Classes and Objects

Readings: Chapters 3 – 4 of the Course Notes

EECS2030: Advanced
Object Oriented Programming
Fall 2017

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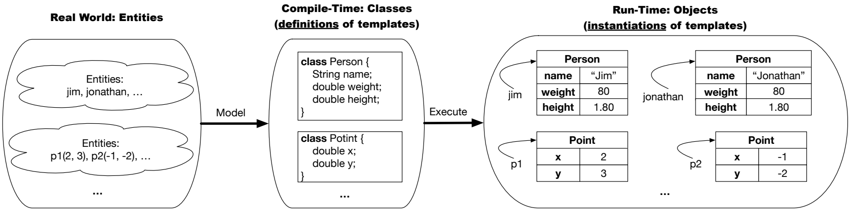
Separation of Concerns: App vs. Model

- So far we have developed:

  Supplier: A single utility class.
  Client: A class with its `main` method using the utility methods.
- In Java:
  - We may define more than one (non-utility) *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



- 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 PersonTester {
  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); } }
```

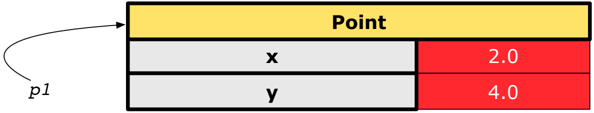
OOP:
Define Constructors for Creating Objects (1.2)

```
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`.



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:
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); } }
```

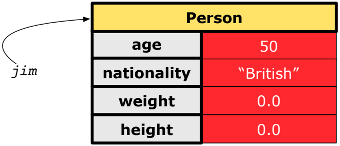
OOP:
Define Constructors for Creating Objects (2.2)

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

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

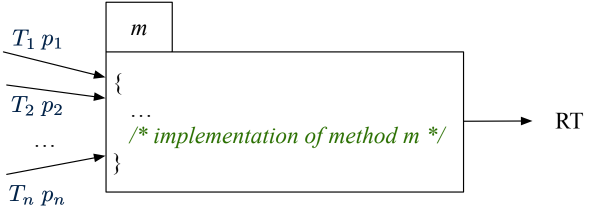
Person	
age	50
nationality	“British”
weight	0.0
height	0.0

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`.



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: 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: 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 + ")");
```

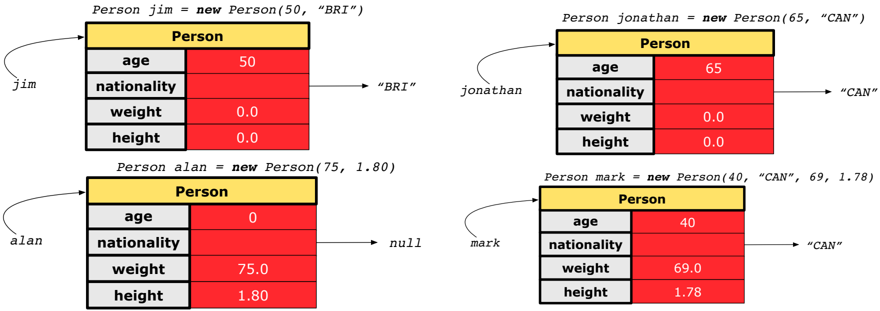
```
(2.0, 4.0)
```

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)

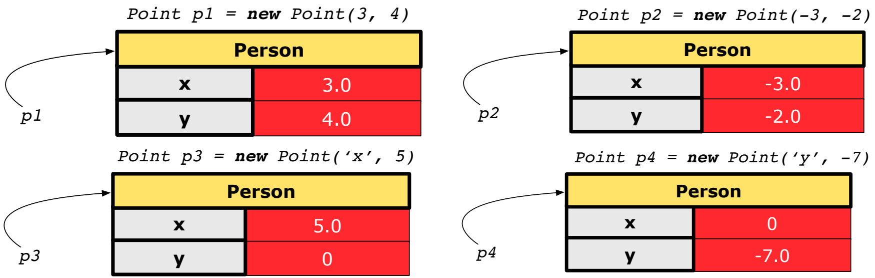


OOP: Object Creation (4)

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)`

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;
  }
}
```

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 be of type *ArrayList*, storing references to other objects.

```
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 `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 (3.2.2)

```
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) */
  }
}
```

Java Data Types (3.3.1)

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 (3.3.2)

```java
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) */
  }
}
```

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);
```

Call by Value vs. Call by Reference (1)

- Consider the general form of a call to some ***mutator method*** `m`, with ***context object*** `co` and **argument value** `arg`:

```
co.m (arg)
```

  - Argument variable **arg** is ***not*** passed directly for the method call.
  - Instead, argument variable **arg** is passed ***indirectly***: a *copy* of the value stored in **arg** is made and passed for the method call.
- What can be the type of variable **arg**? [Primitive or Reference]
  - **arg** is primitive type (e.g., `int`, `char`, `boolean`, *etc.*):
    Call by Value : Copy of **arg**'s *stored value* (e.g., `2`, `'j'`, `true`) is made and passed.
  - **arg** is reference type (e.g., `String`, `Point`, `Person`, *etc.*):
    Call by Reference : Copy of **arg**'s *stored reference/address* (e.g., `Point@5cb0d902`) is made and passed.

Call by Value vs. Call by Reference (2.1)

For illustration, let's assume the following variant of the `Point` class:

```
class Point {
  int x;
  int y;
  Point(int x, int y) {
    this.x = x;
    this.y = y;
  }
  void moveVertically(int y){
    this.y += y;
  }
  void moveHorizontally(int x){
    this.x += x;
  }
}
```

Call by Value vs. Call by Reference (2.2.1)

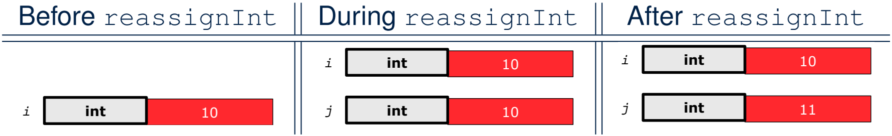
```
public class Util {
  void reassignInt(int j) {
    j = j + 1; }
  void reassignRef(Point q) {
    Point np = new Point(6, 8);
    q = np; }
  void changeViaRef(Point q) {
    q.moveHorizontally(3);
    q.moveVertically(4); } }
```

