Principles of Software Construction: Objects, Design, and Concurrency (Part 2: Designing (Sub-)Systems)

Assigning Responsibilities

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Learning Goals

- Apply GRASP patterns to assign responsibilities in designs
- Reason about tradeoffs among designs

Today's topics

- Object-Oriented Design: "After identifying your requirements and creating a domain model, then add methods to the software classes, and define the messaging between the objects to fulfill the requirements."
- But how?
  - How should concepts be implemented by classes?
  - What method belongs where?
  - How should the objects interact?
  - This is a critical, important, and non-trivial task

Responsibilities

- Responsibilities are related to the obligations of an object in terms of its behavior.
- Two types of responsibilities:
  - knowing
  - doing
- Doing responsibilities of an object include:
  - doing something itself, such as creating an object or doing a calculation
  - initiating action in other objects
  - controlling and coordinating activities in other objects
- Knowing responsibilities of an object include:
  - knowing about private encapsulated data
  - knowing about related objects
  - knowing about things it can derive or calculate

Design Goals, Principles, and Patterns

- Design Goals
  - Design for change, understanding, reuse, division of labor, …
- Design Principle
  - Low coupling, high cohesion
  - Low representational gap
  - Law of demeter
- Design Heuristics (GRASP)
  - Information expert
  - Creator
  - Controller

Goals, Principles, Guidelines

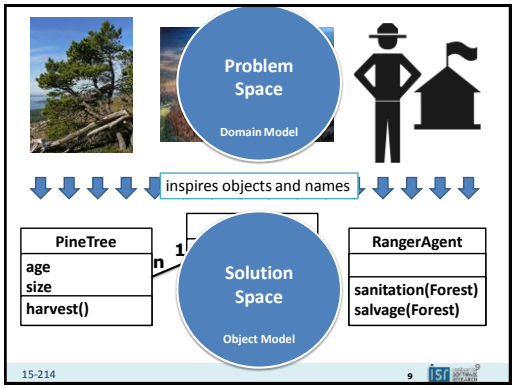
- Design Goals
  - Desired quality attributes of software
  - Driven by cost/benefit economics
  - Examples: design for change, understanding, reuse, …
- Design Principles
  - Guidelines for designing software
  - Support one or more design goals
  - Examples: Information hiding, low repr. gap, low coupling, high cohesion, …
- Design Heuristics
  - Rules of thumb for **low-level** design decisions
  - Promote design principles, and ultimately design goals
  - Example: Creator, Expert, Controller
- Design Patterns
  - General solutions to recurring design problems
  - Promote design goals, but may add complexity or involve tradeoffs
  - Examples: Decorator, Strategy, Template Method

X Goals, principles, heuristics, patterns may conflict
  - Use high-level goals of project to resolve

GRASP Patterns

- GRASP = General Responsibility Assignment Software Patterns
- Patterns of assigning **responsibilities**
  - reason about design trade-offs when assigning methods and fields to classes
- The GRASP patterns are a **learning aid** to
  - help one understand essential object design
  - apply design reasoning in a methodical, rational, explainable way
  - lower level and more local reasoning than most **design patterns**

DESIGN PRINCIPLE: LOW REPRESENTATIONAL GAP



Designs with Low Representational Gap

- Create software class for each domain class, create corresponding relationships
- Design goal: Design for change
- This is only a starting point!
  - Not all domain classes need software correspondence; pure fabrications might be needed
  - Other principles often more important

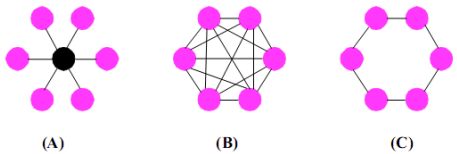
DESIGN PRINCIPLE: LOW COUPLING

Design Principle: Low Coupling

A module should depend on as few other modules as possible

- Enhances understandability (design for underst.)
  - Limited understanding of context, easier to understand in isolation
- Reduces the cost of change (design for change)
  - Little context necessary to make changes
  - When a module interface changes, few modules are affected (reduced rippling effects)
- Enhances reuse (design for reuse)
  - Fewer dependencies, easier to adapt to a new context

Topologies with different coupling



High Coupling is undesirable

- Element with low coupling depends on only few other elements (classes, subsystems, …)
  - "few" is context-dependent
- A class with high coupling relies on many other classes
  - Changes in related classes force local changes; changes in local class forces changes in related classes (brittle, rippling effects)
  - Harder to understand in isolation.
  - Harder to reuse because requires additional presence of other dependent classes
  - Difficult to extend – changes in many places

Which classes are coupled?
How can coupling be improved?

