# 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

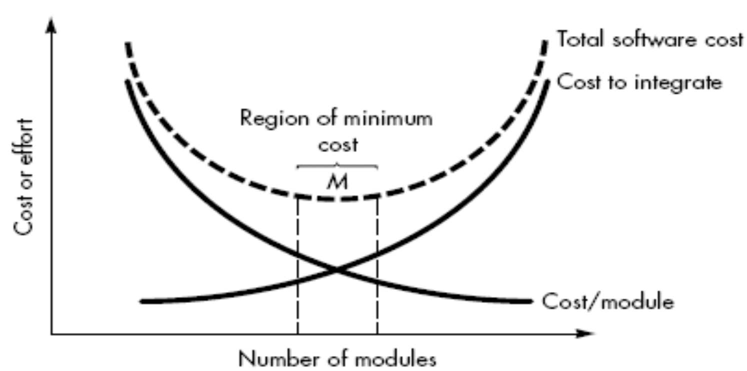
- Modularity
- Cohesion & Coupling
- Information Hiding
- Abstraction & Refinement
- Refactoring

# 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

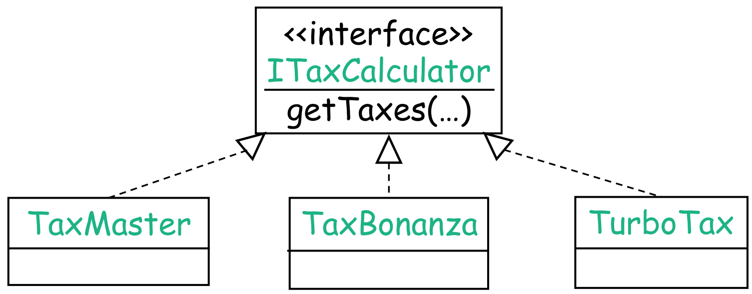


# Abstraction to Reduce Complexity

- 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






## 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

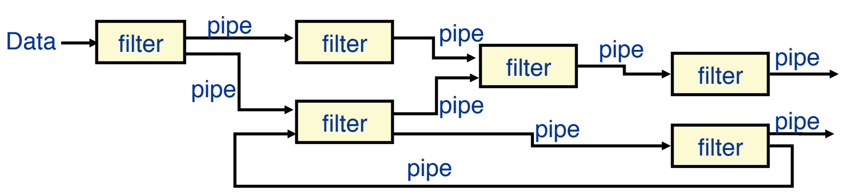
- Architecture composed of
  - Set of components
  - Set of connectors between them
    - Communication, co-ordination, co-operation
  - Constraints
    - How can components be integrated?
  - Semantic models
    - What are the overall properties based on understanding of individual component properties?

# Architecture Patterns

- Common program structures
  - Pipe & Filter Architecture
  - Event-based Architecture
  - Layered Architecture

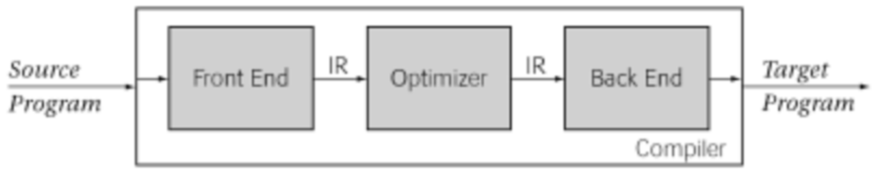


# Pipe & Filter Architecture

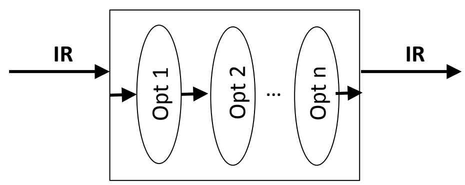



- A pipeline contains a chain of data processing elements
  - The output of each element is the input of the next element
  - Usually some amount of buffering is provided between consecutive elements

# Example: Optimizing Compiler




Compiler Structure



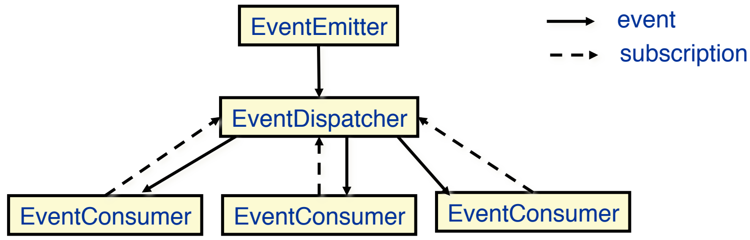

Compiler Optimization
[Engineering a Compiler, K. D. Cooper, L. Torczon]



