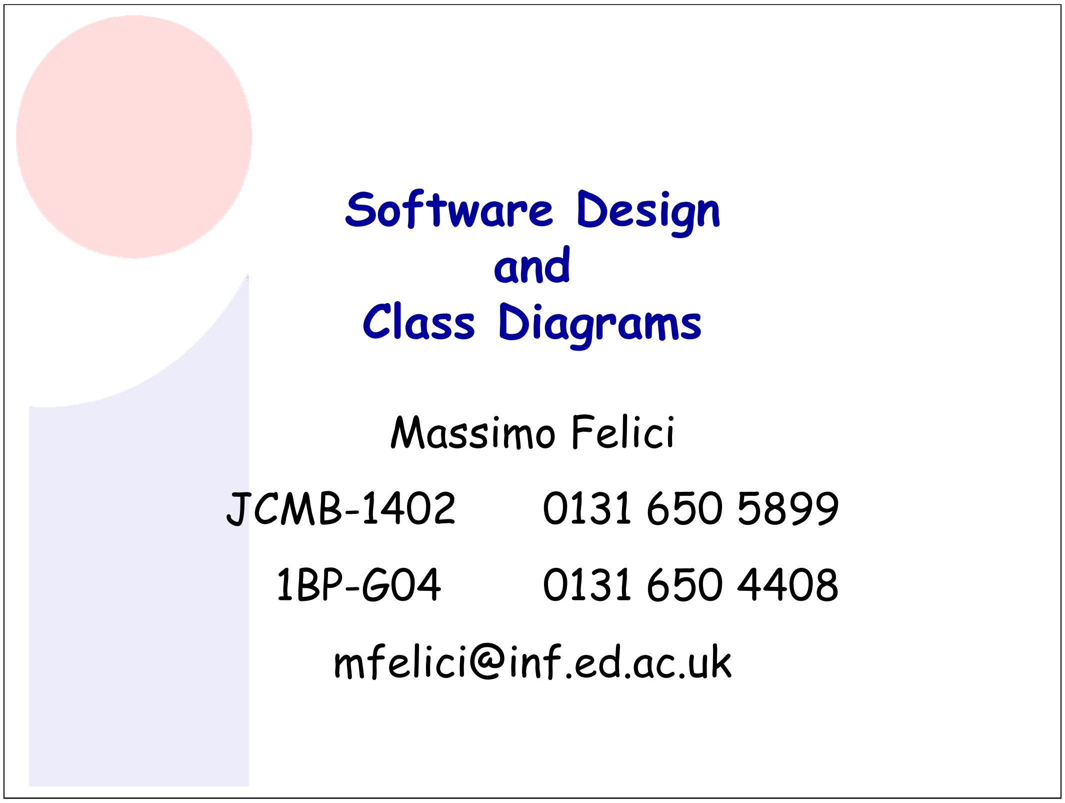

Software Design and Class Diagrams

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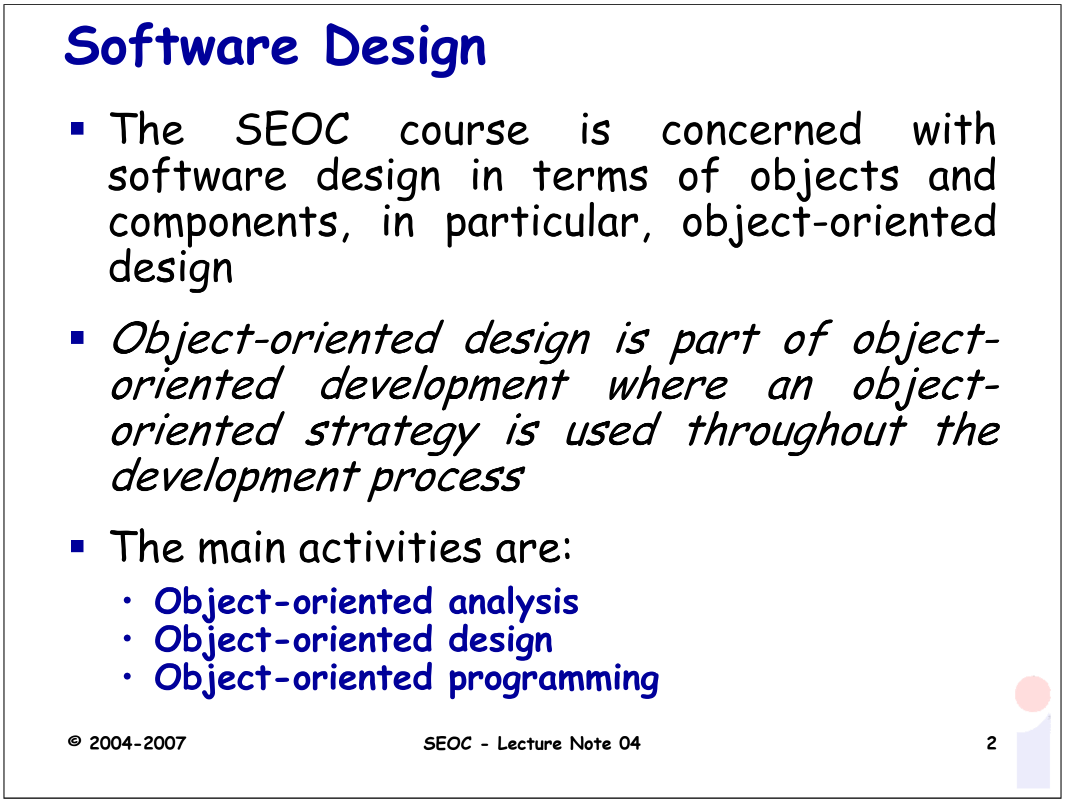

Software Design

- The SEOC course is concerned with software design in terms of objects and components, in particular, object-oriented design
- *Object-oriented design is part of object-oriented development where an object-oriented strategy is used throughout the development process*
- The main activities are:
  - **Object-oriented analysis**
  - **Object-oriented design**
  - **Object-oriented programming**