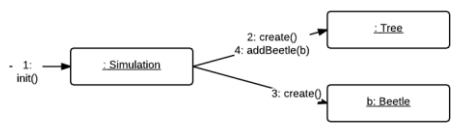
```
class Shipment {
        private List<Box> boxes;
        int getWeight() {
                int w=0;
                for (Box box: boxes)
                        for (Item item: box.getItems())
                                w += item.weight;
                return w;
}
class Box {
        private List<Item> items;
        Iterable<Item> getItems() { return items;}
}
class Item {
        Box containedIn;
        int weight;
}
```


Coupling Example

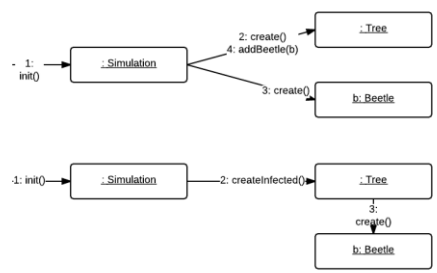
- Create a Tree and "infest" it with beetles

Simulation | Beetle | Tree

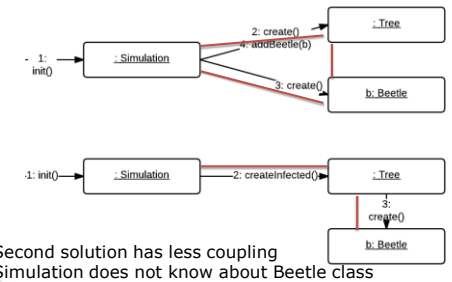
Coupling Example



Coupling Example



Coupling Example



Second solution has less coupling
Simulation does not know about Beetle class

Common Forms of Coupling in OO Languages

- Type X has a field of type Y
- Method m in type X refers to type Y
  - e.g. a method argument, return value, local variable, or static method call
- Type X is a direct or indirect subclass of Type Y
- Type Y is an interface, and Type X implements that interface

Low Coupling: Discussion

- Low Coupling is a principle to keep in mind during all design decisions
- It is an underlying goal to continually consider.
- It is an evaluative principle that a designer applies while evaluating all design decisions.
- Low Coupling supports design of more independent classes; reduces the impact of change.
- Context-dependent; should be considered together with cohesion and other principles and patterns
- Prefer coupling to interfaces over coupling to implementations

Law of Demeter

- *Each module should have only limited knowledge about other units: only units "closely" related to the current unit*
- In particular: Don't talk to strangers!
- For instance, no a.getB().getC().foo()

```
for (Item i: shipment.getBox().getItems())
        i.getWeight() …
```


Coupling: Discussion

- Subclass/superclass coupling is particularly strong
  - protected fields and methods are visible
  - subclass is fragile to many superclass changes, e.g. change in method signatures, added abstract methods
  - *Guideline: prefer composition to inheritance, to reduce coupling*
- High coupling to very stable elements is usually not problematic
  - A stable interface is unlikely to change, and likely well-understood
  - *Prefer coupling to interfaces over coupling to implementations*
- Coupling is one principle among many
  - Consider cohesion, low repr. gap, and other principles

Coupling to "non-standards"

- Libraries or platforms may include non-standard features or extensions
- Example: JavaScript support across Browsers
  - old content
- In JavaScript…
  - MSIE: e1.innerText = "new content"
  - Firefox: e1.textContent = "new content"

W3C-compliant DOM standard

Design Goals

- Explain how low cohesion supports
  - design for change
  - design for understandability
  - design for division of labor
  - design for reuse
  - …

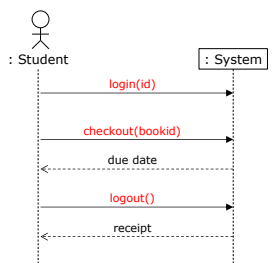
Design Goals

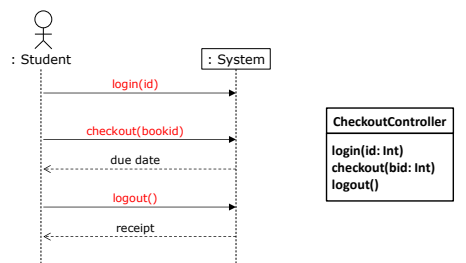
- design for change
  - changes easier because fewer dependencies on fewer other objects
  - changes are less likely to have rippling effects
- design for understandability
  - fewer dependencies to understand (e.g., a.getB().getC().foo())
- design for division of labor
  - smaller interfaces, easier to divide
- design for reuse
  - easier to reuse without complicated dependencies

