Composite & Visitor Design Patterns

EECS4302 A:
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Learning Objectives

1. Motivating Problem: ***Recursive*** Systems
2. Three Design Attempts
3. Inheritance: ***Abstract Class*** vs. ***Interface***
4. Fourth Design Attempt: ***Composite Design Pattern***
5. Implementing and Testing the Composite Design Pattern

Backgroundn Readings

You may want to review the advanced OOP concepts from EECS2030 (`https://www.eecs.yorku.ca/~wangcw/teaching/lectures/index.html#EECS2030_F21`):

- Inheritance [Weeks 7, 8, 9]
  - Static Type vs. Dynamic Types
  - Polymorphic Variable Assignment
  - Polymorphic Arrays
  - Dynamic Binding
- Genericity [Weeks 10, 11]

Motivating Problem (1)

- Many manufactured systems, such as computer systems or stereo systems, are composed of ***individual components*** and ***sub-systems*** that contain components.

  e.g., A computer system is composed of:
  - Base equipment (*hard drives*, *cd-rom drives*)

    e.g., Each *drive* has **properties**: e.g., power consumption and cost.
  - Composite equipment such as *cabinets*, *busses*, and *chassis*

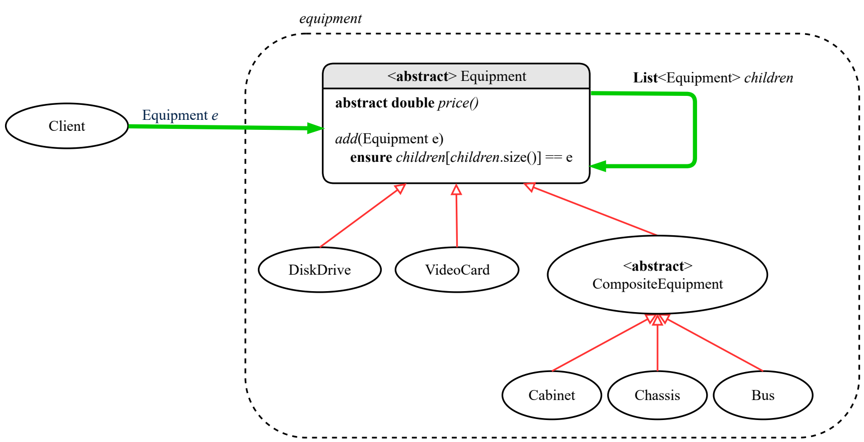
    e.g., Each *cabinet* contains various types of *chassis*, each of which containing components (*hard-drive*, *power-supply*) and *busses* that contain *cards*.
- Design a system that will allow us to easily *build* systems and *compute* their aggregate cost and power consumption.

Motivating Problem (2)

Design of ***hierarchies*** represented in ***tree structures***

Challenge : There are ***base*** and ***recursive*** modelling artifacts.

Design Attempt 1: Architecture



Java List API

Design Attempt 1: Flaw?

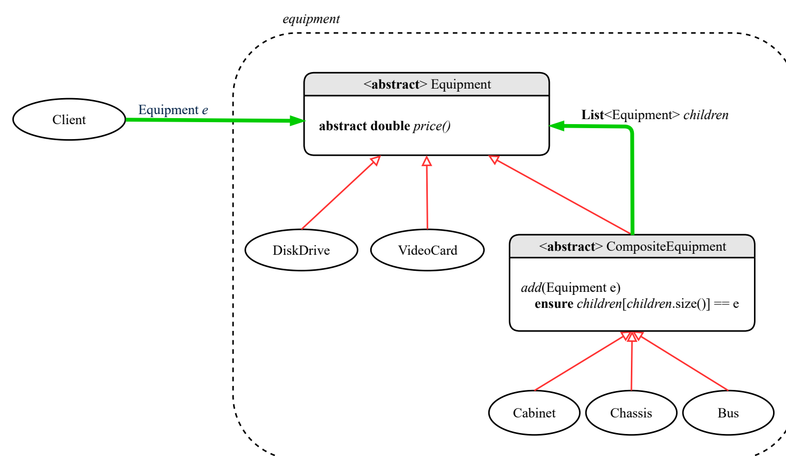
Q: Any flaw of this first design?