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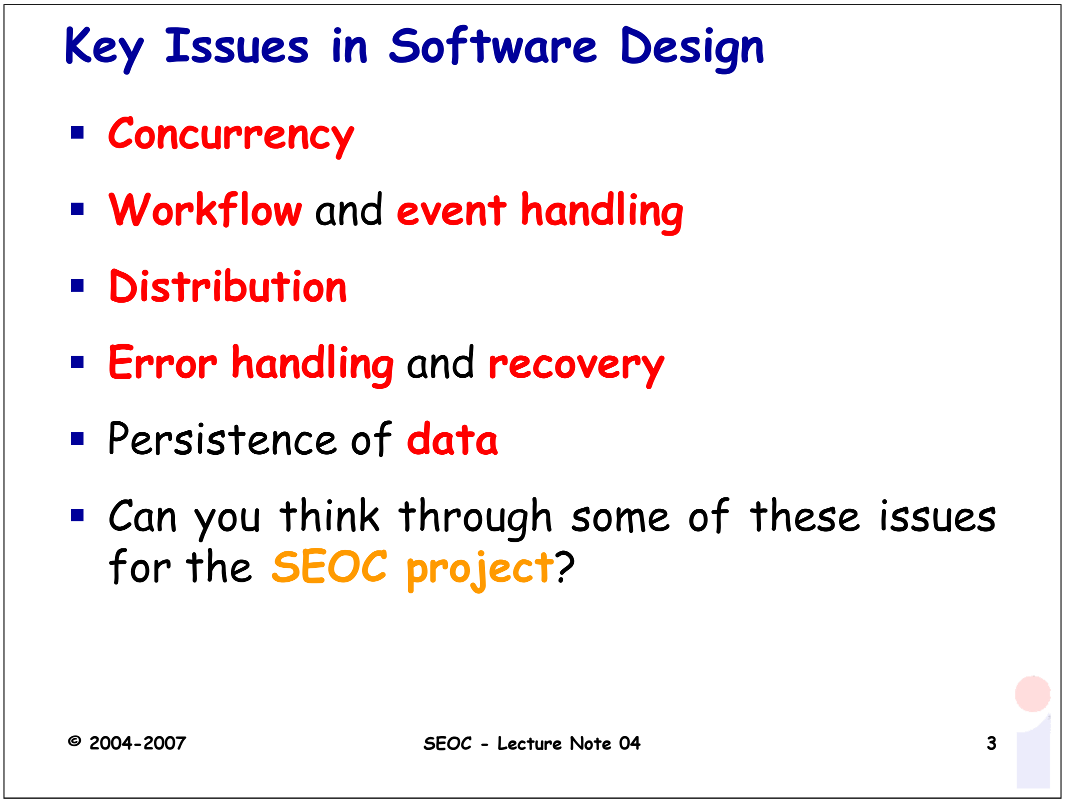
There are various definitions about Software Design. In general, they refer to (the result of) the process of defining a software system design consisting in the definition of the architecture, components (or modules), interfaces and other characteristics (e.g., design constraints) of a system or component. Software design provides a (traceability) link between requirements and an implementable specification. It is a pervasive activity for which often there is no definitive solution.

Design solutions are highly context dependent. Key Design techniques and issues involve the identification of a overall structure or architecture, the identification of the main elements of software that need to be managed. The design activities involve decomposing system (components) into smaller more manageable (definitions of) components that are easily implementable. Usually, design is a two stage process: architectural design and detailed design. Architectural design (or High-level Design) involves (the identification and specification of) the components forming the system and how they relate one another. Moreover, it is concerned with those issues related to the system architecture. Detailed design deals with the function and characteristics of components and how they relate to the overall architecture.

Suggested Readings

- I. Sommerville. Software Engineering, Eighth Edition, Addison-Wesley 2007.
  - Chapter 14 on Object-oriented design



Key Issues in Software Design

- Concurrency
- Workflow and event handling
- Distribution
- Error handling and recovery
- Persistence of data
- Can you think through some of these issues for the SEOC project?

Concurrency. Often there is significant interaction that needs management – What are the main concurrent activities? How do we manage their interaction? For instance, in the VolBank example matching and specifying skills and needs goes on concurrently.

Workflow and event handling – What are the activities inside a workflow? How do we handle events?

Distribution - How is the system distributed over physical (and virtual) systems?

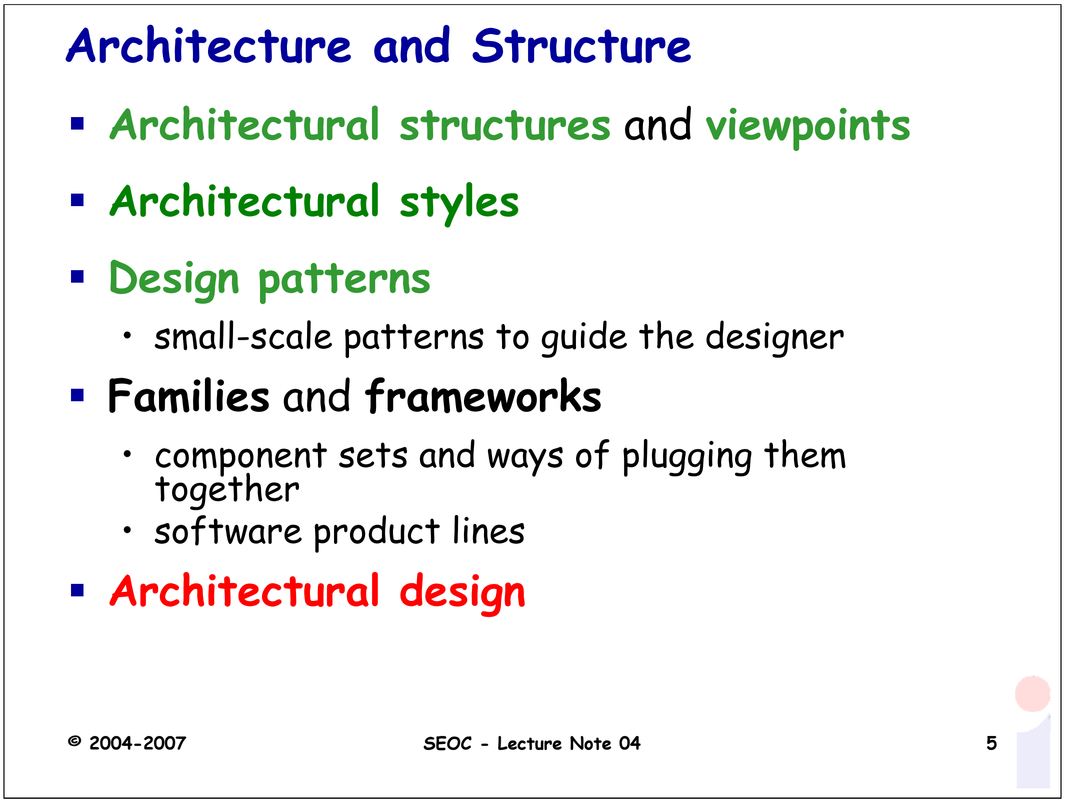
Error handling and recovery – What are suitable actions when a physical component fails (e.g., the database server)? How to handle exceptional circumstances in the world? For instance, in the VolBank example, a volunteer fails to appear.