```
1 @Test
2 public void testCallByVal() {
3   Util u = new Util();
4   int i = 10;
5   assertTrue(i == 10);
6   u.reassignInt(i);
7   assertTrue(i == 10);
8 }
```

- ***Before*** the mutator call at **L6**, *primitive* variable `i` stores `10`.
- **When** executing the mutator call at **L6**, due to *call by value*, a copy of variable `i` is made.

  ⇒ The assignment `i = i + 1` is only effective on this copy, not the original variable `i` itself.
- ∴ ***After*** the mutator call at **L6**, variable `i` still stores `10`.

Call by Value vs. Call by Reference (2.2.2)



Call by Value vs. Call by Reference (2.3.1)

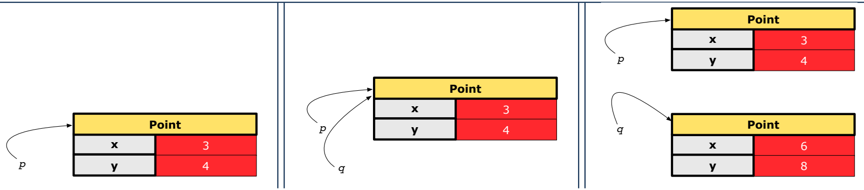
```java
public class Util {
  void reassignInt(int j) {
    j = j + 1; }
  void reassignRef(Point q) {
    Point np = new Point(6, 8);
    q = np; }
  void changeViaRef(Point q) {
    q.moveHorizontally(3);
    q.moveVertically(4); } }
```

```java
1 @Test
2 public void testCallByRef_1() {
3   Util u = new Util();
4   Point p = new Point(3, 4);
5   Point refOfPBefore = p;
6   u.reassignRef(p);
7   assertTrue(p==refOfPBefore);
8   assertTrue(p.x==3 && p.y==4);
9 }
```

- ***Before*** the mutator call at **L6**, *reference* variable `p` stores the *address* of some `Point` object (whose `x` is `3` and `y` is `4`).
- **When** executing the mutator call at **L6**, due to *call by reference*, a *copy of address* stored in `p` is made.
  ⇒ The assignment `p = np` is only effective on this copy, not the original variable `p` itself.
- ∴ ***After*** the mutator call at **L6**, variable `p` still stores the original address (i.e., same as `refOfPBefore`).

Call by Value vs. Call by Reference (2.3.2)

Before `reassignRef`	During `reassignRef`	After `reassignRef`



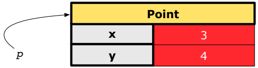
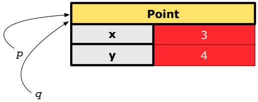
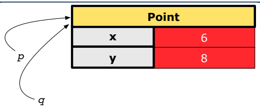
Call by Value vs. Call by Reference (2.4.1)

```
public class Util {
  void reassignInt(int j) {
    j = j + 1; }
  void reassignRef(Point q) {
    Point np = new Point(6, 8);
    q = np; }
  void changeViaRef(Point q) {
    q.moveHorizontally(3);
    q.moveVertically(4); } }
```

```
1 @Test
2 public void testCallByRef_2() {
3   Util u = new Util();
4   Point p = new Point(3, 4);
5   Point refOfPBefore = p;
6   u.changeViaRef(p);
7   assertTrue(p==refOfPBefore);
8   assertTrue(p.x==6 && p.y==8);
9 }
```

- ***Before*** the mutator call at **L6**, *reference* variable `p` stores the *address* of some `Point` object (whose `x` is `3` and `y` is `4`).
- **When** executing the mutator call at **L6**, due to *call by reference*, a *copy of address* stored in `p` is made. [**Alias**: `p` and `q` store same address.]
  - ⇒ Calls to `q.moveHorizontally` and `q.moveVertically` are effective on both `p` and `q`.
- ∴ ***After*** the mutator call at **L6**, variable `p` still stores the original address (i.e., same as `refOfPBefore`), but its `x` and `y` have been modified via `q`.

Call by Value vs. Call by Reference (2.4.2)

Before `changeViaRef`	During `changeViaRef`	After `changeViaRef`
		

Aggregation vs. Composition: Terminology

Container object: an object that contains others.

Containee object: an object that is contained within another.

- e.g., Each course has a faculty member as its instructor.
  - ***Container***: `Course` ***Containee***: `Faculty`.
- e.g., Each student is registered in a list of courses; Each faculty member teaches a list of courses.
  - ***Container***: `Student`, `Faculty` ***Containees***: `Course`.

    e.g., `eecs2030` taken by `jim` (student) and taught by `tom` (faculty).

    ⇒ ***Containees*** **may** be *shared* by different classes of ***containers***.

    e.g., When EECS2030 is finished, `jim` and `jackie` still exist!

    ⇒ ***Containees*** **may** exist *independently* without their ***containers***.
- e.g., In a file system, each directory contains a list of files.
  - ***Container***: `Directory` ***Containees***: `File`.

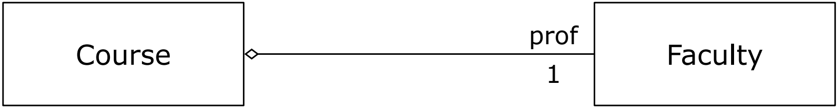
    e.g., Each file has exactly one parent directory.

    ⇒ A ***containee*** **may** be *owned* by only one ***container***.

    e.g., Deleting a directory also deletes the files it contains.

    ⇒ ***Containees*** **may** *co-exist* with their ***containers***.

Aggregation: Independent Containees Shared by Containers (1.1)




```
class Course {
  String title;
  Faculty prof;
  Course(String title) {
    this.title = title;
  }
  void setProf(Faculty prof) {
    this.prof = prof;
  }
  Faculty getProf() {
    return this.prof;
  }
}
```

```
class Faculty {
  String name;
  Faculty(String name) {
    this.name = name;
  }
  void setName(String name) {
    this.name = name;
  }
  String getName() {
    return this.name;
  }
}
```

Aggregation: Independent Containees Shared by Containers (1.2)

```java
@Test
public void testAggregation1() {
  Course eecs2030 = new Course("Advanced OOP");
  Course eecs3311 = new Course("Software Design");
  Faculty prof = new Faculty("Jackie");
  eecs2030.setProf(prof);
  eecs3311.setProf(prof);
  assertTrue(eecs2030.getProf() == eecs3311.getProf());
  /* aliasing */
  prof.setName("Jeff");
  assertTrue(eecs2030.getProf() == eecs3311.getProf());
  assertTrue(eecs2030.getProf().getName().equals("Jeff"));

  Faculty prof2 = new Faculty("Jonathan");
  eecs3311.setProf(prof2);
  assertTrue(eecs2030.getProf() != eecs3311.getProf());
  assertTrue(eecs2030.getProf().getName().equals("Jeff"));
  assertTrue(eecs3311.getProf().getName().equals("Jonathan"));
}
```

Aggregation: Independent Containees Shared by Containers (2.1)


```
class Student {
  String id; ArrayList<Course> cs; /* courses */
  Student(String id) { this.id = id; cs = new ArrayList<>(); }
  void addCourse(Course c) { cs.add(c); }
  ArrayList<Course> getCS() { return cs; }
}
```

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

```
class Faculty {
  String name; ArrayList<Course> te; /* teaching */
  Faculty(String name) { this.name = name; te = new ArrayList<>(); }
  void addTeaching(Course c) { te.add(c); }
  ArrayList<Course> getTE() { return te; }
}
```

Aggregation: Independent Containees Shared by Containers (2.2)

