Classes and Objects

EECS1022:
Programming for Mobile Computing
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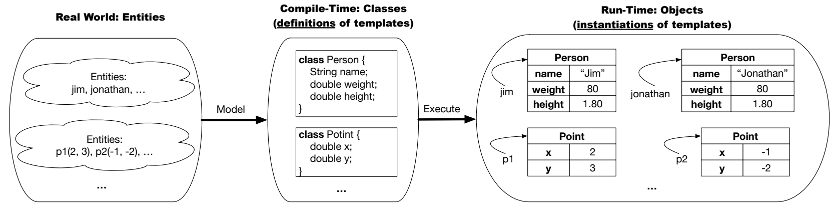
Separation of Concerns: Model vs. Controller/Tester

- So far we have developed:
  - ***Model***: A single Java class (e.g., `Person`).
  - Another Java class that "manipulates" the model class (by creating instances and calling methods):
    - ***Controller*** (e.g., `BMIActivity`): effects seen at connected tablet
    - ***Tester*** (e.g., `PersonTester`): effects seen at console
- In Java:
  - We may define more than one *model 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 *bebaviour*; and
  - Interact with each other.
- Goals: Solve problems *programmatically* by
  - *Classifying* entities of interest
    Entities in the same class share *common* attributes and bebaviour.
  - *Manipulating* data that represent these entities
    Each entity is represented by *specific* values.

OO Thinking: Templates vs. Instances (1.1)

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 (1.2)

- Persons share these common *attributes* and *behaviour*.
  - Each person possesses an age, a weight, and a height.
  - Each person's age, weight, and height might be *distinct*
    e.g., `jim` is 50-years old, 1.8-meters tall and 80-kg heavy
    e.g., `jonathan` is 65-years old, 1.73-meters tall and 90-kg heavy
- Each person, depending on the *specific values* of their attributes, might 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 $[\frac{80}{1.8^2}]$
  - `jonathan`'s BMI is based on his own height and weight $[\frac{90}{1.73^2}]$

OO Thinking: Templates vs. Instances (2.1)

Points on a two-dimensional plane are identified by their signed distances from the X- and Y-axises. 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 (2.2)

- Points share these common *attributes* and *behaviour*.
  - Each point possesses an x-coordinate and a y-coordinate.
  - Each point's location might be *distinct*
    e.g., `p1` is located at $(3, 4)$
    e.g., `p2` is located at $(-4, -3)$
- Each point, depending on the *specific values* of their attributes (i.e., locations), might 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 (3)

- A *template* defines what's **shared** by a set of related entities.
  - Common *attributes* (`age` in `Person`, `x` in `Point`)
  - Common *behaviour* (get older for `Person`, move up for `Point`)
- Each template may be *instantiated* into multiple instances.
  - `Person` instances: `jim` and `jonathan`
  - `Point` instances: `p1` and `p2`
- Each *instance* may have *specific values* for the attributes.
  - Each `Person` instance has an age: `jim` is 50-years old, `jonathan` is 65-years old
  - Each `Point` instance has a location: `p1` is at $(3, 4)$, `p2` is at $(-3, -4)$
- Therefore, instances of the same template may exhibit *distinct behaviour*.
  - Each `Person` instance can get older: `jim` getting older from 50 to 51; `jonathan` getting older from 65 to 66.
  - Each `Point` instance can move up: `p1` moving up from $(3, 3)$ results in $(3, 4)$; `p1` moving up from $(-3, -4)$ results in $(-3, -3)$.

OOP: Classes ≈ 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 {
  int age;
  String nationality;
  double weight;
  double height;
}
```

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


OOP: Define Constructors for Creating Objects (1.1)

- Within class `Point`, you define *constructors*, specifying how instances of the `Point` template may be created.

```
public class Point {
 ... /* attributes: x, y */
 Point(double newX, double newY) {
   x = newX;
   y = newY; } }
```

- In the corresponding tester class, each *call* to the `Point` constructor creates an instance of the `Point` template.