A: Two “composite” features defined at the `Equipment` level:

- `List<Equipment> children`
- `add(Equipment child)`

⇒ Inherited to each ***base*** equipment (e.g., `DiskDrive`), for which such features are **not** applicable.

Design Attempt 2: Architecture



Design Attempt 2: Flaw?

Q: Any flaw of this second design?

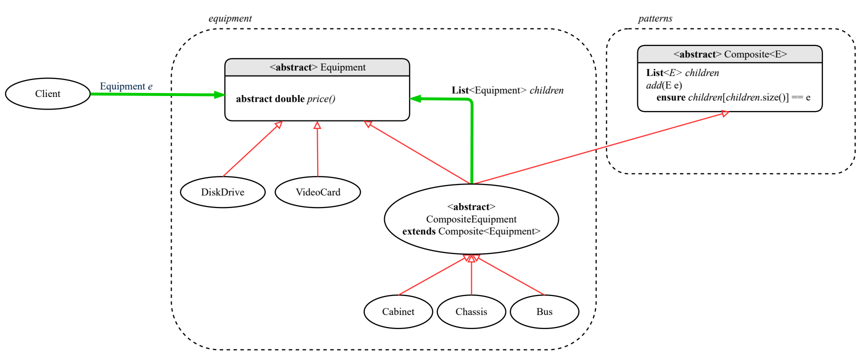
A: Two “composite” features defined at the `Composite` level:

- `List<Equipment> children`
- `add(Equipment child)`

⇒ Multiple ***types*** of the composite (e.g., equipment, furniture) cause duplicates of the `Composite` class.

⇒ Use a ***generic (type) parameter*** to ***abstract*** away the ***concrete*** type of any potential composite.

Design Attempt 3: Architecture



Design Attempt 3: Flaw?

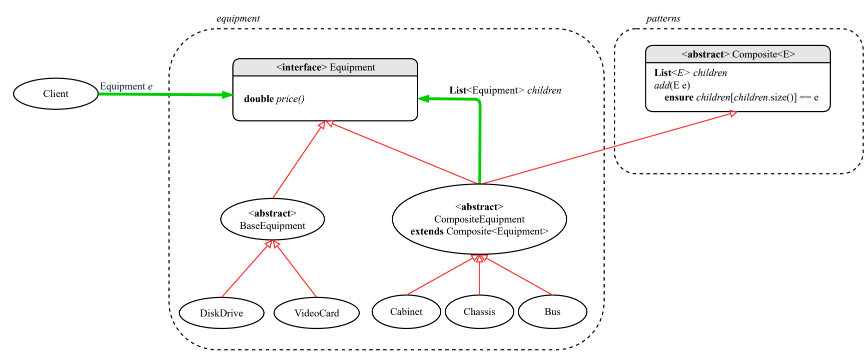
Q: Any flaw of this third design?

A: It does **not** compile:

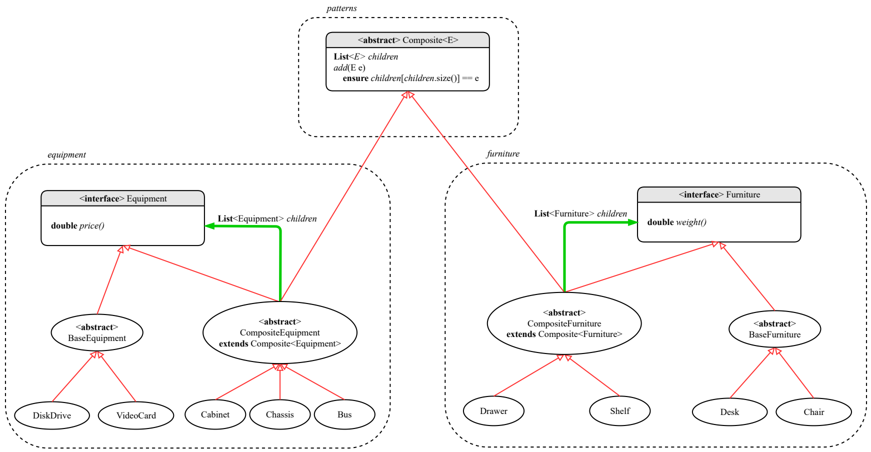
Java does not support ***multiple inheritance***!