```
@Test
public void testAggregation2() {
  Faculty p = new Faculty("Jackie");
  Student s = new Student("Jim");
  Course eecs2030 = new Course("Advanced OOP");
  Course eecs3311 = new Course("Software Design");
  eecs2030.setProf(p);
  eecs3311.setProf(p);
  p.addTeaching(eecs2030);
  p.addTeaching(eecs3311);
  s.addCourse(eecs2030);
  s.addCourse(eecs3311);

  assertTrue(eecs2030.getProf() == s.getCS().get(0).getProf());
  assertTrue(s.getCS().get(0).getProf() == s.getCS().get(1).getProf());
  assertTrue(eecs3311 == s.getCS().get(1));
  assertTrue(s.getCS().get(1) == p.getTE().get(1));
}
```

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)

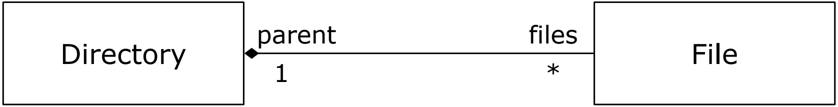
```
class Student {
  String id;
  ArrayList<Course> cs;
}
```

```
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;
  }
}
```

Composition: Dependent Containees Owned by Containers (1.1)

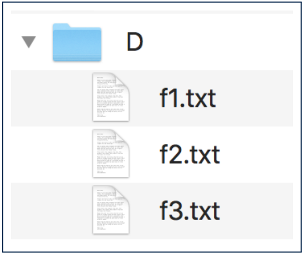


Assumption: Files are not shared among directories.

```
class File {
  String name;
  File(String name) {
    this.name = name;
  }
}
```

```
class Directory {
  String name;
  File[] files;
  int nof; /* num of files */
  Directory(String name) {
    this.name = name;
    files = new File[100];
  }
  void addFile(String fileName) {
    files[nof] = new File(fileName);
    nof ++;
  }
}
```

Composition: Dependent Containees Owned by Containers (1.2.1)

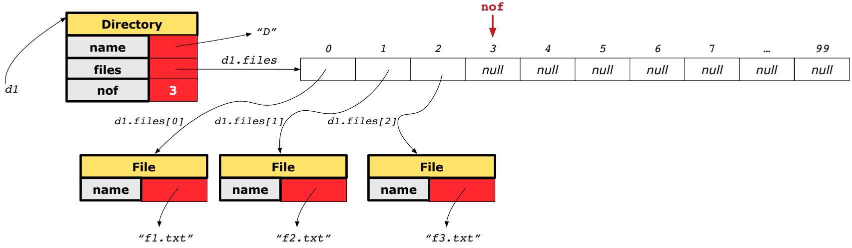



```
1 @Test
2 public void testComposition() {
3   Directory d1 = new Directory("D");
4   d1.addFile("f1.txt");
5   d1.addFile("f2.txt");
6   d1.addFile("f3.txt");
7   assertTrue(
8     d1.files[0].name.equals("f1.txt"));
9 }
```

- **L4**: a 1st `File` object is created and ***owned exclusively*** by `d1`.
  No other directories are sharing this `File` object with `d1`.
- **L5**: a 2nd `File` object is created and ***owned exclusively*** by `d1`.
  No other directories are sharing this `File` object with `d1`.
- **L6**: a 3rd `File` object is created and ***owned exclusively*** by `d1`.

Composition: Dependent Containees Owned by Containers (1.2.2)

Right before test method `testComposition` terminates:



Composition: Dependent Containees Owned by Containers (1.3)

Problem: How do you implement a *copy instructor* for the `Directory` class?

```
class Directory {
  Directory(Directory other) {
    /* ?? */
  }
}
```

Hints:

- The implementation should be consistent with the effect of copying and pasting a directory.
- Separate copies of files are created.

Composition: Dependent Containees Owned by Containers (1.4.1)

Version 1: *Shallow Copy* by copying all attributes using =.

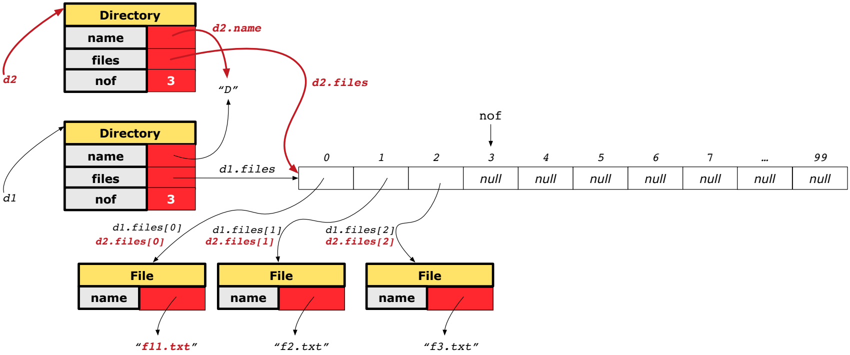
```
class Directory {
  Directory(Directory other) {
    /* value copying for primitive type */
    nof = other.nof;
    /* address copying for reference type */
    name = other.name; files = other.files; } }
```

Is a shallow copy satisfactory to support composition?
i.e., Does it still forbid sharing to occur? [***NO***]

```
@Test
void testShallowCopyConstructor() {
  Directory d1 = new Directory("D");
  d1.addFile("f1.txt"); d1.addFile("f2.txt"); d1.addFile("f3.txt");
  Directory d2 = new Directory(d1);
  assertTrue(d1.files == d2.files); /* violation of composition */
  d2.files[0].changeName("f11.txt");
  assertFalse(d1.files[0].name.equals("f1.txt")); }
```

Composition: Dependent Containees Owned by Containers (1.4.2)

Right before test method `testShallowCopyConstructor` terminates:



Composition: Dependent Containees Owned by Containers (1.5.1)

Version 2: a *Deep Copy*

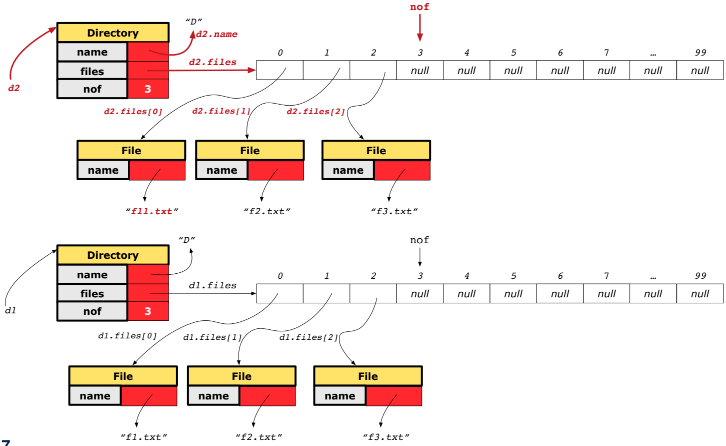
```
class File {
  File(File other) {
    this.name =
      new String(other.name);
  }
}
```