# 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



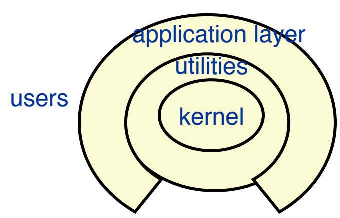
# Example: GUI

# 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

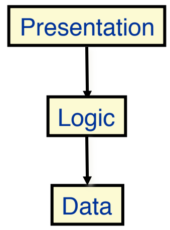


# Layered/Tiered Architecture




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

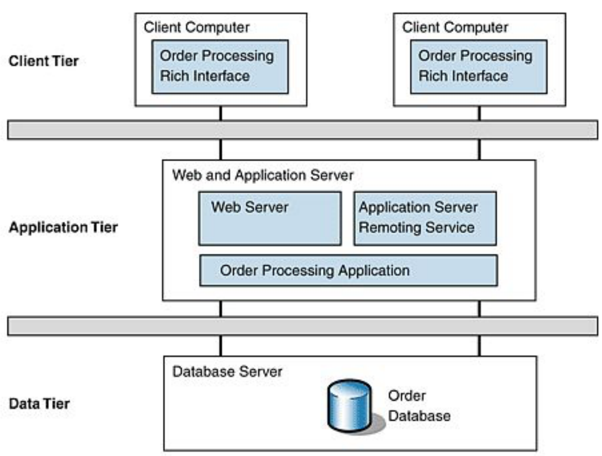
# 3-layer Architecture




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

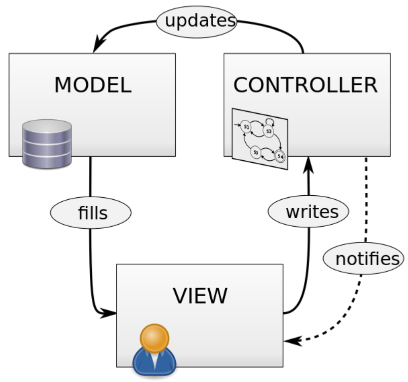


# Example: Online Ordering System




http://www.cardisoft.gr/frontend/article.php?aid=87&cid=96

# Model-View-Controller




Design of Finite State Machine Drawing Tool

https://commons.wikimedia.org/wiki/File:MVC_Diagram_(Model-View-Controller).svg



# 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

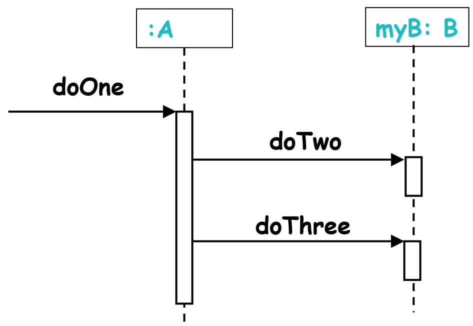


## UML Interaction Diagrams

- 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



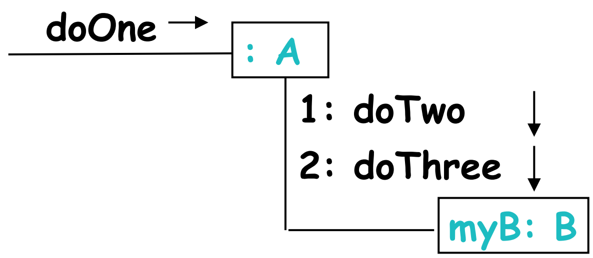



# What Is The Possible Representation in Code?

```
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






## 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

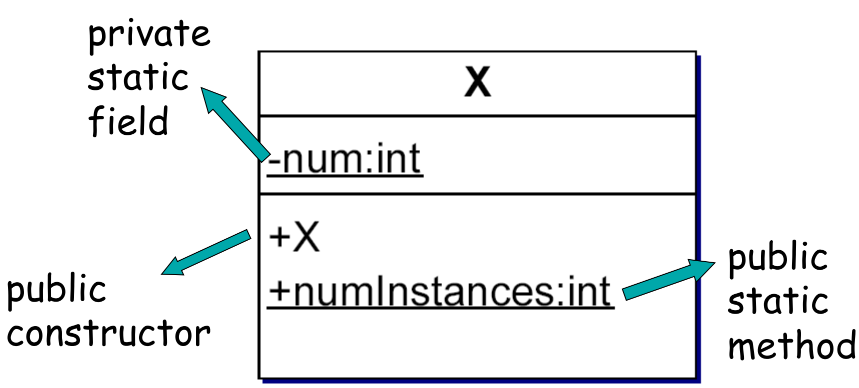
- Types of attributes
- Types of method parameters/returns (can be omitted)

## 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



## UML Class Diagram



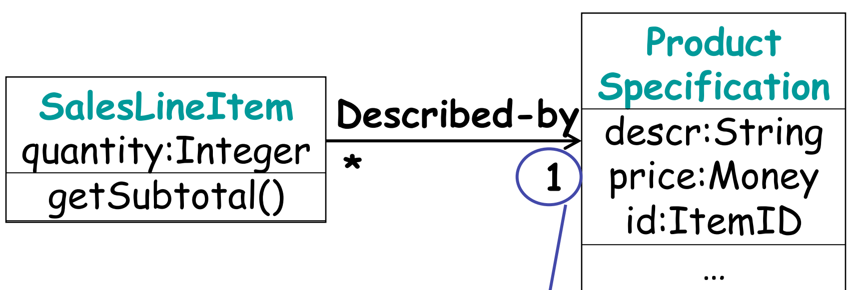