- See: https://docs.oracle.com/javase/tutorial/java/IandI/multipleinheritance.html
- A class may inherit from at most one class (**abstract** or not). **Rationale.** ***MI*** results in name clashes [a.k.a. the ***Diamond Problem***].
- However, a class may implement multiple ***interfaces***. [workaround for implementation]

The Composite Pattern: Architecture



The Composite Pattern: Instantiations



Implementing the Composite Pattern (1)

```
public interface Equipment {
  public String name();
  public double price(); /* uniform access */
}
```

```
public abstract class BaseEquipment implements Equipment {
  private String name;
  private double price;
  public BaseEquipment(String name, double price) {
    this.name = name; this.price = price;
  }
  public String name() { return this.name; }
  public double price() { return this.price; }
}
```

```
public class VideoCard extends BaseEquipment {
  public VideoCard(String name, double price) {
    super(name, price);
  }
}
```


Implementing the Composite Pattern (2.1)

```
import java.util.List;

public abstract class Composite<E> {
  protected List<E> children;

  public void add(E child) {
    children.add(child); /* polymorphism */
  }
}
```


Implementing the Composite Pattern (2.2)

```
import java.util.ArrayList;

public abstract class CompositeEquipment
  extends Composite<Equipment>
  implements Equipment
{
  private String name;
  public CompositeEquipment(String name) {
    this.name = name;
    this.children = new ArrayList<>();
  }
  public String name() { return this.name; }
  public double price() {
    double result = 0.0;
    for(Equipment child : this.children) {
      result = result + child.price(); /* dynamic binding */
    }
    return result;
  }
}
```

Implementing the Composite Pattern (2.2)

```
public class Chassis extends CompositeEquipment {
  public Chassis(String name) {
    super(name);
  }
}
```


Testing the Composite Pattern

```
@Test
public void test_equipment() {
  Equipment card, drive;
  Bus bus;
  Cabinet cabinet;
  Chassis chassis;

  card = new VideoCard("16Mbs Token Ring", 200);
  drive = new DiskDrive("500 GB harddrive", 500);
  bus = new Bus("MCA Bus");
  chassis = new Chassis("PC Chassis");
  cabinet = new Cabinet("PC Cabinet");
  bus.add(card);
  chassis.add(bus);
  chassis.add(drive);
  cabinet.add(chassis);

  assertEquals(700.00, cabinet.price(), 0.1);
}
```


Summay: The Composite Pattern

- **Design**: Categorize into ***base*** artifacts or ***recursive*** artifacts.
- **Programming**:
  Build the ***tree structure*** representing some ***hierarchy***.
- **Runtime**:
  Allow clients to treat ***base*** objects (leafs) and ***recursive*** compositions (nodes) *uniformly* (e.g., `price()`).

  ⇒ *Polymorphism* : ***leafs*** and ***nodes*** are "substitutable".

  ⇒ *Dynamic Binding* : Different versions of the same operation is applied on ***base objects*** and ***composite objects***.

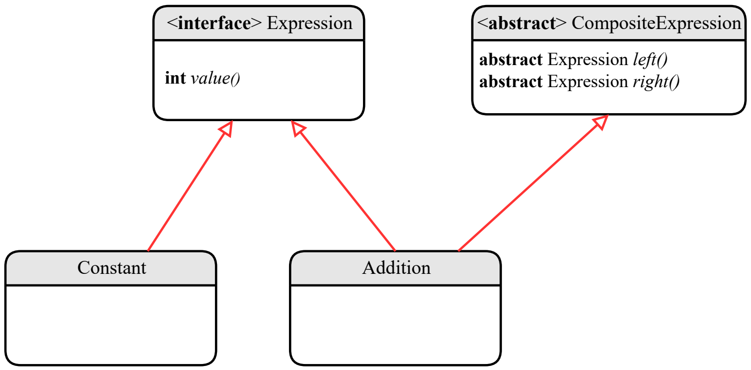
  e.g., Given ***Equipment*** e :
  - `e.price()` may return the unit price, e.g., of a `DiskDrive`.
  - `e.price()` may sum prices, e.g., of a `Chassis`' containing equipment.