Persistence of data – Does data need to persist across uses of the system, how complex? How much of the state of the process?

Can you think through some of these issues for VolBank?

Key Design Techniques

- Abstraction
  - ignoring detail to get the high level structure right
- Decomposition and Modularization
  - big systems are composed from small components
- Encapsulation/information hiding
  - the ability to hide detail (linked to abstraction)
- Defined interfaces
  - separable from implementation
- Evaluation of structure
  - Coupling: How interlinked a component is
  - Cohesion: How coherent a component is



Architecture and Structure

- Architectural structures and viewpoints
- Architectural styles
- Design patterns
  - small-scale patterns to guide the designer
- **Families** and **frameworks**
  - component sets and ways of plugging them together
  - software product lines
- Architectural design

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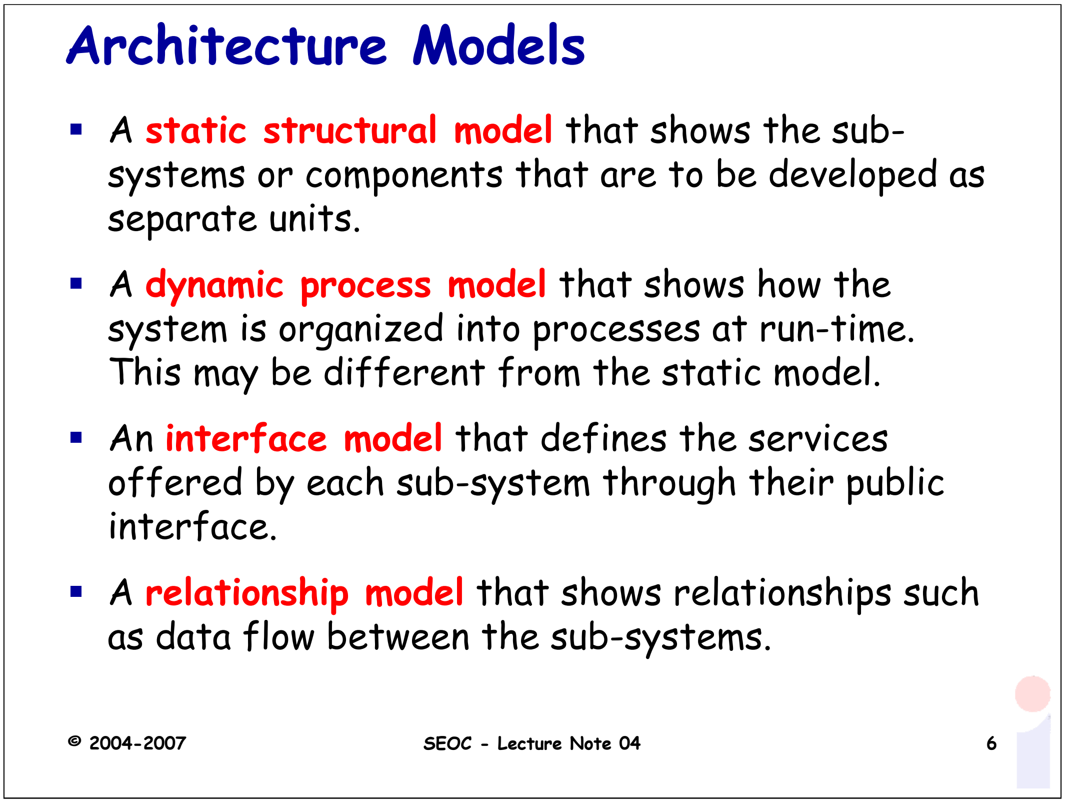
Architectural structures and viewpoints deal with system facets (e.g., physical view, functional or logical view, security view, etc.) separately. Depending on the architectural emphasis, there are different styles, for example, Three-tier architecture for a distributed system (interface, middleware, back-end database), Blackboard, Layered architectures, Model-View-Controller, Time-triggered and so forth.

Architectural Design supports stakeholder communication, system analysis and large-scale reuse. It is possible to distinguish diverse design strategies: function oriented (sees the design of the functions as primary), data oriented (sees the data as the primary structured element and drives design from there), object oriented (sees objects as the primary element of design). There is no clear distinction between Sub-systems and modules. Intuitively, sub-systems are independent and composed of modules, have defined interfaces for communication with other sub-systems. Modules are system components and provide/make use of service(s) to/provided by other modules.

The system architecture affects the quality attributes (e.g., performance, security, availability, modifiability, portability, reusability, testability, maintainability, etc.) of a system. It supports quality analysis (e.g., reviewing techniques, static analysis, simulation, performance analysis, prototyping, etc.). It allows to define (predictive) measures (i.e., metrics) on the design, but they are usually very dependent on the process in use. The software architecture is the fundamental framework for structuring the system. Different architectural models (e.g., system organizational models, modular decomposition models and control models) may be developed. Design decisions enhance system attributes like, for instance, performance (e.g., localize operations to minimize sub-system communication), security (e.g., use a layered architecture with critical assets in inner layers), safety (e.g., isolate safety-critical components), availability (e.g., include redundant components in the architecture) and maintainability (e.g., use fine-grain self-contained components).

Readings

- P. Kruchten, H. Obbink, J. Stafford. The Past, Present and Future of Software Architecture. IEEE Software, March/April 2006.



Architecture Models

- A **static structural model** that shows the sub-systems or components that are to be developed as separate units.
- A **dynamic process model** that shows how the system is organized into processes at run-time. This may be different from the static model.
- An **interface model** that defines the services offered by each sub-system through their public interface.
- A **relationship model** that shows relationships such as data flow between the sub-systems.

