Object Equality

EECS2030 E: Advanced
Object Oriented Programming
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Learning Outcomes

This module is designed to help you learn about:

- ***Call by Value***: Primitive vs. Reference Argument Values
- ***Object equality***: To ***Override*** or ***Not*** to Override
- Asserting ***Object Equality***: `assertSame` vs. `assertEquals`
- Short-Circuit Effect (SCE): `&&` vs. `||`
- Equality for Array-, Reference-Typed Attributes

Call by Value (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 to the method call.
  - Instead, argument variable **arg** is passed **indirectly**: a *copy* of the value stored in **arg** is made and passed to 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 Value: Copy of **arg**'s *stored reference/address*
    (e.g., `Point@5cb0d902`) is made and passed.

Call by Value (2.1)

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

```
public class Point {
  private int x;
  private int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }
  public int getX() { return this.x; }
  public int getY() { return this.y; }
  public void moveVertically(int y){ this.y += y; }
  public void moveHorizontally(int x){ this.x += x; }
}
```

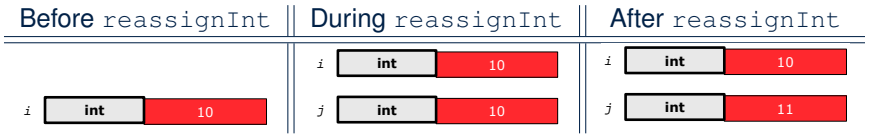
Call by Value (2.2.1)

```
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 (2.2.2)



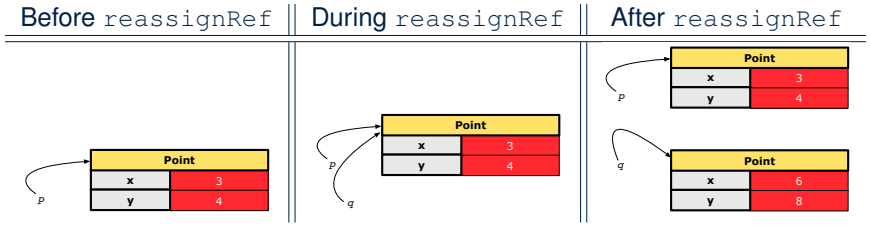
Call by Value (2.3.1)

```
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_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.getX() == 3);
9    assertTrue(p.getY() == 4);
10 }
```

- ***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 value*, 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 (2.3.2)



Call by Value (2.4.1)

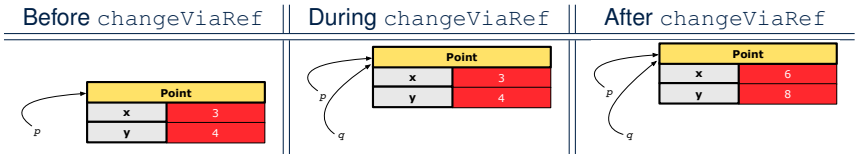
```
public class Util {
  void reassignInt(int j) {
    j = j + 1; }
  void reassignRef(Point q) {
    Point np = new Point(6, 8);
    q = np; }
  void changeViaRef(Point q) {
    q.moveHorizontally(3);
    q.moveVertically(4); } }
```

```
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.getX() == 6);
9    assertTrue(p.getY() == 8);
10 }
```

- ***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 value*, a *copy of address* stored in `p` is made. [**Alias**: `p` and `q` store same address.]

  ⇒ `q.moveHorizontally` impacts the ***same object*** referenced by `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` values have been modified via `q`.

Call by Value (2.4.2)



Equality (1)

- 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 ***values*** 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.

Equality (2.1)

- Implicitly:
  - Every class is a ***child/sub*** class of the **`Object`** class.
  - The **`Object`** class is the ***parent/super*** class of every class.
- There is a useful accessor method that every class ***inherits*** from the **`Object`** class:
  - `public boolean equals(Object obj)`
    - Indicates whether some other object obj is "equal to" `this` one.
    - The default definition inherited from `Object`:

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

    e.g., Say `p1` and `p2` are of type `Point` ***V1***
    in which the `equals` method is not ***redefined/overridden***,
    then `p1.equals(p2)` boils down to (`p1 == p2`).
  - Very often when you define new classes, you want to *redefine* / *override* the inherited definition of `equals`.

Equality (2.2): Common Error

