Object-Orientation Concepts, UML, and OOAD

Organization of This Lecture

- Object-oriented concepts
- Object modelling using Unified Modelling Language (UML)
- Object-oriented software development and patterns
- CASE tools
- Summary

Object-Orientation Concepts

- Object-oriented (OO) design techniques are extremely popular:
  - Inception in early 1980's and nearing maturity.
  - Widespread acceptance in industry and academics.
  - Unified Modelling Language (UML) already an ISO standard (ISO/IEC 19501).

Objects

A system is designed as a set of interacting objects:

Often, real-world entities:

Examples: an employee, a book etc.

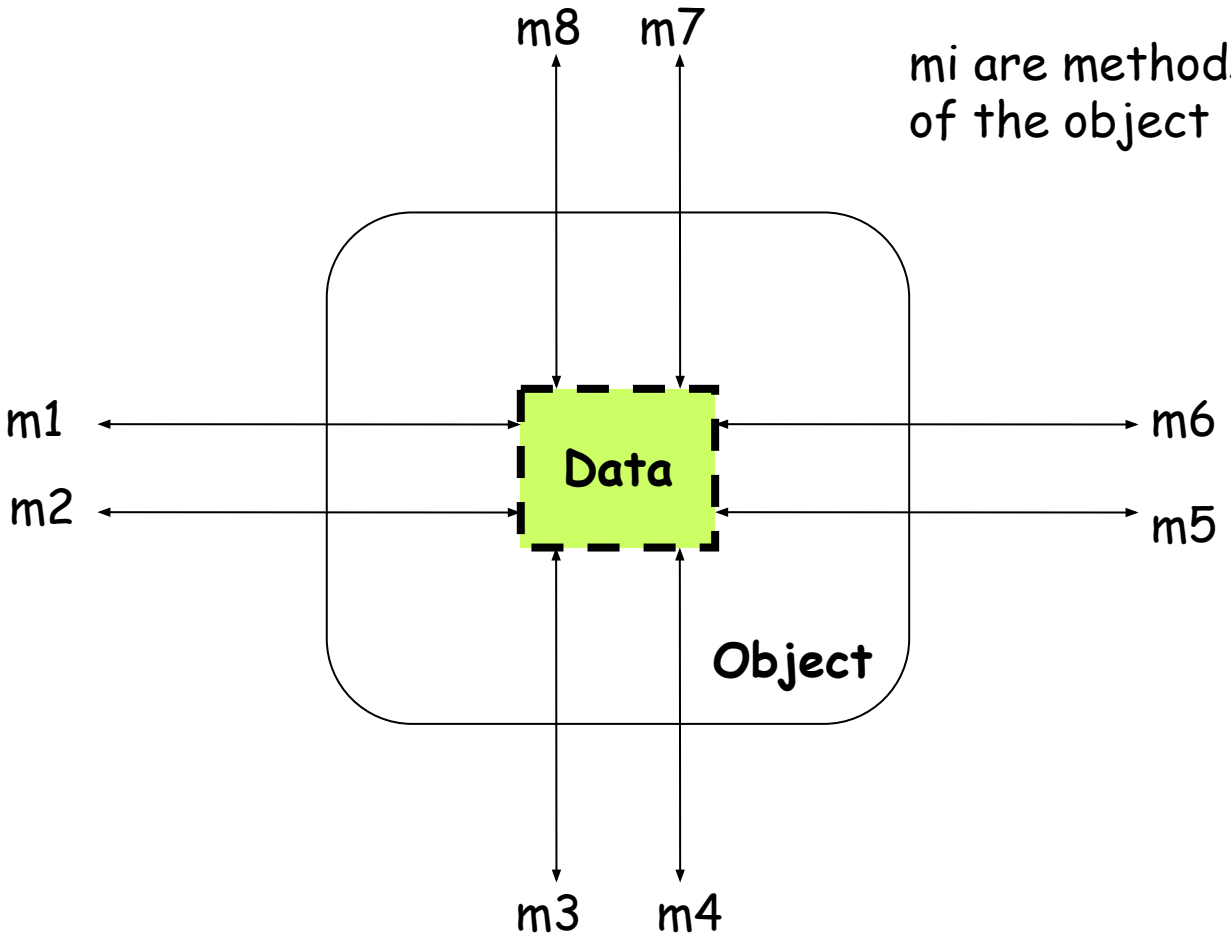
Can be conceptual objects also:

Controller, manager, etc.

Consists of data (attributes) and functions (methods) that operate on data.