```
class Directory {
  Directory(String name) {
    this.name = new String(name);
    files = new File[100]; }
  Directory(Directory other) {
    this (other.name);
    for(int i = 0; i < nof; i ++) {
      File src = other.files[i];
      File nf = new File(src);
      this.addFile(nf); } } }
```

```
@Test
void testDeepCopyConstructor() {
  Directory d1 = new Directory("D");
  d1.addFile("f1.txt"); d1.addFile("f2.txt"); d1.addFile("f3.txt");
  Directory d2 = new Directory(d1);
  assertTrue(d1.files != d2.files); /* composition preserved */
  d2.files[0].changeName("f11.txt");
  assertTrue(d1.files[0].name.equals("f1.txt")); }
```

Composition: Dependent Containees Owned by Containers (1.5.2)

Right before test method `testDeepCopyConstructor` terminates:



Composition: Dependent Containees Owned by Containers (1.6)

Exercise: Implement the accessor in class `Directory`

```
class Directory {
  File[] files;
  int nof;
  File[] getFiles() {
    /* Your Task */
  }
}
```

so that it ***preserves composition***, i.e., does not allow references of files to be shared.

Aggregation vs. Composition (1)

Terminology:

- **Container** object: an object that contains others.
- **Containee** object: an object that is contained within another.

Aggregation :

- Containees (e.g., `Course`) may be *shared* among containers (e.g., `Student`, `Faculty`).
- Containees *exist independently* without their containers.
- When a container is destroyed, its containees still exist.

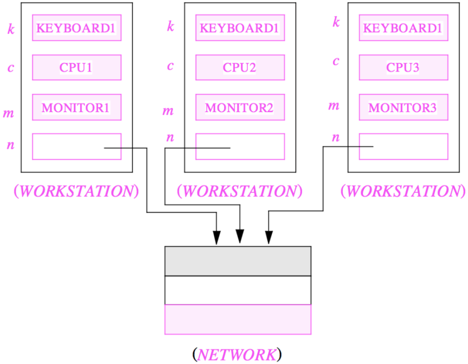
Composition :

- Containers (e.g, `Directory`, `Department`) *own* exclusive access to their containees (e.g., `File`, `Faculty`).
- Containees cannot exist without their containers.
- Destroying a container destroys its containeees *cascadingly*.

Aggregation vs. Composition (2)

Aggregations and *Compositions* may exist at the same time!
e.g., Consider a workstation:

- Each workstation owns CPU, monitor, keyword. [***compositions***]
- All workstations share the same network. [***aggregations***]



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*.

OOP: Equality (3)

- Implicitly:
  - Every class is a *child/sub* class of the `Object` class.
  - The `Object` class is the *parent/super* class of every class.
- There are two useful *accessor methods* that every class *inherits* from the `Object` class:
  - `boolean equals(Object other)`

    Indicates whether some other object is "equal to" this one.
    - The default definition inherited from `Object`:

```
boolean equals(Object other) {
  return (this == other); }
```

  - `String toString()`

    Returns a string representation of the object.
- Very often when you define new classes, you want to *redefine* / *override* the inherited definitions of `equals` and `toString`.

OOP: Contract of `equals`

Given that reference variables `x`, `y`, `z` are not `null`:

-
$$\neg\, x.equals(null)$$

- *Reflexive* :
$$x.equals(x)$$

- *Symmetric*
$$x.equals(y) \iff y.equals(x)$$

- *Transitive*
$$x.equals(y) \land y.equals(z) \Rightarrow x.equals(z)$$

OOP: Equality (4.1)

- How do we compare *contents* rather than addresses?
- Define the *accessor method* `equals`, e.g.,

```
class Point {
  double x; double y;
  boolean equals (Object obj) {
    if(this == obj) { return true; }
    if(obj == null) { return false; }
    if(this.getClass() != obj.getClass()) { return false; }
    Point other = (Point) obj;
    return this.x == other.x && this.y == other.y; } }
```

```
class PointTester {
  String s = "(2, 3)";
  Point p1 = new Point(2, 3); Point p2 = new Point(2, 3);
  System.out.println(p1. equals (p1)); /* true */
  System.out.println(p1.equals(null)); /* false */
  System.out.println(p1.equals(s)); /* false */
  System.out.println(p1 == p2); /* false */
  System.out.println(p1. equals (p2)); /* true */ }
```

OOP: Equality (4.2)

- When making a method call `p.equals(o)`:
  - Variable `p` is of type `Point`
  - Variable `o` can be any type
- We define `p` and `o` as ***equal*** if:
  - Either `p` and `o` refer to the same object;
  - Or:
    - `o` is not null.
    - `p` and `o` are of the same type.
    - The `x` and `y` coordinates are the same.
- **Q**: In the `equals` method of `Point`, why is there no such a line:

```
class Point {
  boolean equals(Object obj) {
    if(this == null) { return false; }
```

A: If `this` is `null`, a `NullPointerException` would have occurred and prevent the body of `equals` from being executed.

OOP: Equality (4.3)

```
1 class Point {
2   boolean equals (Object obj) {
3     ...
4     Point other = (Point) obj;
5     return this.x == other.x && this.y == other.y; } }
```

- `Object obj` at **L2** declares a parameter `obj` of type `Object`.
- `Point p` at **L4** declares a variable `p` of type `Point`.
  We call such types declared at compile time as ***static type***.
- The list of applicable methods that we may call on a variable depends on its ***static type***.
  - e.g., We may only call the small list of methods defined in `Object` class on `obj`, which does not include `x` and `y` (specific to `Point`).
- If we are SURE that an object's "actual" type is different from its ***static type***, then we can *cast* it.
  - e.g., Given that `this.getClass() == obj.getClass()`, we are sure that `obj` is also a `Point`, so we can cast it to `Point`.
- Such cast allows more attributes/methods to be called upon `(Point) obj` at **L5**.

OOP: Equality (5.1)

Exercise: Persons are *equal* if names and measures are equal.

```
1  class Person {
2    String firstName; String lastName; double weight; double height;
3    boolean equals(Object obj) {
4      if(this == obj) { return true }
5      if(obj == null || this.getClass() != obj.getClass()) {
6        return false; }
7      Person other = (Person) obj;
8      return
9          this.weight == other.weight && this.height == other.height
10       && this.firstName.equals(other.firstName)
11       && this.lastName.equals(other.lastName) } }
```

Q: At **L5**, will we get `NullPointerException` if `obj` is `Null`?

A: ***No*** ∵ Short-Circuit Effect of `||`

`obj` is `null`, then `obj == null` evaluates to ***true***

⇒ no need to evaluate the RHS

The left operand `obj == null` acts as a *guard constraint* for the right operand `this.getClass() != obj.getClass()`.

OOP: Equality (5.2)

Exercise: Persons are *equal* if names and measures are equal.