note: "static constructor" is meaningless: by definition, a constructor is invoked on an object

# 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

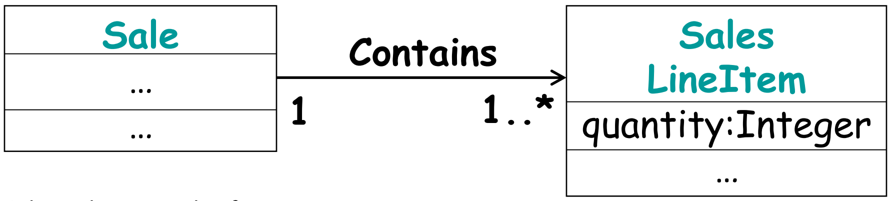


# Mapping Associations (* : 1, 1 : 1)




```
public class SalesLineItem {
   private int quantity;
   private ProductSpecification productSpec;
   public SalesLineItem(ProductSpecification s, int q) {…}
}
```

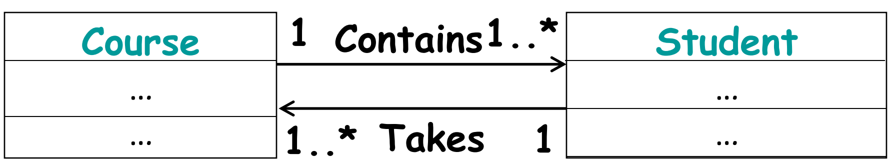
# Mapping Associations (1 : *)




```
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 (* : *)




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

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

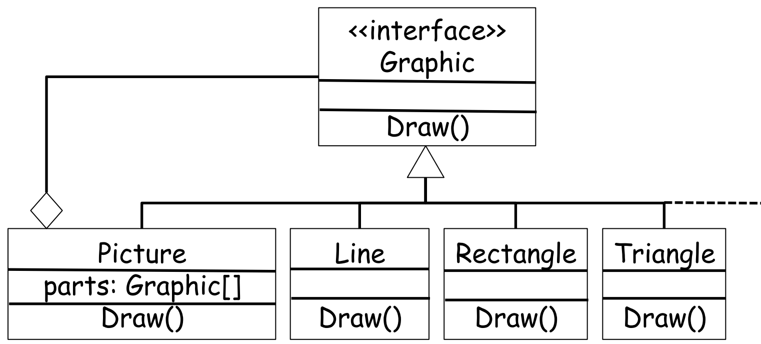
| | | Purpose | | |
|---|---|---|---|---|
| | | Creational | Structural | Behavioral |
| Scope | Class | Factory Method (107) | Adapter (class) (139) | Interpreter (243)<br>Template Method (325) |
| | Object | Abstract Factory (87)<br>Builder (97)<br>Prototype (117)<br>Singleton (127) | Adapter (object) (139)<br>Bridge (151)<br>Composite (163)<br>Decorator (175)<br>Facade (185)<br>Flyweight (195)<br>Proxy (207) | Chain of Responsibility (223)<br>Command (233)<br>Iterator (257)<br>Mediator (273)<br>Memento (283)<br>Observer (293)<br>State (305)<br>Strategy (315)<br>Visitor (331) |



# 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