Learning Objectives

1. Motivating Problem: ***Processing*** Recursive Systems
2. First Design Attempt: Cohesion & Single-Choice Principle?
3. Design Principles:
   - *Cohesion*
   - *Single Choice* Principle
   - *Open-Closed* Principle
4. Second Design Attempt: ***Visitor Design Pattern***
5. Implementing and Testing the Visitor Design Pattern

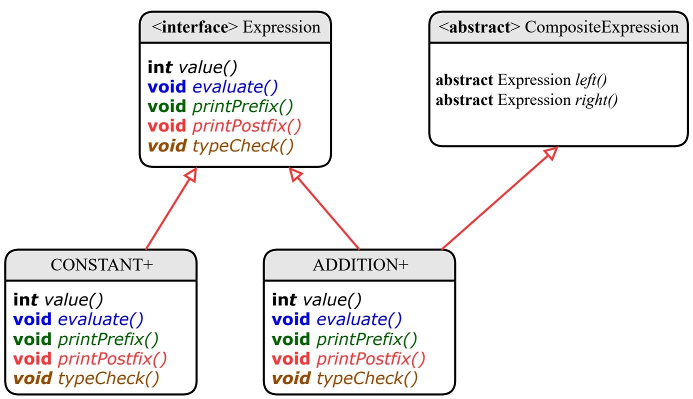
Motivating Problem (1)

Based on the *composite pattern* you learned, design classes to model ***structures*** of arithmetic expressions (e.g., `341`, `2`, `341 + 2`).



Motivating Problem (2)

Extend the *composite pattern* to support ***operations*** such as `evaluate`, pretty printing (`print_prefix`, `print_postfix`), and `type_check`.



Design Principles: Information Hiding & Single Choice

- ***Cohesion***:
  - A class/module groups ***relevant*** features (data & operations).
- ***Single Choice Principle*** (SCP):
  - When a ***change*** is needed, there should be ***a single place*** (or ***a minimal number of places***) where you need to make that change.
  - Violation of SCP means that your design contains ***redundancies***.

Problems of Extended Composite Pattern

- Distributing **unrelated** ***operations*** across nodes of the ***abstract syntax tree*** violates the ***single-choice principle***:

  To add/delete/modify an operation

  ⇒ Change of all descendants of `Expression`
- Each node class lacks in ***cohesion***:

  A **class** should group ***relevant*** concepts in a **single** place.

  ⇒ Confusing to mix codes for evaluation, pretty printing, type checking.

  ⇒ Avoid "polluting" the classes with these **unrelated** operations.

Open/Closed Principle

- Software entities (classes, features, etc.) should be ***open*** for ***extension***, but ***closed*** for ***modification***.

  ⇒ As a system evolves, we:
  - May add/modify the ***open*** (unstable) part of system.
  - May **not** add/modify the ***closed*** (stable) part of system.
- e.g., In designing the application of an expression language:
  - **ALTERNATIVE 1**:
    Syntactic constructs of the language may be ***open***, whereas operations on the language may be ***closed***.
  - **ALTERNATIVE 2**:
    Syntactic constructs of the language may be ***closed***, whereas operations on the language may be ***open***.