```
1  class Person {
2    String firstName; String lastName; double weight; double height;
3    boolean equals (Object obj) {
4      if(this == obj) { return true }
5      if(obj == null || this.getClass() != obj.getClass()) {
6        return false; }
7      Person other = (Person) obj;
8      return
9          this.weight == other.weight && this.height == other.height
10       && this.firstName. equals (other.firstName)
11       && this.lastName. equals (other.lastName) } }
```

Q: At **L5**, if swapping the order of two operands of disjunction:

`this.getClass() != obj.getClass() || obj == null`

Will we get `NullPointerException` if `obj` is `Null`?

A: ***Yes*** ∵ Evaluation of operands is from left to right.

OOP: Equality (5.3)

Exercise: Persons are *equal* if names and measures are equal.

```
1  class Person {
2    String firstName; String lastName; double weight; double height;
3    boolean equals (Object obj) {
4      if(this == obj) { return true }
5      if(obj == null || this.getClass() != obj.getClass()) {
6        return false; }
7      Person other = (Person) obj;
8      return
9          this.weight == other.weight && this.height == other.height
10       && this.firstName. equals (other.firstName)
11       && this.lastName. equals (other.lastName) } }
```

L10 & L11 call `equals` method defined in the `String` class.

When defining `equals` method for your own class, ***reuse*** `equals` methods defined in other classes wherever possible.

OOP: Equality (6)

Two notions of *equality* for variables of *reference* types:

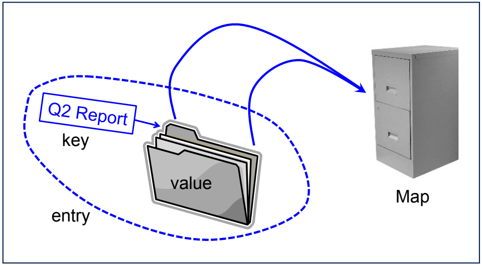
- *Reference Equality* : use == to compare *addresses*
- *Object Equality* : define `equals` method to compare *contents*

```
Point p1 = new Point(3, 4);
Point p2 = new Point(3, 4);
Point p3 = new Point(4, 5);
System.out.println(p1 == p1);  /* true */
System.out.println(p1.equals(p1));  /* true */
System.out.println(p1 == p2);  /* false */
System.out.println(p1.equals(p2));  /* true */
System.out.println(p2 == p3);  /* false */
System.out.println(p2.equals(p3));  /* false */
```

- Being *reference*-equal implies being *object*-equal
- Being *object*-equal does *not* imply being *reference*-equal

Hashing: What is a Map?

- A **map** (a.k.a. table or dictionary) stores a collection of *entries*.



ENTRY	
(SEARCH) KEY	VALUE
1	D
25	C
3	F
14	Z
6	A
39	C
7	Q

- Each *entry* is a pair: a *value* and its *(search) key*.
- Each *search key* :
  - *Uniquely* identifies an object in the map
  - Should be used to *efficiently* retrieve the associated value
- Search keys must be *unique* (i.e., do not contain duplicates).

Hashing: Arrays are Maps

- Each array *entry* is a pair: an object and its *numerical* index.
  e.g., say `String[] a = {"A", "B", "C"}`, how many entries?
  3 entries: `(0, "A")`, `(1, "B")`, `(2, "C")`
- *Search keys* are the set of numerical index values.
- The set of index values are *unique* [e.g., $0 .. (a.length - 1)$]
- Given a *valid* index value i, we can
  - *Uniquely* determines where the object is [$(i + 1)^{th}$ item]
  - *Efficiently* retrieves that object [`a[i]` ≈ fast memory access]
- Maps in general may have *non-numerical* key values:
  - Student ID [student record]
  - Social Security Number [resident record]
  - Passport Number [citizen record]
  - Residential Address [household record]
  - Media Access Control (MAC) Address [PC/Laptop record]
  - Web URL [web page]

  ...

Hashing: Naive Implementation of Map

- **Problem**: Support the construction of this simple map:

ENTRY	
(SEARCH) KEY	VALUE
1	D
25	C
3	F
14	Z
6	A
39	C
7	Q

  Let's just assume that the maximum map capacity is 100.

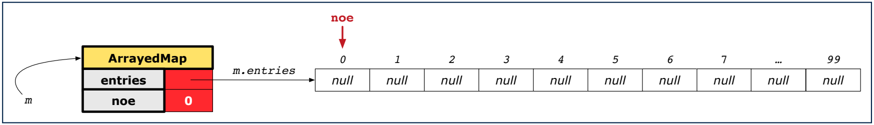
- **Naive Solution**:

  Let's understand the expected runtime structures before seeing the Java code!

Hashing: Naive Implementation of Map (0)

After executing `ArrayedMap m = new ArrayedMap()`:

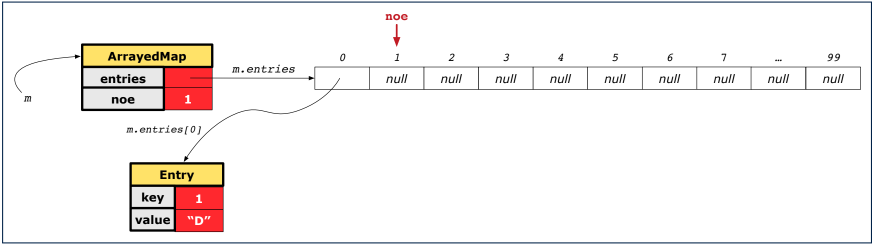
- Attribute `m.entries` initialized as an array of 100 `null` slots.
- Attribute `m.noe` is 0, meaning:
  - Current number of entries stored in the map is 0.
  - Index for storing the next new entry is 0.



Hashing: Naive Implementation of Map (1)

After executing `m.put(new Entry(1, "D"))`:

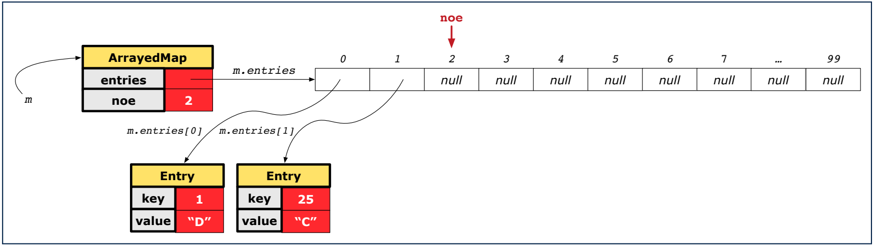
- Attribute `m.entries` has 99 `null` slots.
- Attribute `m.noe` is 1, meaning:
  - Current number of entries stored in the map is 1.
  - Index for storing the next new entry is 1.



Hashing: Naive Implementation of Map (2)

After executing `m.put(new Entry(25, "C"))`:

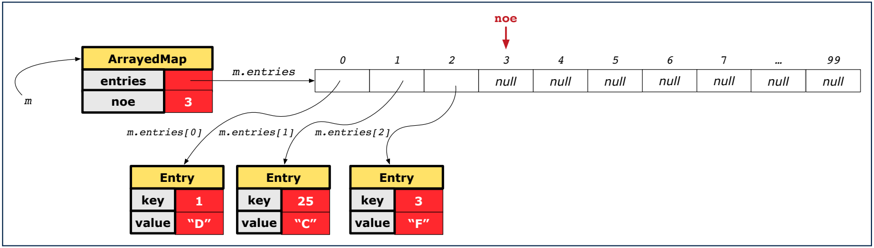
- Attribute `m.entries` has 98 `null` slots.
- Attribute `m.noe` is 2, meaning:
  - Current number of entries stored in the map is 2.
  - Index for storing the next new entry is 2.



Hashing: Naive Implementation of Map (3)

After executing `m.put(new Entry(3, "F"))`:

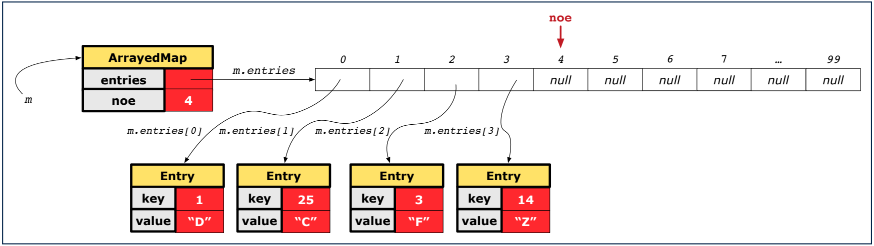
- Attribute `m.entries` has 97 `null` slots.
- Attribute `m.noe` is 3, meaning:
  - Current number of entries stored in the map is 3.
  - Index for storing the next new entry is 3.



Hashing: Naive Implementation of Map (4)

After executing `m.put(new Entry(14, "Z"))`:

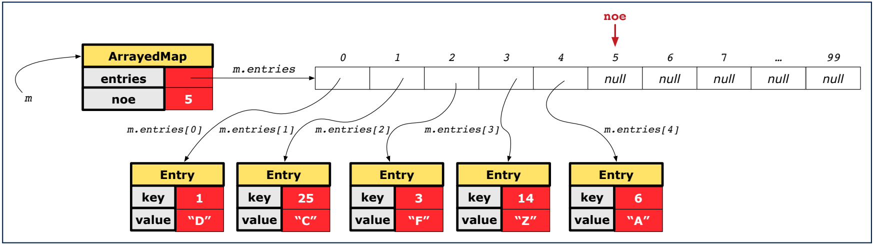
- Attribute `m.entries` has 96 `null` slots.
- Attribute `m.noe` is 4, meaning:
  - Current number of entries stored in the map is 4.
  - Index for storing the next new entry is 4.



Hashing: Naive Implementation of Map (5)

After executing `m.put(new Entry(6, "A"))`:

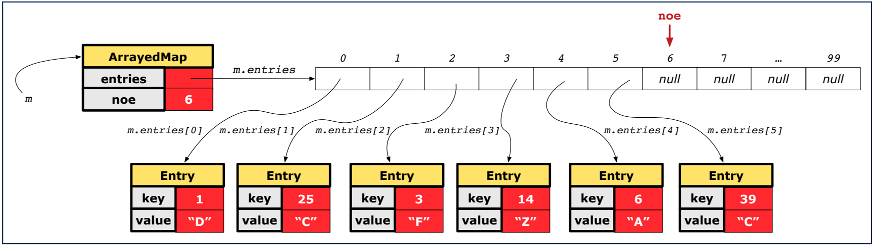
- Attribute `m.entries` has 95 `null` slots.
- Attribute `m.noe` is 5, meaning:
  - Current number of entries stored in the map is 5.
  - Index for storing the next new entry is 5.



Hashing: Naive Implementation of Map (6)

After executing `m.put(new Entry(39, "C"))`:

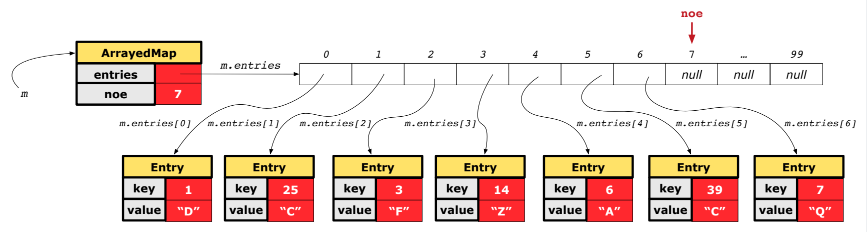
- Attribute `m.entries` has 94 `null` slots.
- Attribute `m.noe` is 6, meaning:
  - Current number of entries stored in the map is 6.
  - Index for storing the next new entry is 6.



Hashing: Naive Implementation of Map (7)

After executing `m.put(new Entry(7, "Q"))`:

- Attribute `m.entries` has 93 `null` slots.
- Attribute `m.noe` is 7, meaning:
  - Current number of entries stored in the map is 7.
  - Index for storing the next new entry is 7.



Hashing: Naive Implementation of Map (8.1)

