Design Engineering

Overview

• What is software design?
• How to do it?
• Principles, concepts, and practices
• High-level design
• Low-level design
Design Engineering

• The process of making decisions about HOW to implement software solutions to meet requirements
• Encompasses the set of concepts, principles, and practices that lead to the development of high-quality systems

Concepts in Software Design

• Modularity
• Cohesion & Coupling
• Information Hiding
• Abstraction & Refinement
• Refactoring
Modularity

- Software is divided into separately named and addressable components, sometimes called modules, that are integrated to satisfy problem requirements
- Divide-and-conquer

Modularity and Software Cost
Cohesion & Coupling

• Cohesion
  – The degree to which the elements of a module belong together
  – A cohesive module performs a single task requiring little interaction with other modules

• Coupling
  – The degree of interdependence between modules

• High cohesion and low coupling

Information Hiding

• Do not expose internal information of a module unless necessary
  – E.g., private fields, getter & setter methods
Abstraction & Refinement

• Abstraction
  – To manage the complexity of software,
  – To anticipate detail variations and future changes
• Refinement
  – A top-down design strategy to reveal low-level details from high-level abstraction as design progresses

Abstraction to Reduce Complexity

• We abstract complexity at different levels
  – At the highest level, a solution is stated in broad terms, such as “process sale”
  – At any lower level, a more detailed description of the solution is provided, such as the internal algorithm of the function and data structure
Abstraction to Anticipate Changes

• Define interfaces to leave implementation details undecided
• Polymorphism

<interface>
ITaxCalculator
getTaxes(...)

TaxMaster
TaxBonanza
TurboTax

Refinement

• The process to reveal lower-level details
  – High-level architecture software design
  – Low-level software design
    • Classes & objects
    • Algorithms
    • Data
    • UI
Refactoring

“...the process of changing a software system in such a way that it does not alter the external behavior of the code [design] yet improves its internal structure” --Martin Fowler

• Goal: to make software easier to integrate, test, and maintain.

Software Design Practices Include:

• Two stages
  – High-level: Architecture design
    • Define major components and their relationship
  – Low-level: Detailed design
    • Decide classes, interfaces, and implementation algorithms for each component
How to Do Software Design?

• Reuse or modify existing design models
  – High-level: Architectural styles
  – Low-level: Design patterns, Refactorings

• Iterative and evolutionary design
  – Package diagram
  – Detailed class diagram
  – Detailed sequence diagram

Software Architecture

• “The architecture of a system is comprehensive framework that describes its form and structure -- its components and how they fit together”
  -- Jerrold Grochow
What is Architectural Design?

• Design overall shape & structure of system
  – the components
  – their externally visible properties
  – their relationships
• Goal: choose architecture to reduce risks in SW construction & meet requirements

SW Architectural Styles

• Architecture composed of
  – Set of components
  – Set of connectors between them
    • Communication, co-ordination, co-operation
  – Constraints
    • How can components be integrated?
  – Semantic models
    • What are the overall properties based on understanding of individual component properties?
Architecture Patterns

• **Common program structures**
  – Pipe & Filter Architecture
  – Event-based Architecture
  – Layered Architecture

Pipe & Filter Architecture

• **A pipeline contains a chain of data processing elements**
  – The output of each element is the input of the next element
  – Usually some amount of buffering is provided between consecutive elements
Example: Optimizing Compiler

![Compilation Structure Diagram]

Pros and Cons

- **Other examples**
  - UNIX pipes, signal processors

- **Pros**
  - Easy to add or remove filters
  - Filter pipelines perform multiple operations concurrently

- **Cons**
  - Hard to handle errors
  - May need encoding/decoding of input/output
**Event-based Architecture**

- Promotes the production, detection, consumption of, and reaction to events
- *More like event-driven programming*

**Example: GUI**

![GUI example](image)
Pros and Cons

• Other examples:
  – Breakpoint debuggers, phone apps, robotics

• Pros
  – Anonymous handlers of events
  – Support reuse and evolution, new consumers easy to add

• Cons
  – Components have no control over order of execution

Layered/Tiered Architecture

• Multiple layers are defined to allocate responsibilities of a software product
• The communication between layers is hierarchical
• Examples: OS, network protocols
3-layer Architecture

- **Presentation**: UI to interact with users
- **Logic**: coordinate applications and perform calculations
- **Data**: store and retrieve information as needed

Example: Online Ordering System

Model-View-Controller

Key Points about MVC

• View layer should not handle system events
• Controller layer has the application logic to handle events
• Model layer only respond to data operation
Layered Architecture: Pros and Cons

- **Pros**
  - Support increasing levels of abstraction during design
  - Support reuse and enhancement
- **Cons**
  - The performance may degrade
  - Hard to maintain

Detailed Design

- To decompose subsystems into modules
- Two approaches of decomposition
  - Procedural
    - System is decomposed into functional modules which accept input data and transform it to output data
    - Achieves mostly procedural abstractions
  - Object-oriented
    - System is decomposed into a set of communicating objects
    - Achieves both procedural + data abstractions
Work Results

• Dynamic models
  – help design the logic or behaviors of the code
  – UML interaction diagrams
    • (Detailed) sequence diagrams, or
    • Communication diagrams

• Static models
  – help design the definition of packages, class names, attributes, and method signatures
  – (Detailed) UML class diagrams

OOD

• To identify responsibilities and assign them to classes and objects

• Responsibilities for doing
  – E.g., create an object, perform calculations, invoke operations on other objects

• Responsibilities for knowing
  – E.g., attributes, data involved in calculations, parameters when invoking operations
Guidelines

- Spend significant time doing interaction diagrams, not just class diagrams
- Do static modeling after dynamic modeling