Visitor Pattern

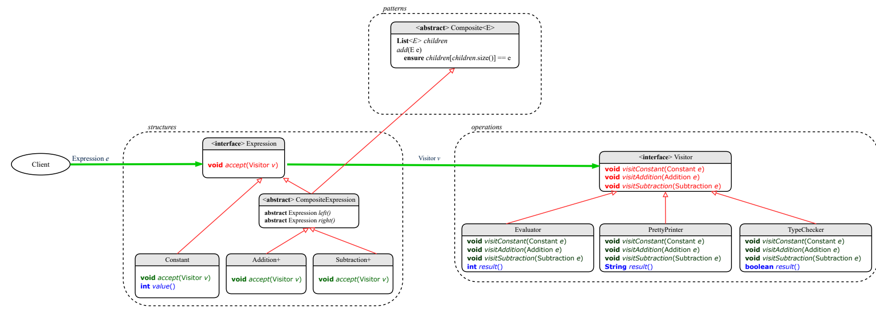
- ***Separation of concerns***:
  - Set of language (syntactic) constructs
  - Set of operations

  ⇒ Classes from these two sets are *decoupled* and organized into two separate packages.
- ***Open-Closed Principle*** (OCP): [**ALTERNATIVE 2**]
  - ***Closed***, staple part of system: set of language constructs
  - ***Open***, unstable part of system: set of operations

  ⇒ ***OCP*** helps us determine if the ***Visitor Pattern*** is applicable.

  ⇒ If it is determined that language constructs are ***open*** and operations are ***closed***, then do **not** use the Visitor Pattern.

Visitor Pattern: Architecture



Visitor Pattern Implementation: Structures

Package ***structures***
- Declare `void accept(Visitor v)` in abstract class `Expression`.
- Implement `accept` in each of `Expression`'s descendant classes.

```
public class Constant implements Expression {
  ...
  public void accept(Visitor v) {
    v.visitConstant(this);
  }
}
```

```
public class Addition extends CompositeExpression {
  ...
  public void accept(Visitor v) {
    v.visitAddition(this);
  }
}
```

Visitor Pattern Implementation: Operations

Package ***operations***

- For each descendant class `C` of `Expression`, declare a method header `void visitC (e: C)` in the ***interface*** `Visitor`.

```
public interface Visitor {
  public void visitConstant(Constant e);
  public void visitAddition(Addition e);
  public void visitSubtraction(Subtraction e);
}
```

- Each descendant of `VISITOR` denotes a kind of operation.

```
public class Evaluator implements Visitor {
  private int result;
  ...
  public void visitConstant(Constant e) {
    this.result = e.value();
  }
  public void visitAddition(Addition e) {
    Evaluator evalL = new Evaluator();
    Evaluator evalR = new Evaluator();
    e.getLeft().accept(evalL);
    e.getRight().accept(evalR);
    this.result = evalL.result() + evalR.result();
  }
}
```


Testing the Visitor Pattern

```
1  @Test
2  public void test_expression_evaluation() {
3    CompositeExpression add;
4    Expression c1, c2;
5    Visitor v;
6    c1 = new Constant(1); c2 = new Constant(2);
7    add = new Addition(c1, c2);
8    v = new Evaluator();
9    add.accept(v);
10   assertEquals(3, ((Evaluator) v).result());
11 }
```

Double Dispatch in **Line 9**:

1. ***DT*** of `add` is `Addition` ⇒ Call `accept` in `ADDITION`.
   `v.visitAddition(add)`
2. ***DT*** of `v` is `Evaluator` ⇒ Call `visitAddition` in `Evaluator`.
   visiting result of `add.left()` + visiting result of `add.right()`

To Use or Not to Use the Visitor Pattern

- In the ***visitor pattern***, what kind of ***extensions*** is easy?
  Adding a new kind of ***operation*** element is easy.
  To introduce a new operation for generating C code, we only need to introduce a new descendant class `CCodeGenerator` of `Visitor`, then implement how to handle each language element in that class.
  ⇒ *Single Choice Principle* is satisfied.
- In the ***visitor pattern***, what kind of ***extensions*** is hard?
  Adding a new kind of ***structure*** element is hard.
  After adding a descendant class `Multiplcation` of `Expression`, every concrete visitor (i.e., descendant of `Visitor`) must be amended with a new `visitMultiplication` operation.
  ⇒ *Single Choice Principle* is violated.
- The applicability of the visitor pattern depends on to what extent the ***structure*** will change.
  ⇒ Use visitor if ***operations*** (applied to structure) change often.
  ⇒ Do not use visitor if the ***structure*** changes often.

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