```
public class Entry {
  private int key;
  private String value;

  public Entry(int key, String value) {
    this.key = key;
    this.value = value;
  }
  /* Getters and Setters for key and value */
}
```

Hashing: Naive Implementation of Map (8.2)

```
public class ArrayedMap {
  private final int MAX_CAPCAITY = 100;
  private Entry[] entries;
  private int noe; /* number of entries */
  public ArrayedMap() {
    entries = new Entry[MAX_CAPCAITY];
    noe = 0;
  }
  public int size() {
    return noe;
  }
  public void put(int key, String value) {
    Entry e = new Entry(key, value);
    entries[noe] = e;
    noe ++;
  }
```

Required Reading: Point and PointCollector

Hashing: Naive Implementation of Map (8.3)

```
@Test
public void testArrayedMap() {
  ArrayedMap m = new ArrayedMap();
  assertTrue(m.size() == 0);
  m.put(1, "D");
  m.put(25, "C");
  m.put(3, "F");
  m.put(14, "Z");
  m.put(6, "A");
  m.put(39, "C");
  m.put(7, "Q");
  assertTrue(m.size() == 7);
  /* inquiries of existing key */
  assertTrue(m.get(1).equals("D"));
  assertTrue(m.get(7).equals("Q"));
  /* inquiry of non-existing key */
  assertTrue(m.get(31) == null);
}
```

Hashing: Naive Implementation of Map (8.4)