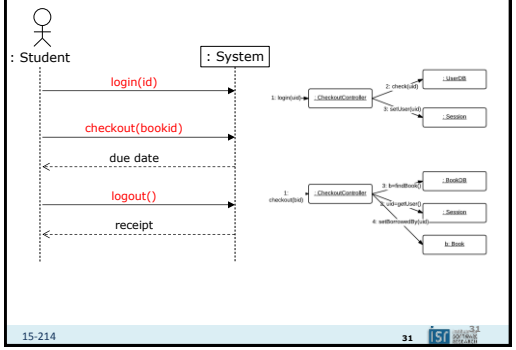
GRASP PATTERN: CONTROLLER
DESIGN PATTERN: FAÇADE

Controller (GRASP)

- Problem: What object receives and coordinates a system operation (event)?
- Solution: Assign the responsibility to an object representing
  - the overall system, device, or subsystem (façade controller), or
  - a use case scenario within which the system event occurs (use case controller)







Controller: Discussion

- A Controller is a coordinator
  - does not do much work itself
  - delegates to other objects
- Façade controllers suitable when not "too many" system events
  - -> one overall controller for the system
- Use case controller suitable when façade controller "bloated" with excessive responsibilities (low cohesion, high coupling)
  - -> several smaller controllers for specific tasks
- Closely related to Façade design pattern (future lecture)

Controller: Discussion of Design Goals/Strategies

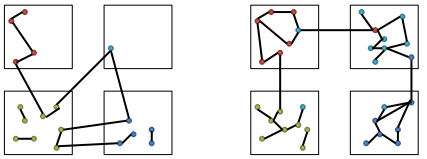
- Decrease coupling
  - User interface and domain logic are decoupled from each other
    - Understandability: can understand these in isolation, leading to:
    - Evolvability: both the UI and domain logic are easier to change
  - Both are coupled to the controller, which serves as a mediator, but this coupling is less harmful
    - The controller is a smaller and more stable interface
    - Changes to the domain logic affect the controller, not the UI
    - The UI can be changed without knowing the domain logic design
- Support reuse
  - Controller serves as an interface to the domain logic
  - Smaller, explicit interfaces support evolvability
- But, bloated controllers increase coupling and decrease cohesion; split if applicable

DESIGN PRINCIPLE: HIGH COHESION

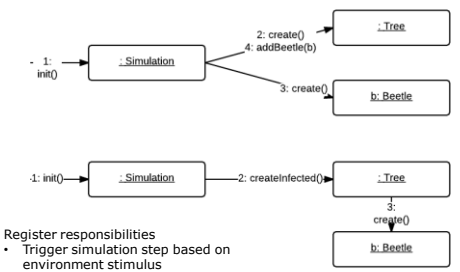
Design Principle: Cohesion

A module should have a small set of related responsibilities

- Enhances understandability (design for understandability)
  - A small set of responsibilities is easier to understand
- Enhances reuse (design for reuse)
  - A cohesive set of responsibilities is more likely to recur in another application



Cohesion in Coupling Example



Register responsibilities
- Trigger simulation step based on environment stimulus
- Coordinate creation of domain objects


```
class DatabaseApplication
        //... database fields
        //... Logging Stream
        //... Cache Status
        public void authorizeOrder(Data data, User currentUser, ...){
                // check authorization
                // lock objects for synchronization
                // validate buffer
                // log start of operation
                // perform operation
                // log end of operation
                // release lock on objects
        }
        public void startShipping(OtherData data, User currentUser, ...){
                // check authorization
                // lock objects for synchronization
                // validate buffer
                // log start of operation
                // perform operation
                // log end of operation
                // release lock on objects
        }
}
```


Cohesion in Graph Implementations

Graph is tasked with not just data, but also algorithmic responsibilities

```
class Graph {
        Node[] nodes;
        boolean[] isVisited;
}
class Algorithm {
        int shortestPath(Graph g, Node n, Node m) {
                for (int i; ...)
                        if (!g.isVisited[i]) {
                                ...
                                g.isVisited[i] = true;
                        }
                }
                return v;
        }
}
```


Monopoly Example

Which design has higher cohesion?

```
class Player {
        Board board;
        /* in code somewhere... */ getSquare(n);
        Square getSquare(String name) {
                for (Square s: board.getSquares())
                        if (s.getName().equals(name))
                                return s;
                return null;
}}
```

```
class Player {
        Board board;
        /* in code somewhere... */ board.getSquare(n);
}
class Board{
        List<Square> squares;
        Square getSquare(String name) {
                for (Square s: squares)
                        if (s.getName().equals(name))
                                return s;
                return null;
}}
```


Hints for Identifying Cohesion

- Use one color per concept
- Highlight all code of that concept with the color
- => Classes/ methods should have few colors

Hints for Identifying Cohesion

- There is no clear definition of what is a "concept"
- Concepts can be split into smaller concepts
  - Graph with search vs. Basic Graph + Search Algorithm vs. Basic Graph + Search Framework + Concrete Search Algorithm etc
- Requires engineering judgment