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Comparing Architecture Design Notations

- **Modeling Components**: Interface, Types, Semantics, Constraints, Evolution, Non-functional Properties
- **Modeling Connectors**: Interface, Types, Semantics, Constraints, Evolution, Non-functional Properties
- **Modeling Configurations**: Understandable Specifications, Compositionality (and Conposability), Refinement and Traceability, Heterogeneity, Scalability, Evolvability, Dynamism, Constraints, Non-functional Properties

UML Design Notations

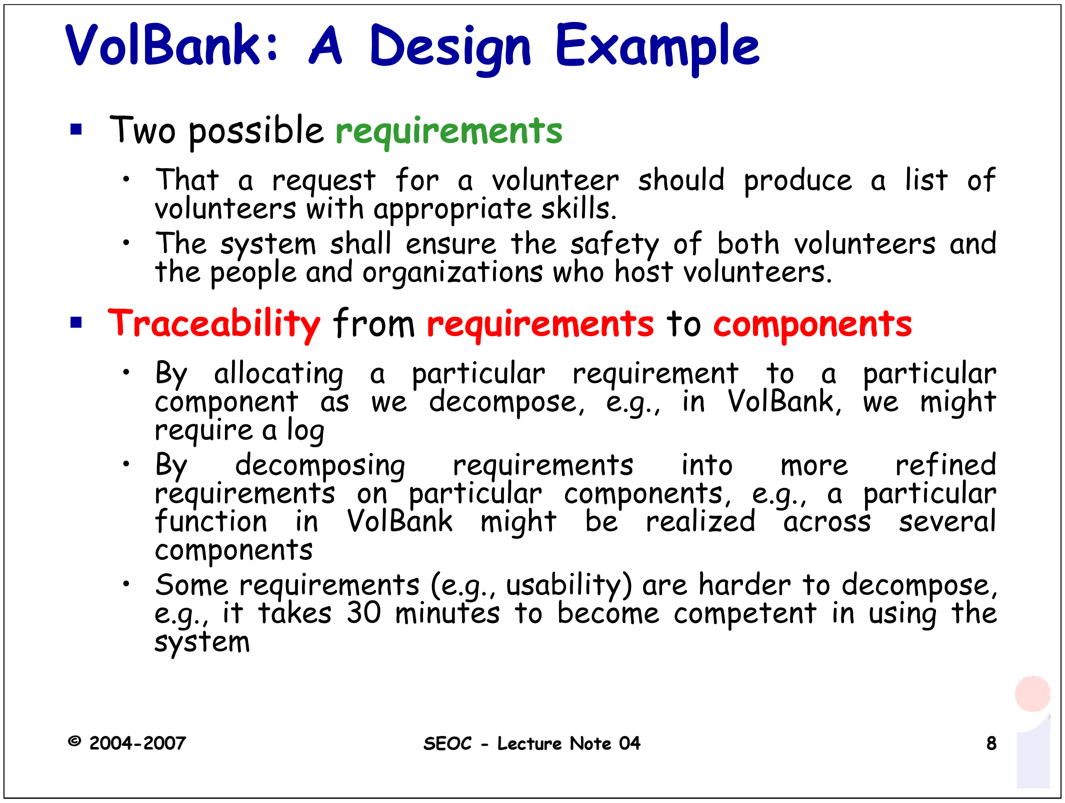
- **Static Notations**: Class and object diagrams, Component diagrams, Deployment diagrams, CRC Cards
- **Dynamic Notations**: Activity diagrams, Communication diagrams, Statecharts, Sequence diagrams

What are the Architect's Duties?

- Get it **Defined**, **documented** and **communicated,** Act as the emissary of the architecture, Maintain morale
- Make sure everyone is **using** it (correctly), management understands it, the **software** and system **architectures** are in synchronization, the right **modeling** is being done, to know that **quality attributes** are going to be met, the architecture is not only the right one for **operations**, but also for **deployment** and **maintenance**
- Identify architecture timely **stages** that support the overall organization progress, suitable **tools** and **design** environments, (and interact) with **stakeholders**
- Resolve disputes and make tradeoffs, technical problems
- Manage **risk** identification and risk **mitigation strategies** associated with the architecture, understand and plan for **evolution**

Class Diagrams

- Support **architectural design**
  - Provide a structural view of systems
- Represent the basics of **Object-Oriented systems**
  - identify what **classes** there are, how they **interrelate** and how they **interact**
  - Capture the **static** structure of Object-Oriented systems - how systems are structured rather than how they behave
- Constrain interactions and collaborations that support functional requirements
  - Link to Requirements

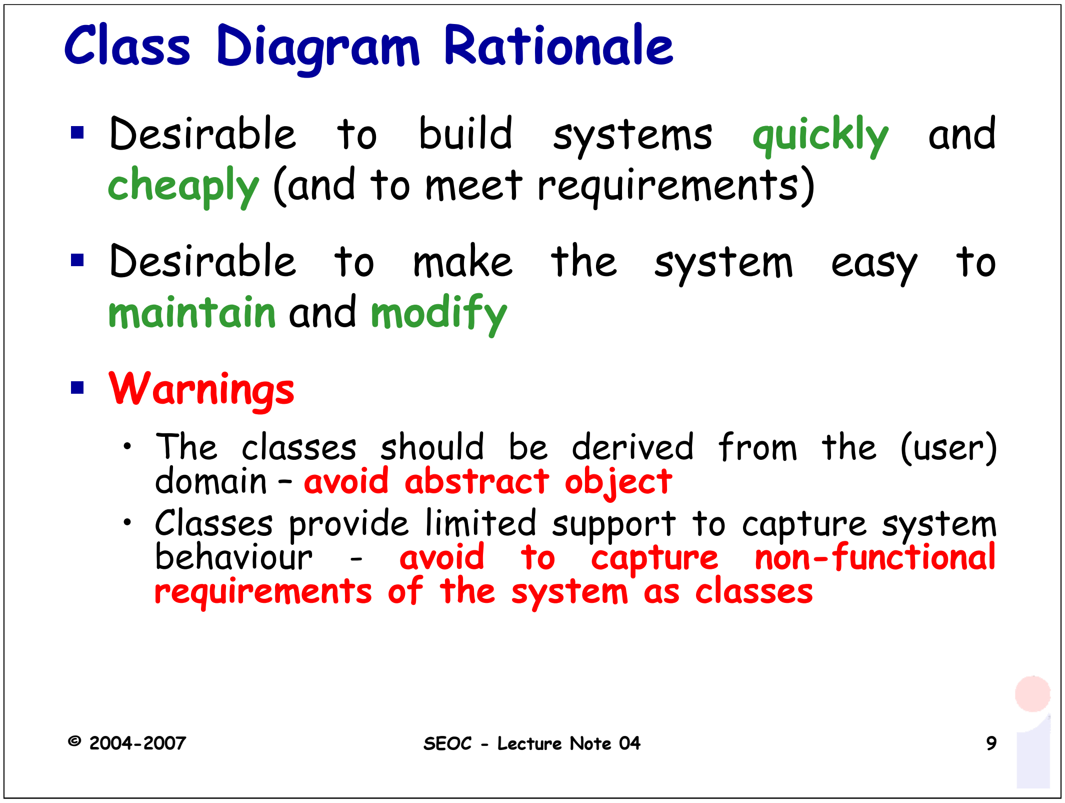


VolBank: A Design Example

- Two possible **requirements**
  - That a request for a volunteer should produce a list of volunteers with appropriate skills.
  - The system shall ensure the safety of both volunteers and the people and organizations who host volunteers.
- **Traceability** from **requirements** to **components**
  - By allocating a particular requirement to a particular component as we decompose, e.g., in VolBank, we might require a log
  - By decomposing requirements into more refined requirements on particular components, e.g., a particular function in VolBank might be realized across several components
  - Some requirements (e.g., usability) are harder to decompose, e.g., it takes 30 minutes to become competent in using the system