UML Interaction Diagrams

- To illustrate how objects interact via messages
- Two types of interaction diagrams
  - Sequence diagrams
  - Communication diagrams
Sequence diagram

• Illustrate interactions in a kind of fence format, in which each new object is added to the right

What Is The Possible Representation in Code?

```java
public class A {
    private B myB = new B();
    public void doOne() {
        myB.doTwo();
        myB.doThree();
    }
}
```
Communication Diagram

• To illustrate object interactions in a graph or network format, in which objects can be placed anywhere on the diagram

```
  doOne -> : A
  1: doTwo
  2: doThree
  myB: B
```

Sequence vs. Communication

• Sequence diagram
  – Tool support is better and more notation options are available
  – Easier to see the call flow sequence

• Communication diagram
  – More space-efficient
  – Modifying wall sketches is easier
Design Class Diagrams

- Differences from Conceptual Class Diagrams in Domain model
  - Contain types, directed associations with multiplicities, methods
  - Provide visibility between objects

Type Information

- Types of attributes
- Types of method parameters/returns (can be omitted)

<table>
<thead>
<tr>
<th>Sale</th>
</tr>
</thead>
<tbody>
<tr>
<td>date: Date</td>
</tr>
<tr>
<td>isComplete:bool</td>
</tr>
<tr>
<td>...</td>
</tr>
</tbody>
</table>
Accessibility of Methods and Fields

- **public**: can be accessed by any code
  - UML notation: +foo
- **private**: can be accessed only by code inside the class
  - UML notation: -foo
- **protected**: can be accessed only by code in the class and in its subclasses
  - UML notation: #foo
- Fields usually are not public, but have getters and setters instead

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**UML Class Diagram**

- **private static field**
- **public constructor**
- **public static method**

**note**: “static constructor” is meaningless: by definition, a constructor is invoked on an object
**Mapping Design to Code**

- **DCDs -> classes in code**
  - DCD: class names, methods, attributes, superclasses, associations, etc.
  - Tools can do this automatically
- **Interaction diagrams -> method bodies**
  - Interactions in the design model imply that certain method calls should be included in a method’s body

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**Mapping Associations (* : 1, 1 : 1)**

```java
public class SalesLineItem {
    private int quantity;
    private ProductSpecification productSpec;

    public SalesLineItem(ProductSpecification s, int q) {...}
}
```

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45

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46
### Mapping Associations (1 : *)

**Sale**

- Contains
- **Sales LineItem**
  - quantity: Integer

```java
public class Sale {
    private List<SalesLineItem> lineItems = new ArrayList<SalesLineItem>();
    private Date date = new Date();
    public void makeLineItem(ProductDescription desc, int qnty) {
        lineItems.add(new SalesLineItem(desc, qnty));
    }
    ...
}
```

### Mapping Associations (* : *)

**Course**

- Contains 1..* 1..*
- **Student**

```java
public class Course {
    private List<Student> students = new ArrayList<Student>();
    public addStudent(int sid) {...}
}
```

```java
public class Student {
    private List<Course> courses = new ArrayList<Course>();
    public addCourse(int cid) {...}
}
```
Design Patterns

• Definition
  – A named general reusable solution to common design problems
  – Used in Java libraries

• Major source: GoF book 1995
  – “Design Patterns: Elements of Reusable Object-Oriented Software”
  – 24 design patterns

Purpose-based Pattern Classification

• Creational
  – About the process of object creation

• Structural
  – About composition of classes or objects

• Behavioral
  – About how classes or objects interact and distribute responsibility
Design pattern space

<table>
<thead>
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<th>Purpose</th>
<th>Creational</th>
<th>Structural</th>
<th>Behavioral</th>
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<td><strong>Scope</strong></td>
<td><strong>Class</strong></td>
<td><strong>Class</strong></td>
<td><strong>Class</strong></td>
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<td>Abstract Factory (87)</td>
<td>Adapter (object) (139)</td>
<td>Chain of Responsibility (223)</td>
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<tr>
<td></td>
<td>Builder (97)</td>
<td>Bridge (151)</td>
<td>Command (233)</td>
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<tr>
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<td>Prototype (117)</td>
<td>Composite (163)</td>
<td>Iterator (257)</td>
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<tr>
<td></td>
<td>Singleton (127)</td>
<td>Decorator (175)</td>
<td>Mediator (273)</td>
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<td></td>
<td>Facade (185)</td>
<td>Memento (283)</td>
</tr>
<tr>
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<td></td>
<td>Flyweight (195)</td>
<td>Observer (293)</td>
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<td></td>
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<td>State (305)</td>
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<td>Visitor (331)</td>
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Visitor Pattern

- **Scenario**: Given a set of objects in a heterogeneous aggregate structure, such as a tree, you want to define and perform various distinct and unrelated operations on them
Example

- What will you do if you always need to add operations to the objects, such as Add(), Remove(), Update()?

Visitor Pattern

- You want to limit the scope of introduced changes
  - Within a class vs. across different classes
- You want to avoid “polluting” the node classes with various operations
- Create a Visitor class hierarchy that defines a virtual visit() method for each node type
- Add a virtual accept() method to the base class of all node classes
Visitor Pattern

```java
Visitor
  accept(v: Visitor)

Graphic
  accept(v: Visitor)

Picture
  parts: Graphic[]
  accept(v: Visitor)

Rectangle
  accept(v: Visitor)

Line
  accept(v: Visitor)

Triangle
  accept(v: Visitor)

<<interface>>
Visitor
  visit(g: Picture)
  visit(g: Rectangle)
  visit(g: Line)
  visit(g: Triangle)

DrawVisitor

UpdateVisitor
```

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