Cohesion: Discussion

- Very Low Cohesion: A Class is solely responsible for many things in very different functional areas
- Low Cohesion: A class has sole responsibility for a complex task in one functional area
- High Cohesion: A class has moderate responsibilities in one functional area and collaborates with classes to fulfil tasks
- Advantages of high cohesion
  - Classes are easier to maintain
  - Easier to understand
  - Often support low coupling
  - Supports reuse because of fine grained responsibility
- Rule of thumb: a class with high cohesion has relatively few methods of highly related functionality; does not do too much work

Coupling vs Cohesion (Extreme cases)

Think about extreme cases:

- Very low coupling?
- Very high cohesion?

```
class Graph {
        Node[] nodes;
        boolean[] isVisited;
}
class Algorithm {
        int shortestPath(Graph g, Node n, Node m) {
                for (int i; ...)
                        if (!g.isVisited[i]) {
                                ...
                                g.isVisited[i] = true;
                        }
                }
                return v;
        }
```


Coupling vs Cohesion (Extreme cases)

- All code in one class/method
  - very low coupling, but very low cohesion
- Every statement separated
  - very high cohesion, but very high coupling
- Find good tradeoff; consider also other principles, e.g., low representational gap

GRASP PATTERN: INFORMATION EXPERT

Information Expert (GRASP Pattern/Design Heuristic)

- Heuristic: **Assign a responsibility to the class that has the information necessary to fulfill the responsibility**
- Start assigning responsibilities by clearly stating responsibilities!
- Typically follows common intuition
- Software classes instead of Domain Model classes
  - If software classes do not yet exist, look in Domain Model for fitting abstractions (-> correspondence)

Which class has all the information to compute the shipment's weight?

```
class Shipment {
        private List<Box> boxes;
        int getWeight() {
                int w=0;
                for (Box box: boxes)
                        for (Item item: box.getItems())
                                w += item.weight;
                return w;
}
class Box {
        private List<Item> items;
        Iterable<Item> getItems() { return items;}
}
class Item {
        Box containedIn;
        int weight;
}
```

Information Expert -> "Do It Myself Strategy"

- Expert usually leads to designs where a software object does those operations that are normally done to the inanimate real-world thing it represents
  - a sale does not tell you its total; it is an inanimate thing
- In OO design, all software objects are "alive" or "animated," and they can take on responsibilities and do things.
- They do things related to the information they know.

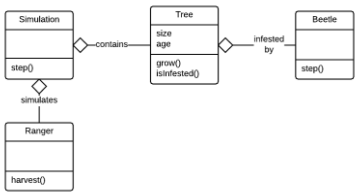
GRASP PATTERN: CREATOR

Creator (GRASP Pattern/Design Heuristic)

- Problem: Who creates an A?
- Solution: **Assign class responsibility of creating instance of class A to B if**
  - B aggregates A objects
  - B contains A objects
  - B records instances of A objects
  - B closely uses A objects
  - B has the initializing data for creating A objects
- the more the better; where there is a choice, prefer
  - B aggregates or contains A objects
- Key idea: Creator needs to keep reference anyway and will frequently use the created object

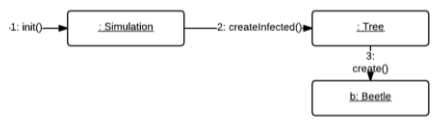
Creator (GRASP)

- Who is responsible for **creating** Beetle objects? Tree objects?



Creator : Example

- Who is responsible for creating Beetle objects?
  - Creator pattern suggests Tree
- Interaction diagram:



Creator (GRASP)

- Problem: Assigning responsibilities for creating objects
  - Who creates Nodes in a Graph?
  - Who creates instances of SalesItem?
  - Who creates Children in a simulation?
  - Who creates Tiles in a Monopoly game?
    - AI? Player? Main class? Board? Meeple (Dog)?

Creator: Discussion of Design Goals/Principles

- Promotes **low coupling**, **high cohesion**
  - class responsible for creating objects it needs to reference
  - creating the objects themselves avoids depending on another class to create the object
- Promotes **evolvability** (design for change)
  - Object creation is hidden, can be replaced locally

- Contra: sometimes objects must be created in special ways
  - complex initialization
  - instantiate different classes in different circumstances
  - *then **cohesion** suggests putting creation in a different object*
    - see *design patterns* such as builder, factory method

Take-Home Messages

- Design is driven by quality attributes
  - Evolvability, separate development, reuse, performance, …
- Design principles provide guidance on achieving qualities
  - Low coupling, high cohesion, high correspondence, …
- GRASP design heuristics promote these principles
  - Creator, Expert, Controller, …

Which design is better? Argue with design goals, principles, heuristics, and patterns that you know