The second requirements, for instance, may decompose into many more specific requirements:

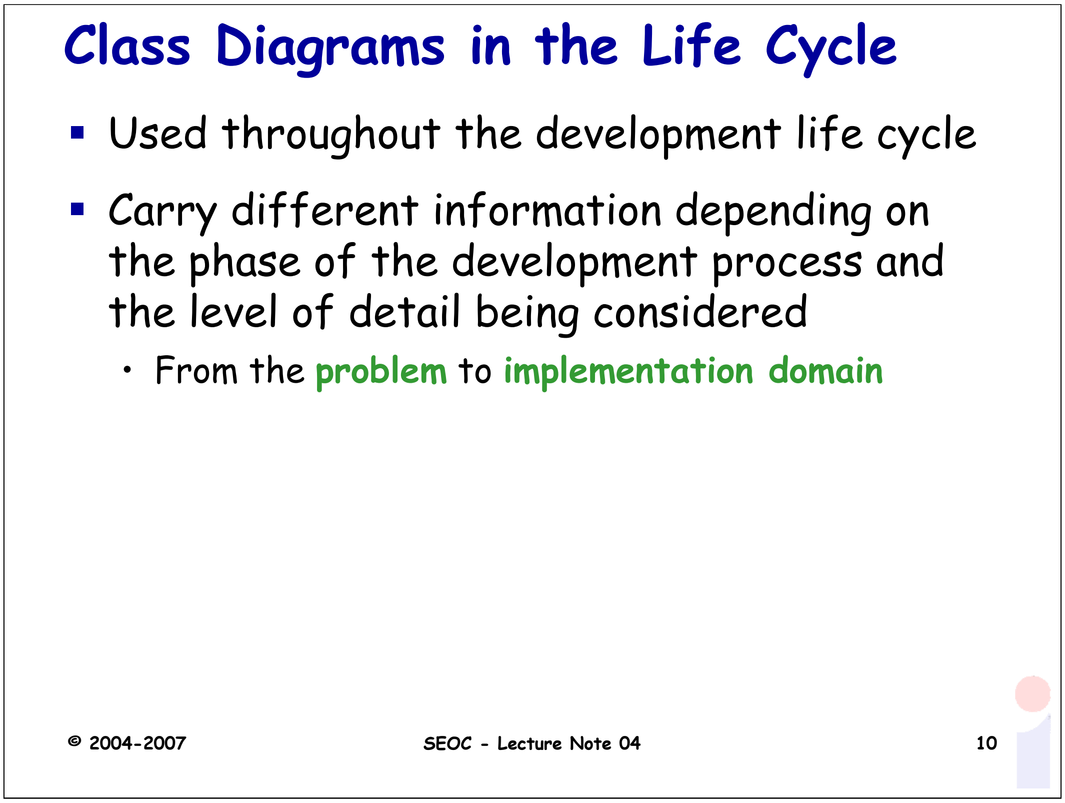
- That the organization has made reasonable efforts to ensure a volunteer is bona fide.
- That we have a confirmed address for the individual: i.e., the original address is correct, and only the volunteer can effect a change in address.



Class Diagram Rationale

- Desirable to build systems **quickly** and **cheaply** (and to meet requirements)
- Desirable to make the system easy to **maintain** and **modify**
- **Warnings**
  - The classes should be derived from the (user) domain – **avoid abstract object**
  - Classes provide limited support to capture system behaviour - **avoid to capture non-functional requirements of the system as classes**

The system consists of a collection of objects in the implemented classes (e.g., there may be a GUI coordinate human interaction with the other parts of the system). Objects (instances of the classes) of the system realize the required behaviour.



Class Diagrams in the Life Cycle

- Used throughout the development life cycle
- Carry different information depending on the phase of the development process and the level of detail being considered
  - From the **problem** to **implementation domain**

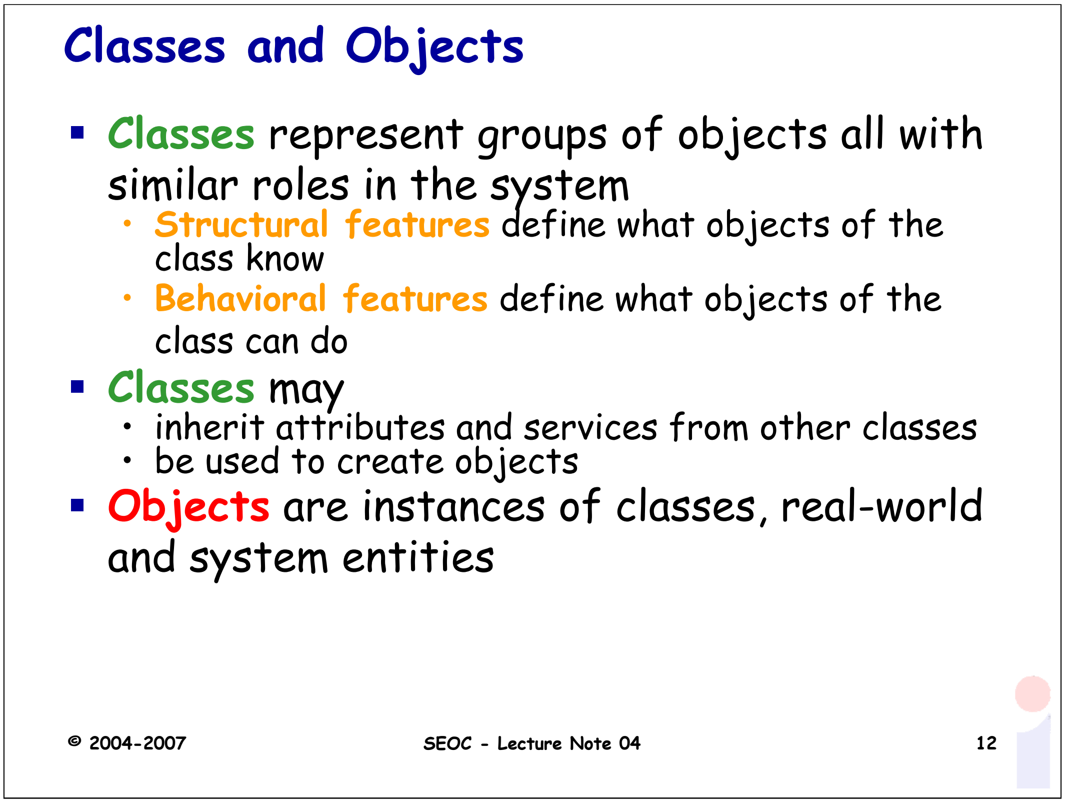
Class diagrams can be used throughout the development life cycle. They carry different information depending on the phase of the development process and the level of detail being considered. The contents of a class diagram will reflect this change in emphasis during the development process. Initially, class diagrams reflect the problem domain, which is familiar to end-users. As development progresses, class diagrams move towards the implementation domain, which is familiar to software engineers.