```
int i = 10;
int j = 12;
boolean sameValue = i.equals(j);
```

Compilation Error

The `equals` method is only applicable to reference types.

Fix

Write `i == j` instead.

Equality (3)

```
public class PointV1 {
  private int x; private int y;
  public PointV1(int x, int y) { this.x = x; this.y = y; }
}
```

```
1  String s = "(2, 3)";
2  PointV1 p1 = new PointV1(2, 3);
3  PointV1 p2 = new PointV1(2, 3);
4  PointV1 p3 = new PointV1(4, 6);
5  System.out.println(p1 == p2);  /* false */
6  System.out.println(p2 == p3);  /* false */
7  System.out.println(p1.equals(p1));  /* true */
8  System.out.println(p1.equals(null));  /* false */
9  System.out.println(p1.equals(s));  /* false */
10 System.out.println(p1.equals(p2));  /* false */
11 System.out.println(p2.equals(p3));  /* false */
```

- The `equals` method is not explicitly redefined/overridden in class `PointV1` ⇒ The default version inherited from class `Object` is called. e.g., Executing `p1.equals(null)` boils down to (`p1 == null`).
- To compare contents of `PointV1` objects, ***redefine/override*** `equals`.

Equality (4.1)

To compare ***contents*** rather than addresses, override `equals`.

```
public class PointV2 {
  private int x; private int y;
  public boolean equals (Object obj) {
    if(this == obj) { return true; }
    if(obj == null) { return false; }
    if(this.getClass() != obj.getClass()) { return false; }
    PointV2 other = (PointV2) obj;
    return this.x == other.x && this.y == other.y;
  }
}
```

```
1  String s = "(2, 3)";
2  PointV2 p1 = new PointV2(2, 3);
3  PointV2 p2 = new PointV2(2, 3);
4  PointV2 p3 = new PointV2(4, 6);
5  System.out.println(p1 == p2);  /* false */
6  System.out.println(p2 == p3);  /* false */
7  System.out.println(p1.equals(p1));  /* true */
8  System.out.println(p1.equals(null));  /* false */
9  System.out.println(p1.equals(s));  /* false */
10 System.out.println(p1.equals(p2));  /* true */
11 System.out.println(p2.equals(p3));  /* false */
```


Equality (4.2)

- When making a method call `p.equals(o)`:
  - Say variable `p` is declared of type `PointV2`
  - Variable `o` can be declared of any type (e.g., `PointV2`, `String`)
- We define `p` and `o` as ***equal*** if:
  - Either `p` and `o` refer to the same object;
  - Or:
    - `o` does **not** store the `null` address.
    - `p` and `o` at runtime point to objects 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 PointV2 {
  public boolean equals(Object obj) {
    if(this == null) { return false; }
```

A: If `this` was `null`, a ***NullPointerException*** would have occurred, preventing the body of `equals` from being executed.

Equality (4.3)

```
1  public class PointV2 {
2    public boolean equals(Object obj) {
3      ...
4      if(this.getClass() != obj.getClass()) { return false; }
5      PointV2 other = (PointV2) obj;
6      return this.x == other.x && this.y == other.y;
7    }
8  }
```

- `Object obj` at **L2** declares a parameter `obj` of type `Object`.
- `PointV2 other` at **L5** declares a variable `p` of type `PointV2`.
  We call such types declared at **compile time** as ***static type***.
- *Applicable attributes/methods* callable upon 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 `PointV2`).
- If we are **certain** 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 `PointV2`.
- The ***cast*** `(PointV2) obj` creates an **alias** of `obj`, upon which (or upon its alias such as `other`) more methods can be invoked.

Equality (5)

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

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

```
1  PointV2 p1 = new PointV2(3, 4);
2  PointV2 p2 = new PointV2(3, 4);
3  PointV2 p3 = new PointV2(4, 5);
4  System.out.println(p1 == p1);  /* true */
5  System.out.println(p1.equals(p1));  /* true */
6  System.out.println(p1 == p2);  /* false */
7  System.out.println(p1.equals(p2));  /* true */
8  System.out.println(p2 == p3);  /* false */
9  System.out.println(p2.equals(p3));  /* false */
```

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

Requirements 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*
  $x.equals(y) \wedge y.equals(z) \Rightarrow x.equals(z)$

API of `equals`

Equality in JUnit (1.1)