Hides organization of internal

Model of an Object



Class

Instances are objects

Template for object creation

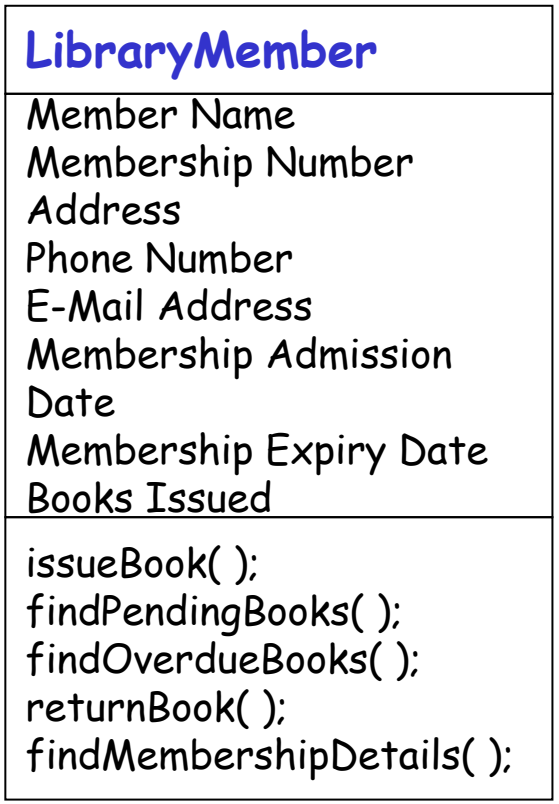
Considered as abstract data type (ADT)

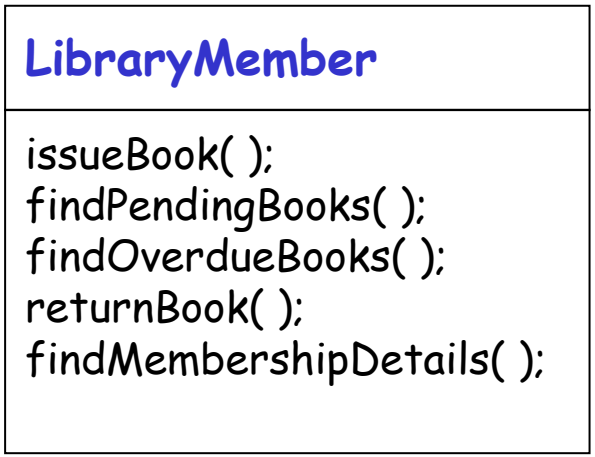
Examples: Employees, Books, etc.

Sometimes not intended to produce instances:

- Abstract classes

Example Class Diagram





Different representations of the LibraryMember class

Methods and Messages

Operations supported by an object:

- Means for manipulating the data of other objects.
- Invoked by sending a message (method call).
- Examples: calculate_salary, issue-book, member_details, etc.

What are the Different Types of Relationships Among Classes?

Four types of relationships:

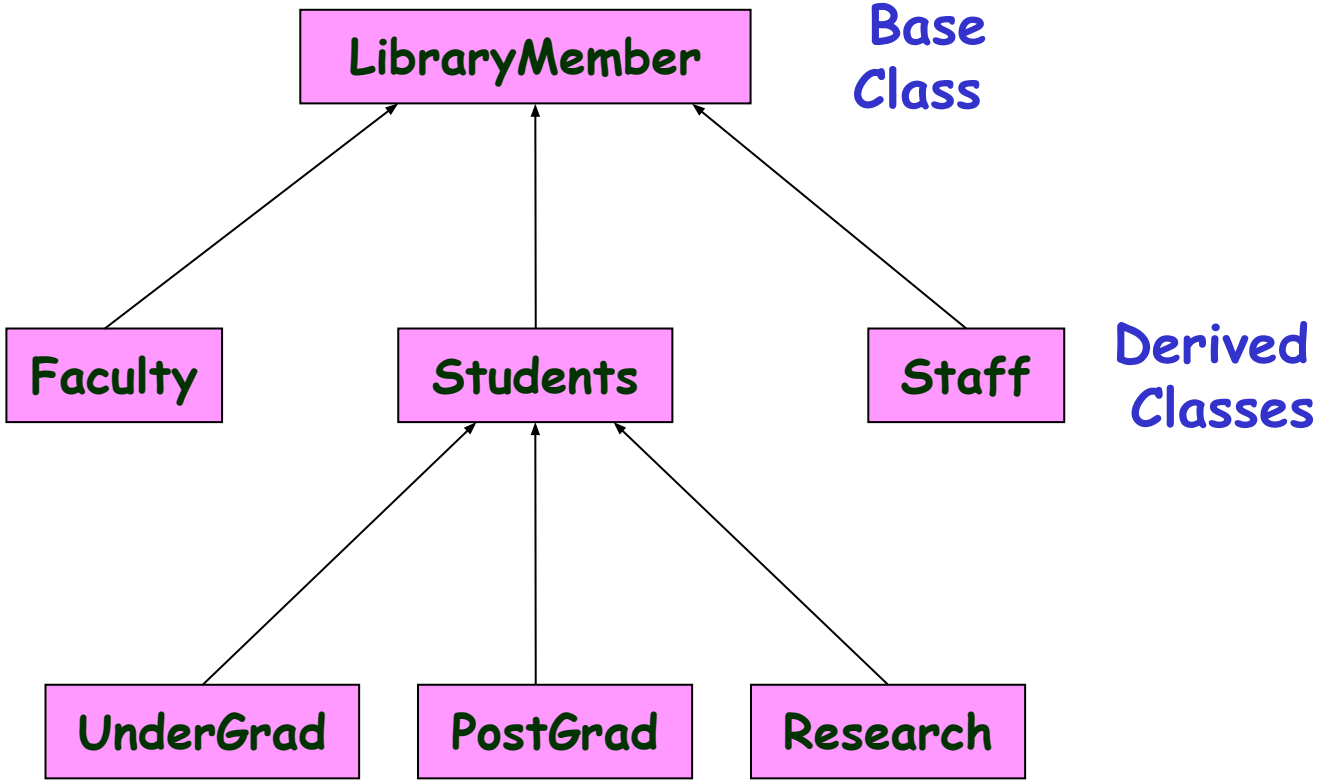
- Inheritance
- Association
- Aggregation/Composition
- Dependency