Class Diagram Basics

- Classes
  - Basic Class Components
  - Attributes and Operations
- Class Relationships
  - Associations
  - Generalizations
  - Aggregations and Compositions

Construction involves

1. Modeling classes
2. Modeling relationships between classes and
3. Refining and elaborate as necessary



Classes and Objects

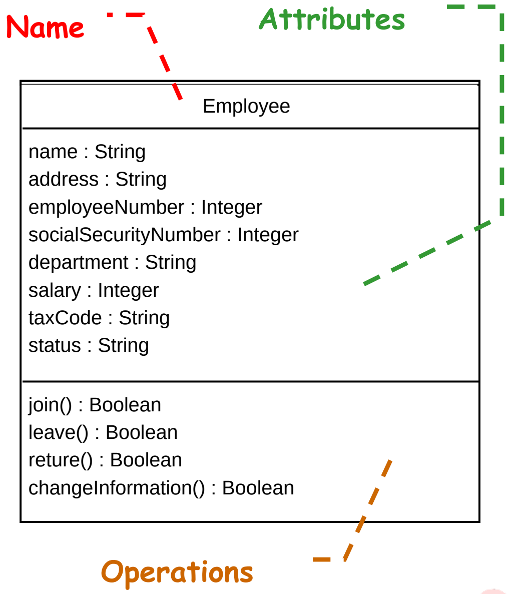
- Classes represent groups of objects all with similar roles in the system
  - Structural features define what objects of the class know
  - Behavioral features define what objects of the class can do
- Classes may
  - inherit attributes and services from other classes
  - be used to create objects
- Objects are instances of classes, real-world and system entities

Objects are entities in a software system which represent instances of real-world and system entities. Objects derive from things (e.g., tangible, real-world objects, etc.), roles (e.g., classes of actors in systems like students, managers, nurses, etc.), events (e.g., admission, registration, matriculation, etc.) and interactions (e.g., meetings, tutorials, etc.).

Objects are created according to some class definition. A class definition serves as a template for objects and includes declarations of all the attributes and operations which should be associated with an object of that class. Note that the level of detail known or displayed for attributes and operations depends on the phase of the development process. An object is an entity that has a state and a defined set of operations which operate on that state. The state is represented as a set of object attributes. The operations associated with the object provide services to other objects, which request these services when some functionality is required.

Basic Class Compartments

- Name
- Attributes
  - represent the state of an object of the class
  - are descriptions of the structural or static features of a class
- Operations
  - define the way in which objects may interact
  - are descriptions of behavioral or dynamic features of a class



Name

Attributes

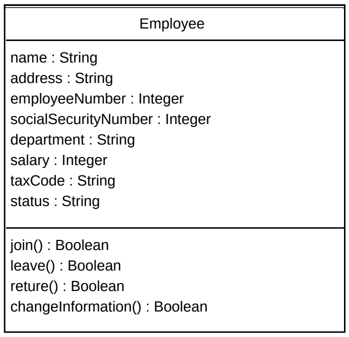
Employee

name : String
address : String
employeeNumber : Integer
socialSecurityNumber : Integer
department : String
salary : Integer
taxCode : String
status : String

join() : Boolean
leave() : Boolean
reture() : Boolean
changeInformation() : Boolean

Operations

Java Class Definition



Employee

name : String
address : String
employeeNumber : Integer
socialSecurityNumber : Integer
department : String
salary : Integer
taxCode : String
status : String

join() : Boolean
leave() : Boolean
reture() : Boolean
changeInformation() : Boolean

```
class Employee {
  public String name;
  public String address;
  public Integer employeeNumber;
  public Integer socialSecurityNumber;
  public String department;
  public Integer salary;
  public String taxCode;
  /**
   *  current
   */
  public String status;
  public Boolean join() {
  return null;
  }
  public Boolean leave() {
  return null;
  }
  public Boolean reture() {
  return null;
  }
  public Boolean changeInformation() {
  return null;
  }
}
```

Attribute Definition

visibility / name : type multiplicity = default {property strings and constraints}

- visibility
- / derived attribute – Attributes by relationship allow the definition of complex attributes
- name
- type is the data type of the attribute or the data returned by the operation
- multiplicity specifies how many instances of the attribute's type are referenced by this attribute
- property strings: readOnly, union, subset <attribute-name>, redefines <attribute-name> composite, ordered, bag, sequence, coposite
- constraints

Visibility and Multiplicity

- **Visibility**
  - public (**+**), protected (**#**), package(**~**), private (**-**)

  From **More accessible** to **Less Accessible**
  - Warnings: Java allows access to protected parts of a class to any class in the same package
- **Multiplicity** specifies how many instances of the attribute's type are referenced by this attribute
  - **[n..m]** - **n** to **m** instances
  - **0..1 -** zero or one instance
  - **0..*** or *** -** no limit on the number of instances (including none)
  - **1 -** exactly one instance
  - **1..*** at least one instance

Operation Definition

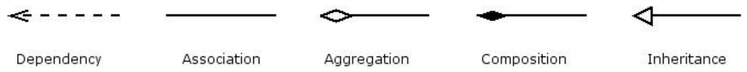
visibility name (parameters) : return-type {properties}