```
public class PointTester {
 public static void main(String[] args) {
   Point p1 = new Point(2, 4);
   println(p1.x + " " + p1.y);
   Point p2 = new Point(-4, -3);
   println(p2.x + " " + p2.y); } }
```

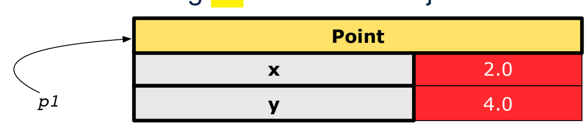

OOP: Define Constructors for Creating Objects (1.2)

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

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

Point	
x	2.0
y	4.0

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



OOP: Define Constructors for Creating Objects (2.1)

- Within class `Person`, you define *constructors*, specifying how instances of the `Person` template may be created.

```
public class Person {
 ... /* attributes: age, nationality, weight, height */
 Person(int newAge, String newNationality) {
   age = newAge;
   nationality = newNationality; } }
```

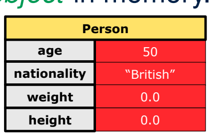
- In the corresponding tester class, each *call* to the `Person` constructor creates an instance of the `Person` template.

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

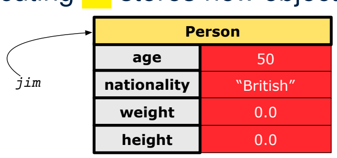

OOP: Define Constructors for Creating Objects (2.2)

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

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



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



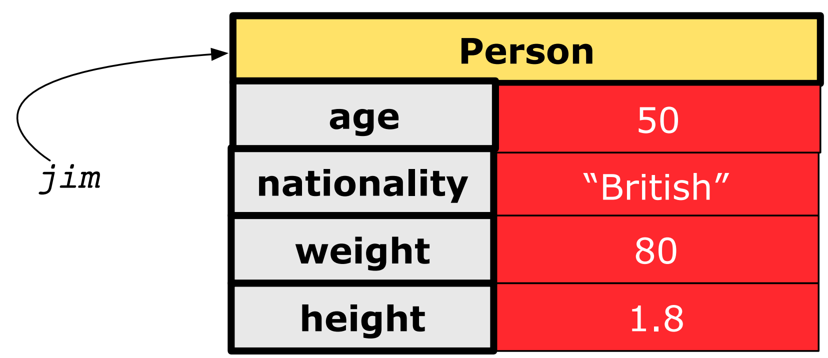
Visualizing Objects at Runtime (1)

- 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);
```

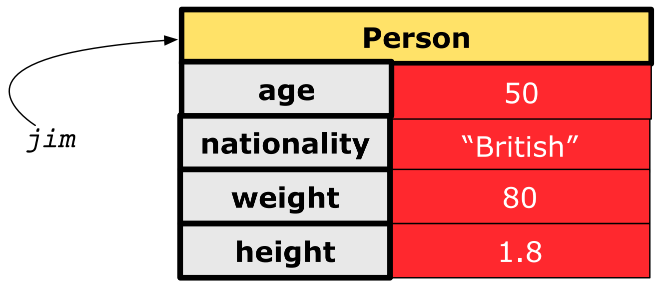


Visualizing Objects at Runtime (2.2)

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

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

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



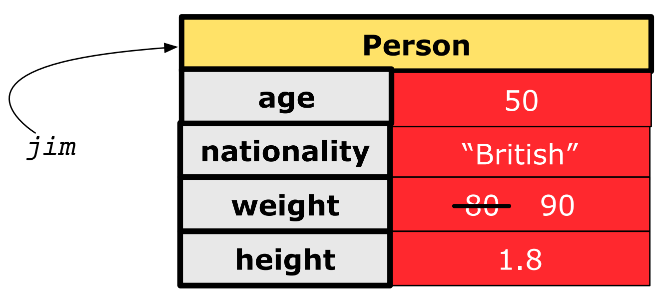
Visualizing Objects at Runtime (2.3)

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!