```
public class ArrayedMap {
  private final int MAX_CAPCAITY = 100;
  public String getValue (int key) {
    for(int i = 0; i < noe; i ++) {
      Entry e = entries[i];
      int k = e.getKey();
      if(k == key) { return e.getValue(); }
    }
    return null;
  }
```

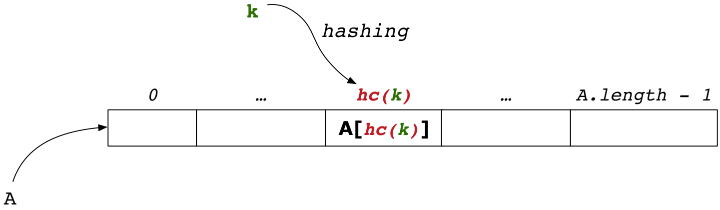
Say `entries` is: {(1, D), (25, C), (3, F), (14, Z), (6, A), (39, C), (7, Q), null, . . .}

- How efficient is `m.get(1)`? [1 iteration]
- How efficient is `m.get(7)`? [7 iterations]
- If `m` is full, worst case of `m.get(k)`? [100 iterations]
- If `m` with 10^6 entries, worst case of `m.get(k)`? [10^6 iterations]

⇒ `get`'s worst-case performance is *linear* on size of `m.entries`!

A much *faster* (and ***correct***) solution is possible!

Hashing: Hash Table (1)

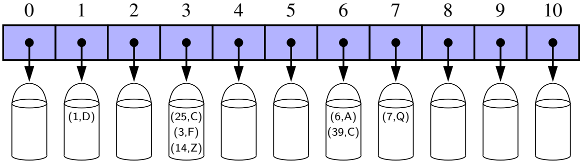


- Given a (numerical or non-numerical) search key ***k***:
  - Apply a function ***hc*** so that ***hc(k)*** returns an integer.
    - We call ***hc(k)*** the *hash code* of key ***k***.
    - Value of ***hc(k)*** denotes a ***valid index*** of some array `A`.
  - Rather than searching through array `A`, go directly to `A`[***hc***(***k***)] to get the associated value.
- Both computations are fast:
  - Converting ***k*** to ***hc(k)***
  - Indexing into `A`[***hc***(***k***)]

Hashing: Hash Table as a Bucket Array (2)

For illustration, assume `A.length` is 10 and $hc(k) = k\%11$.

$hc(k) = k\%11$	(SEARCH) KEY	VALUE
1	1	D
3	25	C
3	3	F
3	14	Z
6	6	A
6	39	C
7	7	Q



- **Collision**: unequal keys have same hash code (e.g., 25, 3, 14)
  ⇒ Unavoidable as number of entries ↑, but a *good* hash function should have sizes of the buckets uniformly distributed.

Hashing: Contract of Hash Function

- Principle of defining a hash function ***hc***:

$$\textbf{\textit{k1}}.equals(\textbf{\textit{k2}}) \Rightarrow \textbf{\textit{hc}}(\textbf{\textit{k1}}) == \textbf{\textit{hc}}(\textbf{\textit{k2}})$$

  Equal keys always have the same hash code.

- Equivalently, according to contrapositive:

$$\textbf{\textit{hc}}(\textbf{\textit{k1}}) \neq \textbf{\textit{hc}}(\textbf{\textit{k2}}) \Rightarrow \neg \textbf{\textit{k1}}.equals(\textbf{\textit{k2}})$$

  Different hash codes must be generated from unequal keys.

Hashing: Defining Hash Function in Java (1)

The `Object` class (common super class of all classes) has the method for redefining the hash function for your own class:

```
public class IntegerKey {
  private int k;
  public IntegerKey(int k) { this.k = k; }
  @Override
  public int hashCode() { return k % 11; }
  @Override
  public boolean equals(Object obj) {
    if(this == obj) { return true; }
    if(obj == null) { return false; }
    if(this.getClass() != obj.getClass()) { return false; }
    IntegerKey other = (IntegerKey) obj;
    return this.k == other.k;
  } }
```

Q: Can we define `equals` as `return this.hashCode == other.hashCode()`? [*No* ∵ Collision; see contract of `equals`]

Hashing: Defining Hash Function in Java (2)

```
@Test
public void testCustomizedHashFunction() {
  IntegerKey ik1 = new IntegerKey(1);
  /* 1 % 11 == 1 */
  assertTrue(ik1.hashCode() == 1);

  IntegerKey ik39_1 = new IntegerKey(39);
  /* 39 % 11 == 3 */
  assertTrue(ik39_1.hashCode() == 6);

  IntegerKey ik39_2 = new IntegerKey(39);
  assertTrue(ik39_1.equals(ik39_2));
  assertTrue(ik39_1.hashCode() == ik39_2.hashCode());
}
```

Hashing: Using Hash Table in Java

```
@Test
public void testHashTable() {
  Hashtable<IntegerKey, String> table = new Hashtable<>();
  IntegerKey k1 = new IntegerKey(39);
  IntegerKey k2 = new IntegerKey(39);
  assertTrue(k1.equals(k2));
  assertTrue(k1.hashCode() == k2.hashCode());
  table.put(k1, "D");
  assertTrue(table.get(k2).equals("D"));
}
```

Hashing: Defining Hash Function in Java (3)

- When you are given instructions as to how the `hashCode` method of a class should be defined, override it manually.
- Otherwise, use Eclipse to generate the `equals` and `hashCode` methods for you.
  - Right click on the class.
  - Select `Source`.
  - Select `Generate hashCode() and equals()`.
  - Select the relevant attributes that will be used to compute the hash value.

Hashing: Defining Hash Function in Java (4.1)

Caveat : Always make sure that the `hashCode` and `equals` are redefined/overridden to work together consistently.

e.g., Consider an alternative version of the `IntegerKey` class:

```
public class IntegerKey {
  private int k;
  public IntegerKey(int k) { this.k = k; }
  /* hashCode() inherited from Object NOT overridden. */
  @Override
  public boolean equals(Object obj) {
    if(this == obj) { return true; }
    if(obj == null) { return false; }
    if(this.getClass() != obj.getClass()) { return false; }
    IntegerKey other = (IntegerKey) obj;
    return this.k == other.k;
  } }
```

Problem? [**Hint**: Contract of `hashCode()`]

Hashing: Defining Hash Function in Java (4.2)

```
1  @Test
2  public void testDefaultHashFunction() {
3    IntegerKey ik39_1 = new IntegerKey(39);
4    IntegerKey ik39_2 = new IntegerKey(39);
5    assertTrue(ik39_1.equals(ik39_2));
6    assertTrue(ik39_1.hashCode() != ik39_2.hashCode()); }
7  @Test
8  public void testHashTable() {
9    Hashtable<IntegerKey, String> table = new Hashtable<>();
10   IntegerKey k1 = new IntegerKey(39);
11   IntegerKey k2 = new IntegerKey(39);
12   assertTrue(k1.equals(k2));
13   assertTrue(k1.hashCode() != k2.hashCode());
14   table.put(k1, "D");
15   assertTrue(table.get(k2) == null); }
```

L3, 4, 11, 12: Default version of `hashCode`, inherited from `Object`, returns a *distinct* integer for every new object, *despite its contents*. [***Fix***: Override `hashCode` of your classes!]

Why Ordering Between Objects? (1)

Each employee has their numerical id and salary.

e.g., (*alan*, 2, 4500.34), (*mark*, 3, 3450.67), (*tom*, 1, 3450.67)

- ***Problem***: To facilitate an annual review on their statuses, we want to arrange them so that ones with smaller id's come before ones with larger id's.s

  e.g., ⟨*tom*, *alan*, *mark*⟩

- Even better, arrange them so that ones with larger salaries come first; only compare id's for employees with equal salaries.

  e.g., ⟨*alan*, *tom*, *mark*⟩

- *Solution* :
  - Define ***ordering*** of `Employee` objects.

    [`Comparable` interface, `compareTo` method]
  - Use the library method `Arrays.sort`.

Why Ordering Between Objects? (2)

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```
class Employee {
  int id; double salary;
  Employee(int id) { this.id = id; }
  void setSalary(double salary) { this.salary = salary; } }
```

```
1 @Test
2 public void testUncomparableEmployees() {
3   Employee alan = new Employee(2);
4   Employee mark = new Employee(3);
5   Employee tom = new Employee(1);
6   Employee[] es = {alan, mark, tom};
7   Arrays.sort(es);
8   Employee[] expected = {tom, alan, mark};
9   assertArrayEquals(expected, es); }
```

