Aggregation and Composition

EECS2030 F: 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
- Aggregation vs. Composition: ***Terminology*** and ***Modelling***
- ***Aggregation***: Building Sharing Links & ***Navigating*** Objects
- ***Composition***: Implementation via ***Copy Constructors***
- ***Design Decision***: Aggregation or Composition?

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; }
}
```

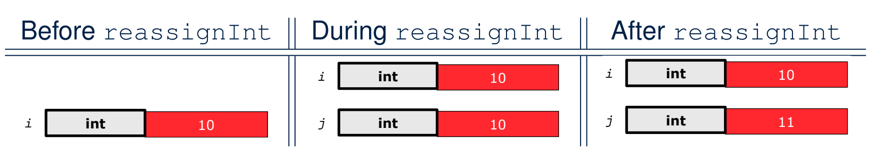
Call by Value (2.2.1)

```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 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)



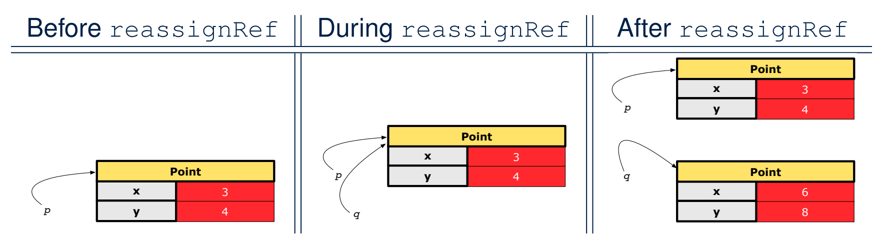
Call by Value (2.3.1)

```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.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)

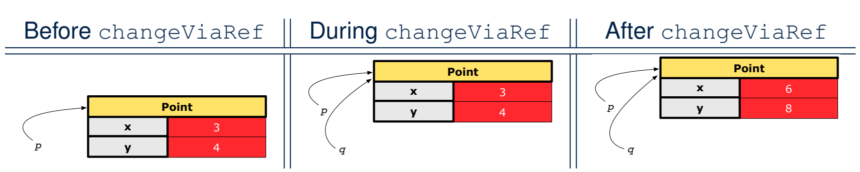
```java
public class Util {
  void reassignInt(int j) {
    j = j + 1; }
  void reassignRef(Point q) {
    Point np = new Point(6, 8);
    q = np; }
  void changeViaRef(Point q) {
    q.moveHorizontally(3);
    q.moveVertically(4); } }
```

```java
1  @Test
2  public void testCallByRef_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)



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 instances 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)


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

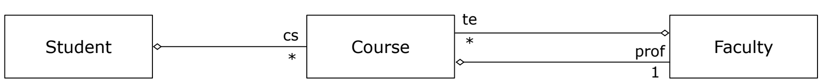
```java
public class Faculty {
  private String name;
  public Faculty(String name) {
    this.name = name;
  }
  public void setName(String name) {
    this.name = name;
  }
  public String getName() {
    return this.name;
  }
}
```

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)




```java
public class Student {
  private String id; Course[] cs; int noc; /* # of courses */
  public Student(String id) { ... }
  public void addCourse(Course c) { ... }
  public Course[] getCS() { ... }
}
```

```java
public class Course { private String title; private Faculty prof; }
```

```java
public class Faculty {
  private String name; Course[] te; int not; /* # of teaching */
  public Faculty(String name) { ... }
  public void addTeaching(Course c) { ... }
  public Course[] getTE() { ... }
}
```

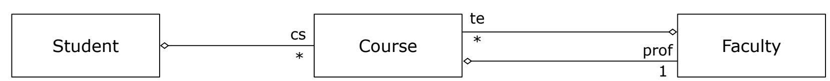

Aggregation: Independent Containees Shared by Containers (2.2)

```java
@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()[0].getProf());
  assertTrue(s.getCS()[0].getProf()
             == s.getCS()[1].getProf());
  assertTrue(eecs3311 == s.getCS()[1]);
  assertTrue(s.getCS()[1] == p.getTE()[1]);
}
```


The Dot Notation (3.1)

In real life, the relationships among classes are sophisticated.