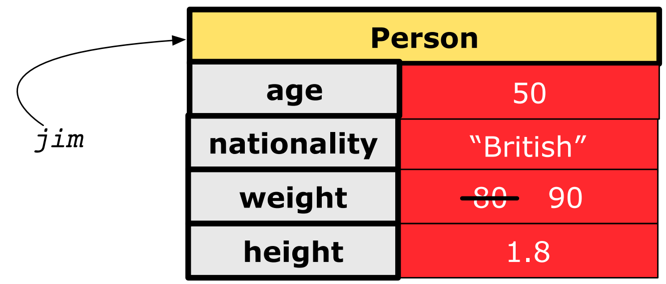


Visualizing Objects at Runtime (2.4)

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

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

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



The `this` Reference (1)

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

```
class Point {
  double x; double y;
  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.

```
class Point {
  double x;
  double y;
  Point(double newX, double newY) {
    this.x = newX;
    this.y = newY;
  }
  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:

```
class Point {
  double x;
  double y;
  Point(double newX, double newY) {
    p1.x = newX;
    p1.y = newY;
  }
  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:

```
class Point {
  double x;
  double y;
  Point(double newX, double newY) {
    p2.x = newX;
    p2.y = newY;
  }
  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*.

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

The `this` Reference (6.1): Common Error

The following code fragment compiles but is problematic:

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

Why? Fix?

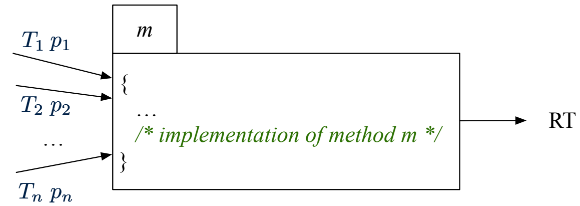
The `this` Reference (6.2): Common Error

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

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


OOP: Methods (1.1)

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



- The *Signature* of a method consists of:
  - Return type [RT (which can be `void`)]
  - Name of method [m]
  - Zero or more *parameter names* [$p_1, p_2, \ldots, p_n$]
  - The corresponding *parameter types* [$T_1, T_2, \ldots, T_n$]
- A call to method m has the form: $m(a_1, a_2, \ldots, a_n)$
  Types of *argument values* $a_1, a_2, \ldots, a_n$ must match the the corresponding parameter types $T_1, T_2, \ldots, T_n$.

OOP: Methods (1.2)

- In the body of the method, you may
  - Declare and use new *local variables*
    Scope of local variables is only within that method.
  - Use or change values of *attributes*.
  - Use values of *parameters*, if any.

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

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

```
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(...)`:
  - `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(p1.getDistanceFromOrigin());`

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()`

OOP: Method Calls

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

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


OOP: Class Constructors (3)

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

  Point(double initX, double initY) {
    x = initX;
    y = initY;
  }

  Point(char axis, double distance) {
    if (axis == 'x') { x = distance; }
    else if (axis == 'y') { y = distance; }
    else { System.out.println("Error: invalid axis.") }
  }
}
```


OOP: Class Constructors (4)

- 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.
  - Each constructor must have a *distinct* list of *input parameter types*.
  - 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: Object Creation (1)

```
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.x + ", " + p1.y + ")");
```

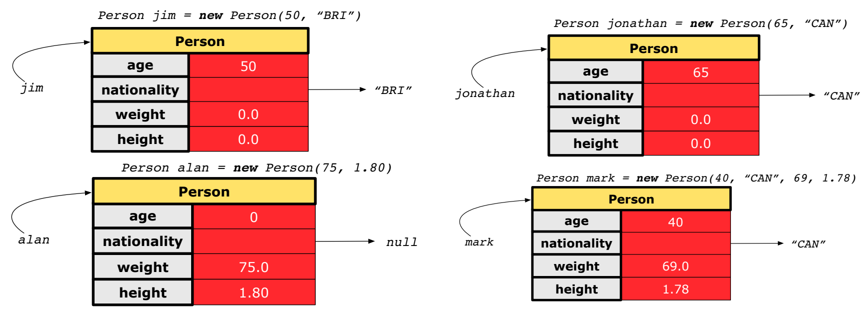
```
(2.0, 4.0)
```


OOP: Object Creation (2)