- ***assertSame***(`exp1`, `exp2`)
  - Passes if `exp1` and `exp2` are references to the same object
    ≈ ***assertTrue***(`exp1 == exp2`)
    ≈ ***assertFalse***(`exp1 != exp2`)

```
PointV1 p1 = new PointV1(3, 4);
PointV1 p2 = new PointV1(3, 4);
PointV1 p3 = p1;
assertSame(p1, p3);  ✓
assertSame(p2, p3);  ×
```

- ***assertEquals***(`exp1`, `exp2`)
  - ≈ `exp1 == exp2` if `exp1` and `exp2` are **primitive** type

```
int i = 10;
int j = 20;
assertEquals(i, j);  ×
```

Equality in JUnit (1.2)

- ***assertEquals***(`exp1`, `exp2`)
  - ≈ `exp1`.**equals**(`exp2`) if `exp1` and `exp2` are ***reference*** type

Case 1: If `equals` is ***not*** explicitly overridden in `exp1`'s dynamic type
≈ ***assertSame***(`exp1`, `exp2`)

```
PointV1 p1 = new PointV1(3, 4);
PointV1 p2 = new PointV1(3, 4);
PointV2 p3 = new PointV2(3, 4);
assertEquals(p1, p2);   × /* ∵ different PointV1 objects */
assertEquals(p2, p3);   × /* ∵ different object addresses */
```

Case 2: If `equals` is explicitly ***overridden*** in `exp1`'s dynamic type
≈ `exp1.equals(exp2)`

```
PointV1 p1 = new PointV1(3, 4);
PointV1 p2 = new PointV1(3, 4);
PointV2 p3 = new PointV2(3, 4);
assertEquals(p1, p2);   × /* ≈ p1.equals(p2) ≈ p1 == p2 */
assertEquals(p2, p3);   × /* ≈ p2.equals(p3) ≈ p2 == p3 */
assertEquals(p3, p2);   × /* ≈ p3.equals(p2) ≈ p3.getClass()==p2.getClass() */
```


Equality in JUnit (2)

```
@Test
public void testEqualityOfPointV1() {
  PointV1 p1 = new PointV1(3, 4); PointV1 p2 = new PointV1(3, 4);
  assertFalse(p1 == p2); assertFalse(p2 == p1);
  /* assertSame(p1, p2); assertSame(p2, p1); */ /* both fail */
  assertFalse(p1.equals(p2)); assertFalse(p2.equals(p1));
  assertTrue(p1.getX() == p2.getX() && p1.getY() == p2.getY());
}
@Test
public void testEqualityOfPointV2() {
  PointV2 p3 = new PointV2(3, 4); PointV2 p4 = new PointV2(3, 4);
  assertFalse(p3 == p4); assertFalse(p4 == p3);
  /* assertSame(p3, p4); assertSame(p4, p3); */ /* both fail */
  assertTrue(p3.equals(p4)); assertTrue(p4.equals(p3));
  assertEquals(p3, p4); assertEquals(p4, p3);
}
@Test
public void testEqualityOfPointV1andPointv2() {
  PointV1 p1 = new PointV1(3, 4); PointV2 p2 = new PointV2(3, 4);
  /* These two assertions do not compile because p1 and p2 are of different types. */
  /* assertFalse(p1 == p2); assertFalse(p2 == p1); */
  /* assertSame can take objects of different types and fail. */
  /* assertSame(p1, p2); */ /* compiles, but fails */
  /* assertSame(p2, p1); */ /* compiles, but fails */
  /* version of equals from Object is called */
  assertFalse(p1.equals(p2));
  /* version of equals from PointP2 is called */
  assertFalse(p2.equals(p1));
}
```


Equality (6.1)

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

```
1  public class Person {
2    private String firstName; private String lastName;
3    private double weight; private double height;
4    public boolean equals(Object obj) {
5      if(this == obj) { return true; }
6      if(obj == null || this.getClass() != obj.getClass()) { return false; }
7      Person other = (Person) obj;
8      return
9          this.weight == other.weight
10       && this.height == other.height
11       && this.firstName.equals(other.firstName)
12       && this.lastName.equals(other.lastName);
13   }
14 }
```

Q: At **L6**, will we get a ***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()`.