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

```java
public class Course {
  private String title;
  private Faculty prof;
}
```

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

- Assume: ***private*** attributs and ***public*** accessors
- ***Aggregation links*** between classes constrain how you can *navigate* among these classes.
- In the context of class `Student`:
  - Writing `cs` denotes the array of registered courses.
  - Writing `cs[i]` (where `i` is a valid index) navigates to the class `Course`, which changes the context to class `Course`.

OOP: The Dot Notation (3.2)

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

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

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

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


OOP: The Dot Notation (3.3)

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

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

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

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


OOP: The Dot Notation (3.4)

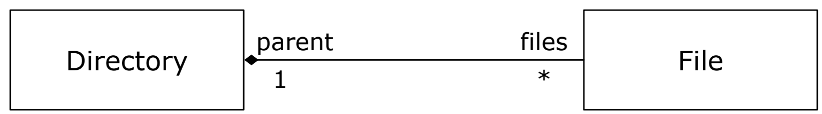
```
public class Student {
  private String id;
  private Course[] cs;
}
```

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

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

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


Composition: Dependent Containees Owned by Containers (1.1)



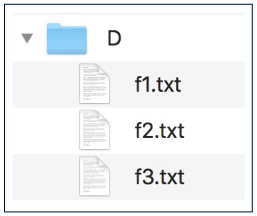
Requirement: Files are not shared among directories.

Assume: ***private*** attributs and ***public*** accessors

```
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)

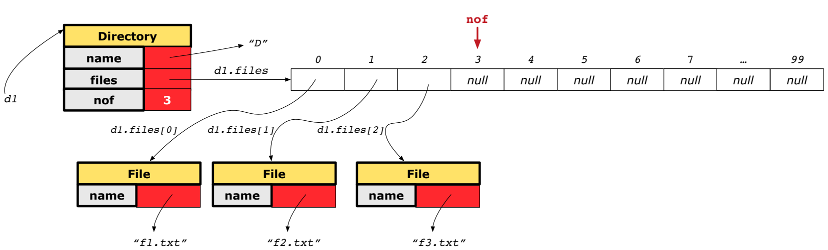



```
1 @Test
2 public void testComposition() {
3   Directory d1 = new Directory("D");
4   d1.addFile("f1.txt");
5   d1.addFile("f2.txt");
6   d1.addFile("f3.txt");
7   assertTrue(d1.getFiles()[0].getName().equals("f1.txt"));
8 }
```

- **L4**: 1st `File` object is created and ***owned exclusively*** by `d1`.
  No other directories are sharing this `File` object with `d1`.
- **L5**: 2nd `File` object is created and ***owned exclusively*** by `d1`.
  No other directories are sharing this `File` object with `d1`.
- **L6**: 3rd `File` object is created and ***owned exclusively*** by `d1`.
  No other directories are sharing this `File` object with `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: Implement a *copy constructor* for `Directory`.
A ***copy constructor*** is a constructor which initializes attributes from the argument object `other` (of the ***same type*** `Directory`).

```
class Directory {
  Directory(Directory other) {
    /* Initialize attributes via attributes of '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 =.

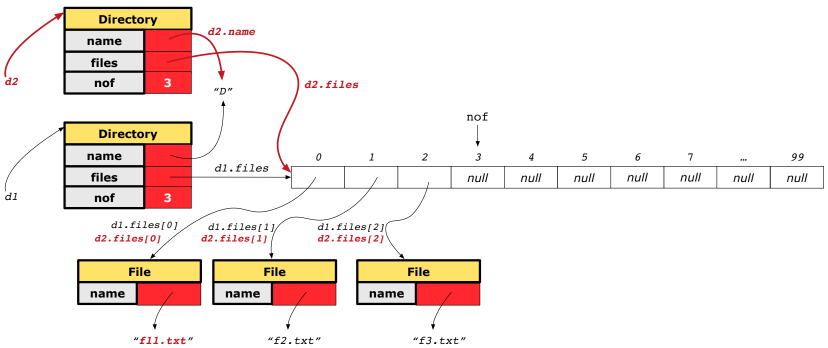
```
class Directory {
  Directory(Directory other) {
    /* value copying for primitive type */
    nof = other.nof;
    /* address copying for reference type */
    name = other.name; files = other.files; } }
```