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)

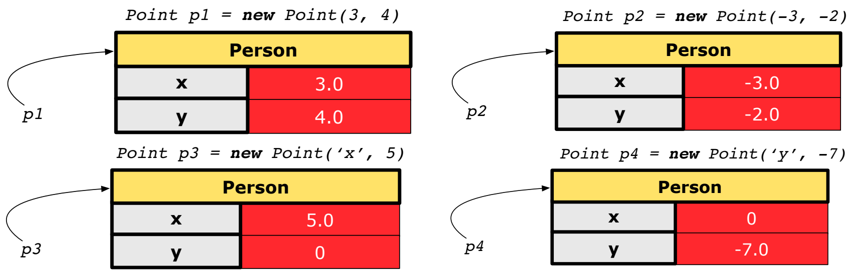


OOP: Object Creation (4)

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 (5)



OOP: Object Creation (6)

- 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: Mutator Methods

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

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

```
public class Point {
  ...
  void moveUp() {
    y = 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 {
  ...
  double getBMI() {
    double bmi = height / (weight * weight);
    return bmi;
  }
}
```

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

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: Object Alias (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 Systme.out.println(p3 == p1 || p3 == p2);  /* false */
5 Systme.out.println(p3.x == p1.x && p3.y == p1.y);  /* true */
6 Systme.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.

OO Program Programming: Object Alias (2.1)

Problem: Consider assignments to *primitive* variables:

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

OO Program Programming: Object Alias (2.2)

Problem: Consider assignments to *reference* variables:

```
Person alan = new Person("Alan");
Person mark = new Person("Mark");
Person tom = new Person("Tom");
Person jim = new Person("Jim");
Person[] persons1 = {alan, mark, tom};
Person[] persons2 = new Person[persons1.length];
for(int i = 0; i < persons1.length; i ++) {
  persons2[i] = persons1[i]; }
persons1[0].setAge(70);
System.out.println(jim.age);
System.out.println(alan.age);
System.out.println(persons2[0].age);
persons1[0] = jim;
persons1[0].setAge(75);
System.out.println(jim.age);
System.out.println(alan.age);
System.out.println(persons2[0].age);
```


Java Data Types (1)

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

1. *Primitive Types*
   - *Integer* Type
     - `int` [set of 32-bit integers]
     - `long` [set of 64-bit integers]
   - *Floating-Point Number* Type
     - `double` [set of 64-bit FP numbers]
   - *Character* Type
     - `char` [set of single characters]
   - *Boolean* Type
     - `boolean` [set of `true` and `false`]
2. *Reference Type* : *Complex Type with Attributes and Methods*
   - *String* [set of references to character sequences]
   - *Person* [set of references to Person objects]
   - *Point* [set of references to Point objects]
   - *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 some object.

```
class Person { Person spouse; }
```

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

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

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

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

Java Data Types (3.2.1)

An attribute may be of type `Point[]`, storing references to `Point` objects.

```
class PointCollector {
 Point[] points; int nop; /* number of points */
 PointCollector() { points = new Point[100]; }
 void addPoint(double x, double y) {
  points[nop] = new Point(x, y); nop++; }
 Point[] getPointsInQuadrantI() {
  Point[] ps = new Point[nop];
  int count = 0; /* number of points in Quadrant I */
  for(int i = 0; i < nop; i ++) {
   Point p = points[i];
   if(p.x > 0 && p.y > 0) { ps[count] = p; count ++; } }
  Point[] q1Points = new Point[count];
  /* ps contains null if count < nop */
  for(int i = 0; i < count; i ++) { q1Points[i] = ps[i] }
  return q1Points ;
 } }
```