Equality (6.2)

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

```
1  public class Person {
2    private String firstName; private String lastName;
3    private double weight; private double height;
4    public boolean equals(Object obj) {
5      if(this == obj) { return true; }
6      if(obj == null || this.getClass() != obj.getClass()) { return false; }
7      Person other = (Person) obj;
8      return
9          this.weight == other.weight
10       && this.height == other.height
11       && this.firstName.equals(other.firstName)
12       && this.lastName.equals(other.lastName);
13   }
14 }
```

Q: At **L6**, if swapping the order of two operands of disjunction:
`this.getClass() != obj.getClass() || obj == null`
Will we get a ***NullPointerException*** if `obj` is **`null`**?
A: ***Yes*** ∵ Evaluation of operands is from left to right.

Equality (6.3)

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

```
1  public class Person {
2    private String firstName; private String lastName;
3    private double weight; private double height;
4    public boolean equals(Object obj) {
5      if(this == obj) { return true; }
6      if(obj == null || this.getClass() != obj.getClass()) { return false; }
7      Person other = (Person) obj;
8      return
9          this.weight == other.weight
10       && this.height == other.height
11       && this.firstName.equals(other.firstName)
12       && this.lastName.equals(other.lastName);
13   }
14 }
```

Q: At **L11 & L12**, where is the `equals` method defined?
A: The `equals` method ***overridden*** in the `String` class.
When implementing the `equals` method for your own class, ***reuse*** the `equals` methods ***overridden*** in other classes wherever possible.

Equality (6.4)

Person collectors are equal if containing equal lists of persons.

```
class PersonCollector {
  private Person[] persons;
  private int nop; /* number of persons */
  public PersonCollector() { ... }
  public void addPerson(Person p) { ... }
  public int getNop() { return this.nop; }
  public Person[] getPersons() { ... }
}
```

Redefine/***Override*** the `equals` method in `PersonCollector`.

```
1  public boolean equals(Object obj) {
2    if(this == obj) { return true; }
3    if(obj == null || this.getClass() != obj.getClass()) { return false; }
4    PersonCollector other = (PersonCollector) obj;
5    boolean equal = false;
6    if(this.nop == other.nop) {
7      equal = true;
8      for(int i = 0; equal && i < this.nop; i ++) {
9        equal = this.persons[i].equals(other.persons[i]);
10     }
11   }
12   return equal;
13 }
```


Equality in JUnit (3)

```
@Test
public void testPersonCollector() {
  Person p1 = new Person("A", "a", 180, 1.8);
  Person p2 = new Person("A", "a", 180, 1.8);
  Person p3 = new Person("B", "b", 200, 2.1);
  Person p4 = p3;
  assertFalse(p1 == p2); assertTrue(p1.equals(p2));
  assertTrue(p3 == p4); assertTrue(p3.equals(p4));
  PersonCollector pc1 = new PersonCollector();
  PersonCollector pc2 = new PersonCollector();
  assertFalse(pc1 == pc2); assertTrue(pc1.equals(pc2));
  pc1.addPerson(p1);
  assertFalse(pc1.equals(pc2));
  pc2.addPerson(p2);
  assertFalse(pc1.getPersons()[0] == pc2.getPersons()[0]);
  assertTrue(pc1.getPersons()[0].equals(pc2.getPersons()[0]));
  assertTrue(pc1.equals(pc2));
  pc1.addPerson(p3);
  pc2.addPerson(p4);
  assertTrue(pc1.getPersons()[1] == pc2.getPersons()[1]);
  assertTrue(pc1.getPersons()[1].equals(pc2.getPersons()[1]));
  assertTrue(pc1.equals(pc2));
  pc1.addPerson(new Person("A", "a", 175, 1.75));
  pc2.addPerson(new Person("A", "a", 165, 1.55));
  assertFalse(pc1.getPersons()[2] == pc2.getPersons()[2]);
  assertFalse(pc1.getPersons()[2].equals(pc2.getPersons()[2]));
  assertFalse(pc1.equals(pc2));
}
```


Beyond this lecture. . .

- Play with the source code `ExampleEqualityPointsPersons.zip`

  Tip. Use the debugger to step into executing the various versions of `equals` method.
- Go back to your Review Tutorial: Extend the `Product`, `Entry`, and `RefurbishedStore` classes by ***overridden*** versions of the `equals` method.

Index (1)

Index (2)

Index (3)