Point p2) {
        return this.getDistanceFrom(p1.x, p1.y) +
            this.getDistanceFrom(p2.x, p2.y) +
            p1.getDistanceFrom(p2.x, p2.y)
    }
}
```

OOP: Helper (Mutator) Methods (4.1)

```
public class Student {
    private String name;
    private double balance;
    public Student(String n, double b) {
        name = n;
        balance = b;
    }

    /* Tasks:
     * 1. A mutator void receiveScholarship(double val)
     * 2. A mutator void payLibraryOverdue(double val)
     * 3. A mutator void payCafeCoupons(double val)
     * 4. A mutator void transfer(Student other, double val)
     */
}
```

OOP: Helper (Mutator) Methods (4.2.1)

```
public class Student {  
    /* name, balance, Student(String n, double b) */  
    public void receiveScholarship(double val) {  
        balance = balance + val;  
    }  
    public void payLibraryOverdue(double val) {  
        balance = balance - val;  
    }  
    public void payCafeCoupons(double val) {  
        balance = balance - val;  
    }  
    public void transfer(Student other, double val) {  
        balance = balance - val;  
        other.balance = other.balance + val;  
    }  
}
```

OOP: Helper (Mutator) Methods (4.2.2)

```
public class Student { /* code smells:repetitions! */
    /* name, balance, Student(String n, double b) */
    public void receiveScholarship(double val) {
        balance = balance + val;
    }
    public void payLibraryOverdue(double val) {
        balance = balance - val;
    }
    public void payCafeCoupons(double val) {
        balance = balance - val;
    }
    public void transfer(Student other, double val) {
        balance = balance - val;
        balance = other.balance + val;
    }
}
```

OOP: Helper (Mutator) Methods (4.3)

```
public class Student { /* Code Smell Eliminated */
    /* name, balance, Student(String n, double b) */
    public void deposit(double val) { /* Helper Method */
        balance = balance + val;
    }
    public void withdraw(double val) { /* Helper Method */
        balance = balance - val;
    }
    public void receiveScholarship(double val) { this.deposit(val); }
    public void payLibraryOverdue(double val) { this.withdraw(val); }
    public void payCafeCoupons(double val) { this.withdraw(val); }
    public void transfer(Student other, double val) {
        this.withdraw(val);
        other.deposit(val);
    }
}
```


Index (1)

Assumptions

Learning Outcomes

Where are we? Where will we go?

Object Orientation:

Observe, Model, and Execute

Object-Oriented Programming (OOP)

OO Thinking: Templates vs. Instances (1.1)

OO Thinking: Templates vs. Instances (1.2)

OO Thinking: Templates vs. Instances (2.1)

OO Thinking: Templates vs. Instances (2.2)

OOP: Classes \approx Templates

Index (2)

OOP: Methods (1.1)

OOP: Methods (1.2)

OOP: Methods (2)

OOP: Methods (3)

OOP: Class Constructors (1.1)

OOP: Class Constructors (1.2)

OOP: Class Constructors (2.1)

OOP: Class Constructors (2.2)

Visualizing Objects at Runtime (1)

Visualizing Objects at Runtime (2.1)

Visualizing Objects at Runtime (2.2)

Index (3)

Visualizing Objects at Runtime (2.3)

Visualizing Objects at Runtime (2.4)

Object Creation (1.1)

Object Creation (1.2)

Object Creation (2)

OOP: Object Creation (3.1.1)

OOP: Object Creation (3.1.2)

OOP: Object Creation (3.2.1)

OOP: Object Creation (3.2.2)

OOP: Object Creation (4)

OOP: The Dot Notation (1)

Index (4)

The `this` Reference (1)

The `this` Reference (2)

The `this` Reference (3)

The `this` Reference (4)

The `this` Reference (5)

The `this` Reference (6.1): Common Error

The `this` Reference (6.2): Common Error

OOP: Mutator Methods

OOP: Accessor Methods

OOP: Method Calls

OOP: Use of Mutator vs. Accessor Methods

Index (5)

OOP: Method Parameters

OOP: Reference Aliasing (1)

OOP: Reference Aliasing (2.1)

OOP: Reference Aliasing (2.2)

Java Data Types (1)

Java Data Types (2)

Java Data Types (3.1)

Java Data Types (3.2.1)

Java Data Types (3.2.2)

Java Data Types (3.3.1)

Java Data Types (3.3.2)

Index (6)

- Anonymous Objects (1)
- Anonymous Objects (2.1)
- Anonymous Objects (2.2)
- The `this` Reference (7.1): Exercise
- The `this` Reference (7.2): Exercise
- OOP: The Dot Notation (2)
- OOP: The Dot Notation (3.1)
- OOP: The Dot Notation (3.2)
- OOP: The Dot Notation (3.3)
- OOP: The Dot Notation (3.4)
- OOP: Equality (1)

Index (7)

OOP: Equality (2)

Static Variables (1)

Static Variables (2)

Static Variables (3)

Static Variables (4.1): Common Error

Static Variables (4.2): Common Error

Static Variables (5.1): Common Error

Static Variables (5.2): Common Error

Static Variables (5.3): Common Error

OOP: Helper Methods (1)

OOP: Helper (Accessor) Methods (2.1)

Index (8)

OOP: Helper (Accessor) Methods (2.2.1)

OOP: Helper (Accessor) Methods (2.2.2)

OOP: Helper (Accessor) Methods (2.3)

OOP: Helper (Accessor) Methods (3.1)

OOP: Helper (Accessor) Methods (3.2)

OOP: Helper (Accessor) Methods (3.3)

OOP: Helper (Accessor) Methods (3.4)

OOP: Helper (Mutator) Methods (4.1)

OOP: Helper (Mutator) Methods (4.2.1)

OOP: Helper (Mutator) Methods (4.2.2)

OOP: Helper (Mutator) Methods (4.3)