Required Reading: Point and PointCollector

Java Data Types (3.2.2)

```
class PointCollectorTester {
 public static void main(String[] args) {
  PointCollector pc = new PointCollector();
  System.out.println(pc.nop);  /* 0 */
  pc.addPoint(3, 4);
  System.out.println(pc.nop);  /* 1 */
  pc.addPoint(-3, 4);
  System.out.println(pc.nop);  /* 2 */
  pc.addPoint(-3, -4);
  System.out.println(pc.nop);  /* 3 */
  pc.addPoint(3, -4);
  System.out.println(pc.nop);  /* 4 */
  Point[] ps = pc.getPointsInQuadrantI();
  System.out.println(ps.length);  /* 1 */
  System.out.println("(" + ps[0].x + ", " + ps[0].y + ")");
  /* (3, 4) */
 }
}
```


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)

```
class PointCollectorTester {
 public static void main(String[] args) {
  PointCollector pc = new PointCollector();
  System.out.println(pc.points.size());  /* 0 */
  pc.addPoint(3, 4);
  System.out.println(pc.points.size());  /* 1 */
  pc.addPoint(-3, 4);
  System.out.println(pc.points.size());  /* 2 */
  pc.addPoint(-3, -4);
  System.out.println(pc.points.size());  /* 3 */
  pc.addPoint(3, -4);
  System.out.println(pc.points.size());  /* 4 */
  ArrayList<Point> ps = pc.getPointsInQuadrantI();
  System.out.println(ps.length);  /* 1 */
  System.out.println("(" + ps[0].x + ", " + ps[0].y + ")");
  /* (3, 4) */
 }
}
```

The `this` Reference (7.1): Exercise

Consider the `Person` class

```
class Person {
  String name;
  Person spouse;
  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

```
void marry(Person other) {
  if(this.spouse != null || other.spouse != null) {
    System.out.println("Error: both must be single.");
  }
  else { this.spouse = other; other.spouse = this; }
}
```

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

```
void marry(Person other) {
  ...
   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

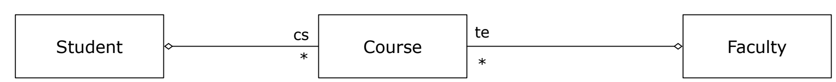
```
class Person {
  String name;
  Person spouse;
}
```

  - 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 trigger *NullPointerException*!!
  - Assuming that:
    - `jim` is not single. [`jim.spouse != null`]
    - The marriage is mutual. [`jim.spouse.spouse != null`]

    What does `jim.spouse.spouse.name` mean? [`jim.name`]

OOP: The Dot Notation (3.1)

In real life, the relationships among classes are sophisticated.




```
class Student {
  String id;
  ArrayList<Course> cs;
}
```

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

```
class Faculty {
  String name;
  ArrayList<Course> te;
}
```

Aggregation links between classes constrain how you can *navigate* among these classes.

e.g., In the context of class `Student`:

- Writing ***`cs`*** denotes the list 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;
  ArrayList<Course> cs;
}
```

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

```
class Faculty {
  String name;
  ArrayList<Course> te;
}
```

```
class Student {
  ... /* attributes */
  /* Get the student's id */
  String getID() { return this.id; }
  /* Get the title of the ith course */
  String getCourseTitle(int i) {
    return this.cs.get(i).title;
  }
  /* Get the instructor's name of the ith course */
  String getInstructorName(int i) {
    return this.cs.get(i).prof.name;
  }
}
```


OOP: The Dot Notation (3.3)

```
class Student {
  String id;
  ArrayList<Course> cs;
}
```

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

```
class Faculty {
  String name;
  ArrayList<Course> te;
}
```

```
class Course {
  ... /* attributes */
  /* Get the course's title */
  String getTitle() { return this.title; }
  /* Get the instructor's name */
  String getInstructorName() {
    return this.prof.name;
  }
  /* Get title of ith teaching course of the instructor */
  String getCourseTitleOfInstructor(int i) {
    return this.prof.te.get(i).title;
  }
}
```


OOP: The Dot Notation (3.4)

