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
  – Discuss tradeoffs in terms of coupling and cohesion
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
Considering the Library problem, which class should **know** which items have been borrowed by a user?

Which should **compute** late fees?
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

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
Problem Space

Domain Model

inspires objects and names

<table>
<thead>
<tr>
<th>PineTree</th>
<th>RangerAgent</th>
</tr>
</thead>
<tbody>
<tr>
<td>age</td>
<td>sanitation(Forest)</td>
</tr>
<tr>
<td>size</td>
<td>salvage(Forest)</td>
</tr>
<tr>
<td>harvest()</td>
<td></td>
</tr>
</tbody>
</table>
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;
}
A different design. How can coupling be improved?

class Box {
    private List<Item> items;
    private Map<Item, Integer> weights;
    Iterable<Item> getItems() { return items; }
    int getWeight(Item item) { return weights.get(item); }
}
class Item {
    private Box containedIn;
    int getWeight() { return containedIn.getWeight(this); }
}
Coupling Example

- Create a Tree and “infest” it with beetles

- Simulation
- Beetle
- Tree
Coupling Example
Coupling Example

- 1: init()
  : Simulation

  2: create()
  : Tree

  3: create()
  b: Beetle

  4: addBeetle(b)

- 1: init()
  : Simulation

  2: createInfected()
  : Tree

  3: create()
  b: Beetle
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()`

```java
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
  – <div id="e1">old content</div>

• In JavaScript...
  – MSIE: e1.innerText = “new content”
  – Firefox: e1.textContent = “new content”
Design Goals

- Explain how low coupling 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)
Student

login(id)

checkout(bookid)

due date

logout()

receipt

: System
Student

: login(id)

checkout(bookid)

due date

logout()

receipt

System

CheckoutController

login(id: Int)

checkout(bid: Int)

logout()
Student

- login(id)
- checkout(bookid)
- due date
- logout()
- receipt

System
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
(OR SINGLE RESPONSIBILITY PRINCIPLE)
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

Simulation responsibilities
• Trigger simulation step based on environment stimulus
• Coordinate creation of domain objects
class DatabaseApplication
    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
    }
}
Anti-Pattern: God Object

class Chat {
    List<String> channels;
    Map<String, List<Msg>> messages;
    Map<String, String> accounts;
    Set<String> bannedUsers;
    File logFile;
    File bannedWords;
    URL serverAddress;
    Map<String, Int> globalSettings;
    Map<String, Int> userSettings;
    Map<String, Graphic> smileys;
    CryptStrategy encryption;
    Widget sendButton, messageList;
}
Anti-Pattern: God Object

class Chat {
    List<String> channels;
    Map<String, List<Msg>> messages;
    Map<String, String> accounts;
    Set<String> bannedUsers;
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    Map<String, Int> globalSettings;
    Map<String, Int> userSettings;
    Map<String, Graphic> smileys;
    CryptStrategy encryption;
    Widget sendButton, messageList;
}

class Chat {
    Content content;
    AccountMgr accounts;
    File logFile;
    ConnectionMgr conns;
}

class ChatUI {
    Chat chat;
    Widget sendButton, ...;
}

class AccountMgr {
    ... accounts, bannedUsr...
}
Façade vs God Object?
Cohesion in Graph Implementations

```java
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;
    }
}
```

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

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;
}
Who should be responsible for knowing the grand total of a sale?

Register
Sale
LineItem
Product Decr.

getTotal(...) → ???
Who should be responsible for knowing the grand total of a sale?
Who should be responsible for knowing the grand total of a sale?

<table>
<thead>
<tr>
<th>Design Class</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sale</td>
<td>knows sale total</td>
</tr>
<tr>
<td>SalesLineItem</td>
<td>knows line item subtotal</td>
</tr>
<tr>
<td>ProductSpecification</td>
<td>knows product price</td>
</tr>
</tbody>
</table>
New method

: Sale

1 *: st = getSubtotal

lineItems[i]: SalesLineItem

1.1: p := getPrice()

: Product Description

N e w  m e t h o d

Sale
time...
getTotal()
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
Which design is better? Argue with design goals, principles, heuristics, and patterns that you know.
Considering the Library problem, which class should **know** which items have been borrowed by a user? Which should **compute** late fees?
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, ...