L8 triggers a ***java.lang.ClassCastException***:
Employee cannot be cast to java.lang.Comparable

∵ `Arrays.sort` expects an array whose element type defines a precise ***ordering*** of its instances/objects.

Defining Ordering Between Objects (1.1)

```
class CEmployee1 implements Comparable<CEmployee1> {
  ... /* attributes, constructor, mutator similar to Employee */
  @Override
  public int compareTo(CEmployee1 e) { return this.id - e.id; }
}
```

- Given two `CEmployee1` objects `ce1` and `ce2`:
  - `ce1.compareTo(ce2) > 0` [`ce1` "is greater than" `ce2`]
  - `ce1.compareTo(ce2) == 0` [`ce1` "is equal to" `ce2`]
  - `ce1.compareTo(ce2) < 0` [`ce1` "is smaller than" `ce2`]
- Say `ces` is an array of `CEmployee1` (`CEmployee1[] ces`), calling `Arrays.sort(ces)` re-arranges `ces`, so that:

$$\underbrace{\texttt{ces[0]}}_{\texttt{CEmployee1}\ \textit{object}} \leq \underbrace{\texttt{ces[1]}}_{\texttt{CEmployee1}\ \textit{object}} \leq \ldots \leq \underbrace{\texttt{ces[ces.length - 1]}}_{\texttt{CEmployee1}\ \textit{object}}$$

Defining Ordering Between Objects (1.2)

```
@Test
public void testComparableEmployees_1() {
  /*
   * CEmployee1 implements the Comparable interface.
   * Method compareTo compares id's only.
   */
  CEmployee1 alan = new CEmployee1(2);
  CEmployee1 mark = new CEmployee1(3);
  CEmployee1 tom = new CEmployee1(1);
  alan.setSalary(4500.34);
  mark.setSalary(3450.67);
  tom.setSalary(3450.67);
  CEmployee1[] es = {alan, mark, tom};
  /* When comparing employees,
   * their salaries are irrelevant.
   */
  Arrays.sort(es);
  CEmployee1[] expected = {tom, alan, mark};
  assertArrayEquals(expected, es);
}
```

Defining Ordering Between Objects (2.1)

Let's now make the comparison more sophisticated:

- Employees with higher salaries come before those with lower salaries.
- When two employees have same salary, whoever with lower id comes first.

```java
1 class CEmployee2 implements Comparable<CEmployee2> {
2   ... /* attributes, constructor, mutator similar to Employee */
3   @Override
4   public int compareTo(CEmployee2 other) {
5     int salaryDiff = Double.compare(this.salary, other.salary);
6     int idDiff = this.id - other.id;
7     if(salaryDiff != 0) { return - salaryDiff; }
8     else { return idDiff; } } }
```

- **L5**: `Double.compare(d1, d2)` returns
  - (`d1 < d2`), 0 (`d1 == d2`), or + (`d1 > d2`).
- **L7**: Why inverting the sign of `salaryDiff`?
  - *this.salary* > *other.salary* ⇒ `Double.compare`(*this.salary*, *other.salary*) > 0
  - But we should consider employee with *higher* salary as "smaller".
    ∵ We want that employee to come *before* the other one!

Defining Ordering Between Objects (2.2)

Alternatively, we can use extra `if` statements to express the logic more clearly.

```
class CEmployee2 implements Comparable <CEmployee2> {
  ... /* attributes, constructor, mutator similar to Employee */
  @Override
  public int compareTo(CEmployee2 other) {
    if(this.salary > other.salary) {
      return -1;
    }
    else if (this.salary < other.salary) {
      return 1;
    }
    else { /* equal salaries */
      return this.id - other.id;
    }
}
```

Defining Ordering Between Objects (2.3)

```
@Test
public void testComparableEmployees_2() {
  /*
   * CEmployee2 implements the Comparable interface.
   * Method compareTo first compares salaries, then
   * compares id's for employees with equal salaries.
   */
  CEmployee2 alan = new CEmployee2(2);
  CEmployee2 mark = new CEmployee2(3);
  CEmployee2 tom = new CEmployee2(1);
  alan.setSalary(4500.34);
  mark.setSalary(3450.67);
  tom.setSalary(3450.67);
  CEmployee2[] es = {alan, mark, tom};
  Arrays.sort(es);
  CEmployee2[] expected = {alan, tom, mark};
  assertArrayEquals(expected, es);
}
```

Defining Ordering Between Objects (3)

When you have your class `C` implement the interface `Comparable<C>`, you should design the `compareTo` method, such that given objects `c1`, `c2`, `c3` of type `C`:

- *Asymmetric* :

$$\neg(c1.compareTo(c2) < 0 \wedge c2.compareTo(c1) < 0)$$
$$\neg(c1.compareTo(c2) > 0 \wedge c2.compareTo(c1) > 0)$$

  $\therefore$ We don't have $c1 < c2$ and $c2 < c1$ at the same time!

- *Transitive* :

$$c1.compareTo(c2) < 0 \wedge c2.compareTo(c3) < 0 \quad \Rightarrow \quad c1.compareTo(c3) < 0$$
$$c1.compareTo(c2) > 0 \wedge c2.compareTo(c3) > 0 \quad \Rightarrow \quad c1.compareTo(c3) > 0$$

  $\therefore$ We have $c1 < c2 \wedge c2 < c3 \Rightarrow c1 < c3$

  Q. How would you define the `compareTo` method for the `Player` class of a rock-paper-scissor game? [**Hint**: Transitivity]

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

```
public class Bank {
   public string branchName;
   public static int nextAccountNumber = 1;
   public static void useAccountNumber() {
      System.out.println (branchName + ...);
      nextAccountNumber ++;
   }
}
```

- 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);
  }
}
```

Index (1)

Index (2)

Index (3)

Index (4)

Index (5)

Index (6)

Index (7)

Index (8)

Index (9)

Index (10)

Index (11)

Index (12)