```
class Student {
  String id;
  ArrayList<Course> cs;
}
```

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

```
class Faculty {
  String name;
  ArrayList<Course> te;
}
```

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


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)

```
class Account {
  int id;
  String owner;
  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.id != acc2.id);
}
```

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

Static Variables (2)

```
class Account {
  static int globalCounter = 1;
  int id; String owner;
  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.id != acc2.id); }
```

- 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 `c1` is also visible to `c2`.

Static Variables (3)

```
class Account {
  static int globalCounter = 1;
  int id; String owner;
  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

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

```
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.accounts[0] */
  steve.addAccount(acc2);
    /* mistakenly added to steve.accounts[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:

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


Static Variables (5.1): Common Error

```
1 public class Bank {
2    public string branchName;
3    public static int nextAccountNumber = 1;
4    public static void useAccountNumber() {
5       System.out.println (branchName + ...);
6       nextAccountNumber ++;
7    }
8 }
```

- *Non-static method cannot be referenced from a static context*
- **Line 4** declares that we *can* call the method `userAccountNumber` without instantiating an object of the class `Bank`.
- However, in **Lined 5**, 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    public string branchName;
3    public static int nextAccountNumber = 1;
4    public static void useAccountNumber() {
5       System.out.println (branchName + ...);
6       nextAccountNumber ++;
7    }
8 }
```

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

```
Bank.useAccountNumber();
```

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

```
Bank b1 = new Bank(); b1.setBranch("Songdo IBK");
System.out.println(b1.branchName);
```

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)

```
class PersonCollector {
  Person[] ps;
  final int MAX = 100; /* max # of persons to be stored */
  int nop; /* number of persons */
  PersonCollector() {
    ps = new Person[MAX];
  }
  void addPerson(Person p) {
    ps[nop] = p;
    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)

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

OOP: Helper (Accessor) Methods (2.2.2)

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


OOP: Helper (Accessor) Methods (2.3)

```
class PersonCollector { /* Eliminate code smell.  */
  /* ps, MAX, nop, PersonCollector(), addPerson */
  int indexOf (String n) { /* Helper Methods */
    int i = -1;
    for(int j = 0; j < nop; j ++) {
      if(ps[j].name.equals(n)) { i = j; }
    }
    return i; /* -1 if not found; >= 0 if found. */
  }
  boolean personExists(String n) { return indexOf (n) >= 0; }
  void changeWeightOf(String n, double w) {
    int i = indexOf (n); if(i >= 0) { ps[i].setWeight(w); }
  }
  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 {
  double x; double y;
  double getDistanceFromOrigin() {
    return Math.sqrt(Math.pow(x - 0, 2) + Math.pow(y - 0, 2)); }
  double getDistancesTo(Point p1, Point p2) {
    return
    Math.sqrt(Math.pow(x - p1.x, 2) + Math.pow(y - p1.y, 2))
    +
    Math.sqrt(Math.pow(x - p2.x, 2), Math.pow(y - p2.y, 2)); }
  double getTriDistances(Point p1, Point p2) {
    return
    Math.sqrt(Math.pow(x - p1.x, 2) + Math.pow(y - p1.y, 2))
    +
    Math.sqrt(Math.pow(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(ohterX - this.x, 2)
     +
     Math.pow(otherY - this.y, 2));
}
```


OOP: Helper (Accessor) Methods (3.4)

```
class Point {
  double x; double y;
  double getDistanceFrom(double otherX, double otherY) {
    return Math.sqrt(Math.pow(ohterX - 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)

```
class Student {
  String name;
  double balance;
  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)

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

OOP: Helper (Mutator) Methods (4.2.2)

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


OOP: Helper (Mutator) Methods (4.3)

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