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

```
@Test
public 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.getFiles() == d2.getFiles()); /* violation of composition */
  d2.getFiles()[0].changeName("f11.txt");
  assertFalse(d1.getFiles()[0].getName().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*

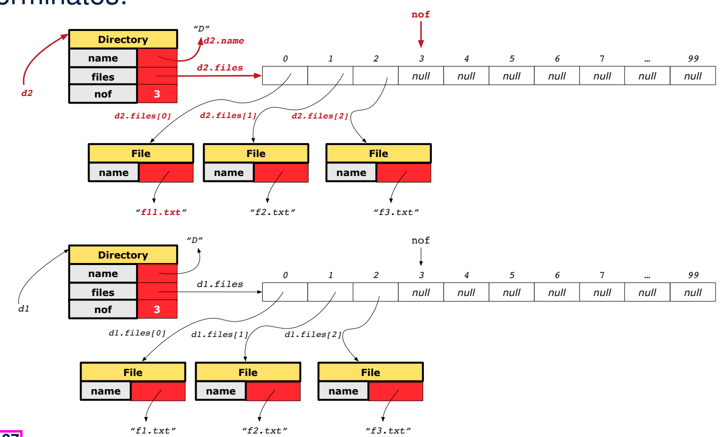
```
class File {
  File(File other) {
    this.name =
      new String(other.name);
  }
}
```

```
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 < other.nof; i ++) {
      File src = other.files[i];
      File nf = new File(src);
      this.addFile(nf);
    }
  }
  void addFile(File f) { ... }
}
```

```
@Test
public 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.getFiles() != d2.getFiles()); /* composition preserved */
  d2.getFiles()[0].changeName("f11.txt");
  assertTrue(d1.getFiles()[0].getName().equals("f1.txt"));
}
```


Composition: Dependent Containees Owned by Containers (1.5.2)

Right before test method `testDeepCopyConstructor` terminates:



Composition: Dependent Containees Owned by Containers (1.5.3)

Q: Composition Violated?

```
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 < other.nof; i ++) {
      File src = other.files[i];
      this.addFile(src);
    }
  }
  void addFile(File f) { ... }
}
```

```
@Test
public 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.getFiles() != d2.getFiles()); /* composition preserved */
  d2.getFiles()[0].changeName("f11.txt");
  assertTrue(d1.getFiles()[0] == d2.getFiles()[0]); /* composition violated! */
}
```

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 :

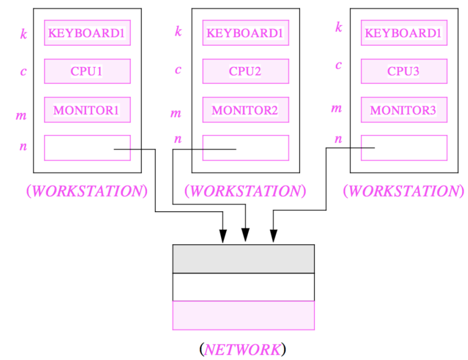
- Containers (e.g, `Directory`, `Department`) *own* exclusive access to their containees (e.g., `File`, `Faculty`).
- Containees cannot exist without their containers.
- Destroying a container destroys its containeees *cascadingly*.

Aggregation vs. Composition (2)

Aggregations and *Compositions* may exist at the same time!

e.g., Consider a workstation:

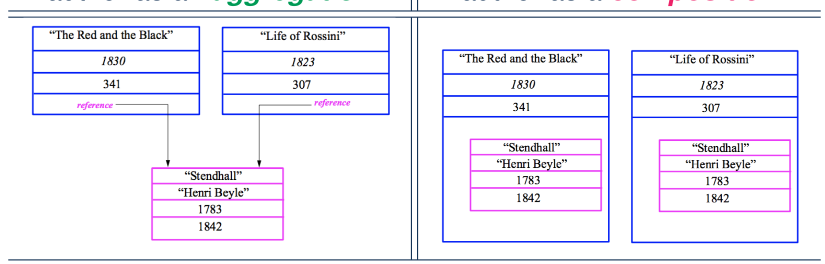
- Each workstation owns CPU, monitor, keyword. [***compositions***]
- All workstations share the same network. [***aggregations***]



Aggregation vs. Composition (3)

Problem: Every published book has an author. Every author may publish more than one books. Should the author field of a book be implemented as an ***aggregation*** or a ***composition***?

author as an ***aggregation***	author as a ***composition***



Hyperlinked author page	Physical printed copies

Beyond this lecture...

Reproduce the ***aggregation*** and ***composition*** code examples in Eclipse.

Tip. Use the debugger to verify whether or not there is ***sharing***.

Index (1)

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