- (Parameters)

direction parameter_name : type [multiplicity] = default_value {properties}

- direction :in, inout, out or return
- Operation constraints :preconditions, postconditions, body conditions, query operations, exceptions
- Static operations :Specify behaviour for the class itself; Invoked directly on the class
- Methods are implementations of an operations; Abstract classes provide operation signatures, but no implementations

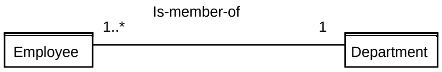
Class Relationships

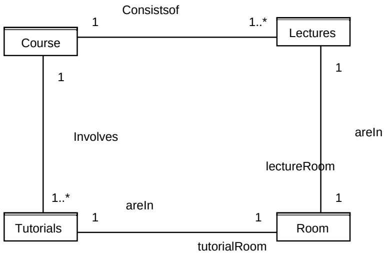


- **Dependency**: objects of one class work briefly with objects of another class
- **Association**: objects of one class work with objects of another class for some prolonged amount of time
- **Aggregation**: one class owns but share a reference to objects of other class
- **Composition**: one class contains objects of another class
- **Inheritance (Generalization)**: one class is a type of another class

Dependency and Association

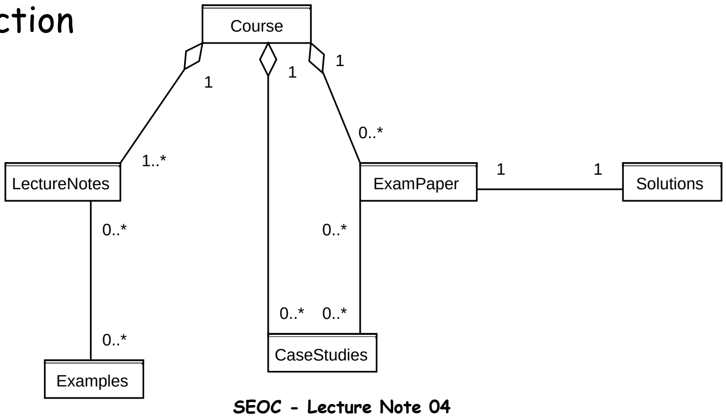
- Dependency between two classes means that one class uses, or has knowledge of, another class (i.e., a transient relationship)
- Associations
  - an attribute of an **object** is an associated **object**
  - a method relies on an associated object
  - an instance of one class must know about the other in order to perform its work
  - Passing messages and receiving responses
- Associations may be annotated with information: Name, Multiplicity, Role Name, Ends, Navigation

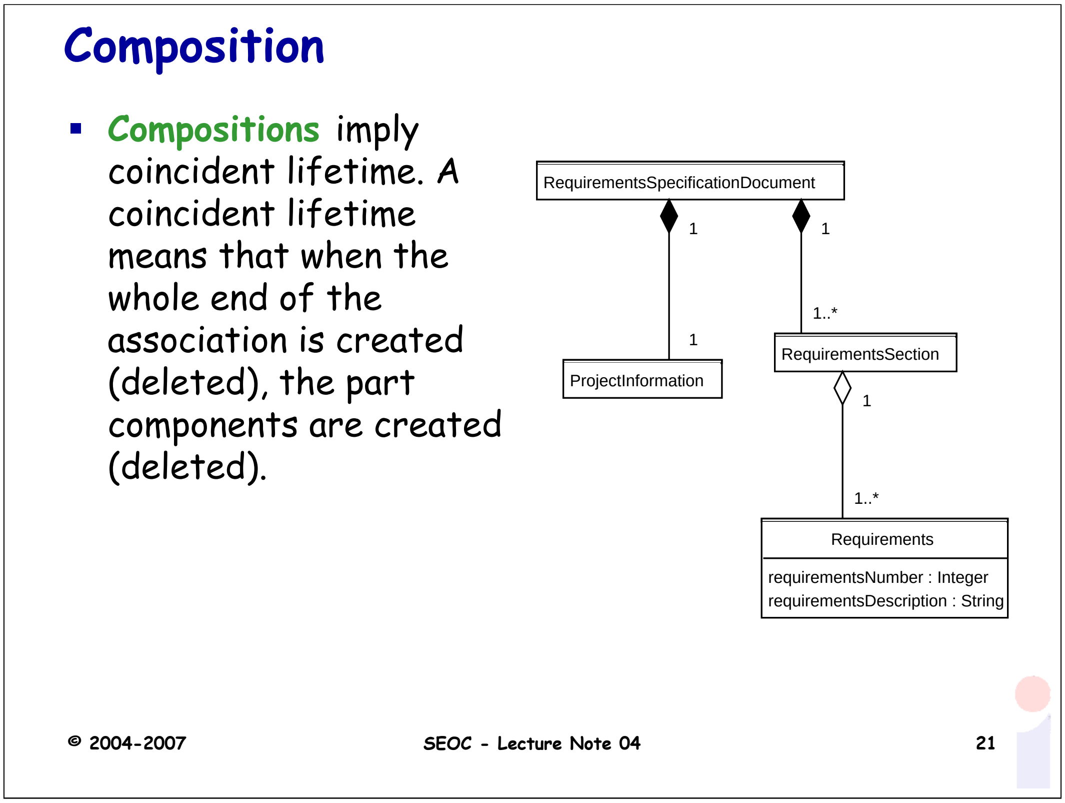




Aggregation

- is a stronger version of association
- is used to indicate that, as well as having attributes of its own, an instance of one class may consist of, or include, instances of another class
- are associations in which one class belongs to a collection



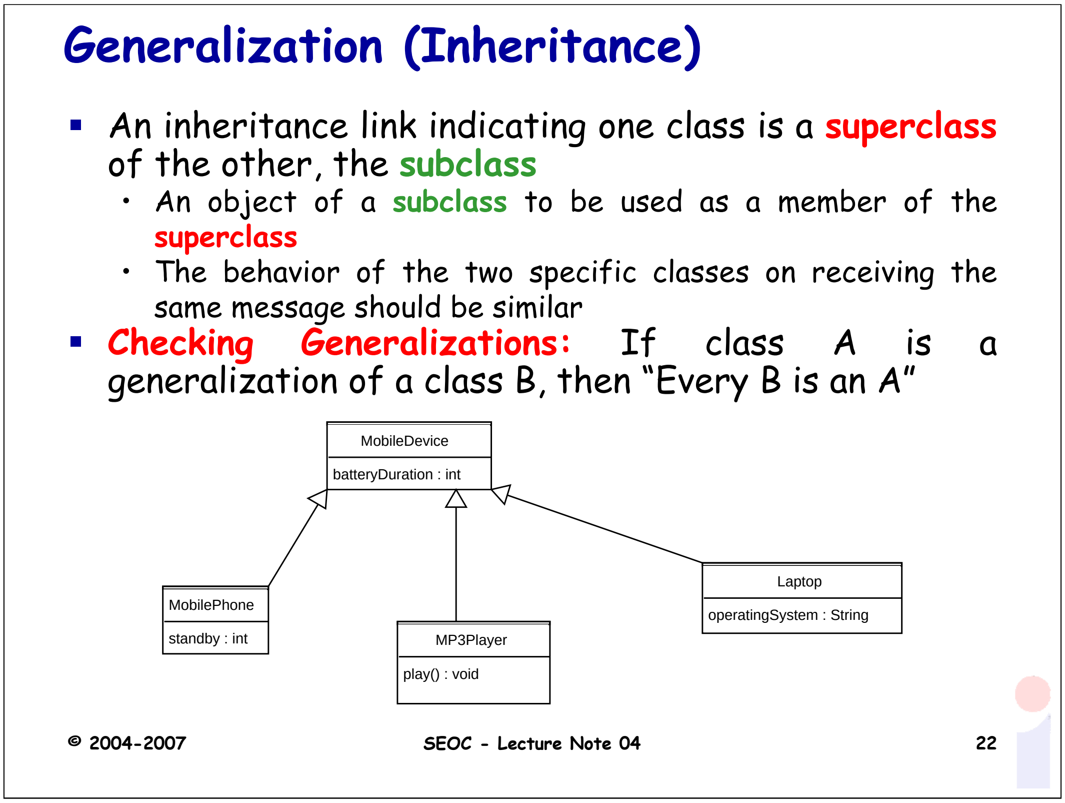


Composition

- **Compositions** imply coincident lifetime. A coincident lifetime means that when the whole end of the association is created (deleted), the part components are created (deleted).

RequirementsSpecificationDocument
1
1
1
1..*
ProjectInformation
RequirementsSection
1
1..*
Requirements
requirementsNumber : Integer
requirementsDescription : String

Note that the java code implementation for an aggregation (composition) relationship is exactly the same as the implementation for an association relationship. It results in the introduction of an attribute.



Generalization (Inheritance)

- An inheritance link indicating one class is a **superclass** of the other, the **subclass**
  - An object of a **subclass** to be used as a member of the **superclass**
  - The behavior of the two specific classes on receiving the same message should be similar
- **Checking Generalizations:** If class A is a generalization of a class B, then "Every B is an A"

MobileDevice
batteryDuration : int
MobilePhone
standby : int
MP3Player
play() : void
Laptop
operatingSystem : String

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Design by Contract. A subclass must keep to the contract of the superclass by ensuring operations observe the pre and post conditions on the methods and that the class invariant is maintained.

Suggested Readings

• B. Meyer. Applying `design by contract‘. IEEE Compute, 25(10):40-51, 1992.

Implementing Generalizations

- Java: creating the subclass by extending the superclass
- Inheritance increases system coupling
- Modifying the superclass methods may require changes in many subclasses
- Restrict inheritance to conceptual modeling
- Avoid using inheritance when some other association is more appropriate

More on Classes

- **Abstract Classes** provide the definition, but not the implementation
- **Interfaces** are collections of operations that have no corresponding method implementations
  - Safer than Abstract classes – avoid many problems associated with multiple inheritance
  - Java allows a class to implement any number of interface, but a class inherit from only one regular or abstract class
- **Templates** – or parameterized classes – allow us to postpone the decision as to which classes a class will work with

Modeling by Class Diagrams

- Class Diagrams (models)
  - from a **conceptual viewpoint**, reflect the requirements of a problem domain
  - From a **specification (or implementation) viewpoint**, reflect the intended design or implementation, respectively, of a software system
- Producing class diagrams involve the following iterative activities:
  - Find classes and associations (directly from the use cases)
  - Identify attributes and operations and allocate to classes
  - Identify generalization structures

How to build a class diagram

- Design is driven by criterion of completeness either of data or responsibility
  - **Data Driven Design** identifies all the data and see it is covered by some collection of objects of the classes of the system
  - **Responsibility Driven Design** identifies all the responsibilities of the system and see they are covered by a collection of objects of the classes of the system
- Noun identification
  - **Identify noun phrases**: look at the use cases and identify a noun phrase. Do this systematically and do not eliminate possibilities
  - **Eliminate inappropriate candidates**: those which are redundant, vague, outside system scope, an attribute of the system, etc.
- Validate the model…

Common Domain Modeling Mistakes

- Overly specific **noun-phrase analysis**
- Counter-intuitive or incomprehensible **class** and **association names**
- Assigning **multiplicities** to associations too soon
- Addressing **implementation issues** too early:
  - Presuming a specific implementation strategy
  - Committing to implementation constructs
  - Tackling implementation issues
- Optimizing for **reuse** before checking use cases achieved

Class and Object Pitfalls

- Confusing basic **class relationships** (i.e., is-a, has-a, is-implemented-using)
- Poor use of **inheritance**
  - Violating encapsulation and/or increasing coupling
  - Base classes do too much or too little
  - Not preserving base class invariants
  - Confusing interface inheritance with implementation inheritance
  - Using multiple inheritance to invert is-a

(Suggested) Readings

Readings

- **UML course textbook**
  - Chapter 4 on Class Diagram: Classes and Associations
  - Chapter 5 on Class Diagram: Aggregation, Composition and Generalization
  - Chapter 6 on Class Diagram: More on Associations
  - Chapter 7 on Class Diagram: Other Notations
- P. Kruchten, H. Obbink, J. Stafford. The Past, Present and Future of Software Architecture. IEEE Software, March/April 2006.

Suggested Readings

- I. Sommerville. Software Engineering, Eighth Edition, Addison-Wesley 2007.
  - Chapter 14 on Object-oriented design
- B. Meyer. Applying `design by contract‘. IEEE Compute, 25(10):40-51, 1992.

Summary

- Design is a complex matter
- Design links requirements to construction, essential to ensure traceability
- Class Diagram Rationale
- Classes
- Class Relationships
- Modeling by Class Diagrams
- How to build a class diagram
- Common domain modeling mistakes
- Class and Object Pitfalls