Inheritance

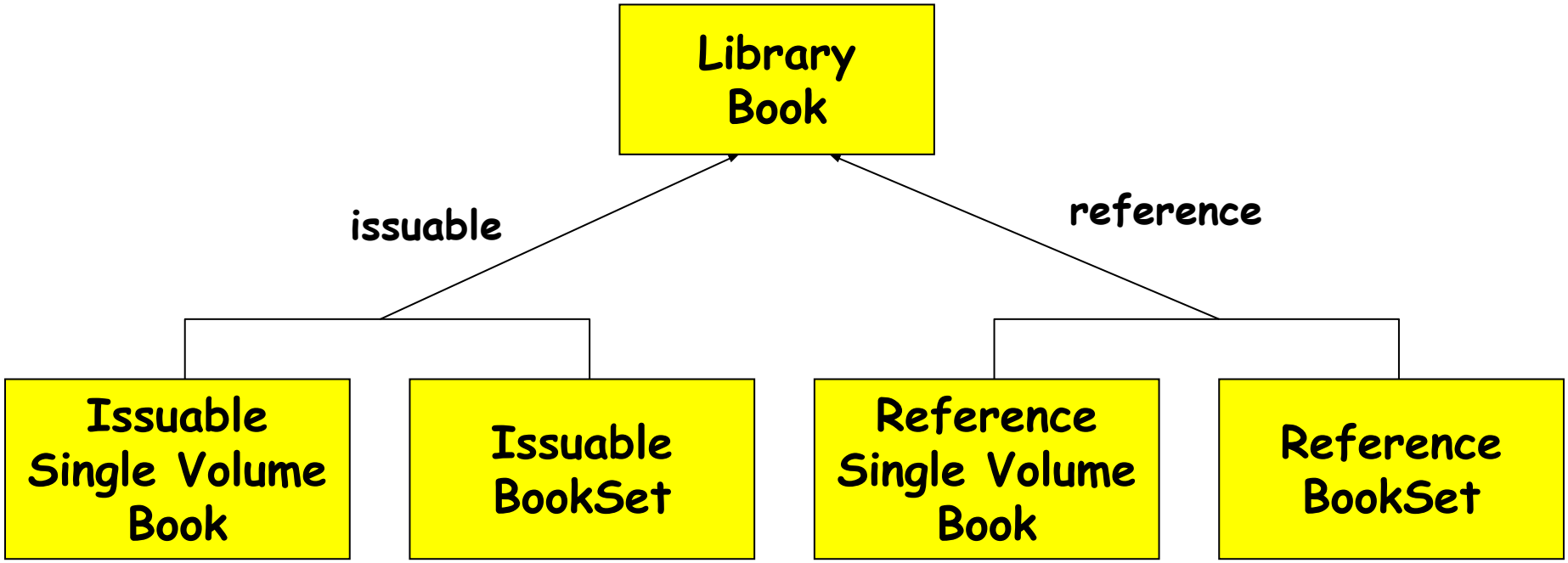
- Allows to define a new class (derived class) by extending or modifying existing class (base class).
  - Represents generalization-specialization relationship.
  - Allows redefinition of the existing methods (method overriding).

Inheritance

Lets a subclass inherit attributes and methods from more than one base class.

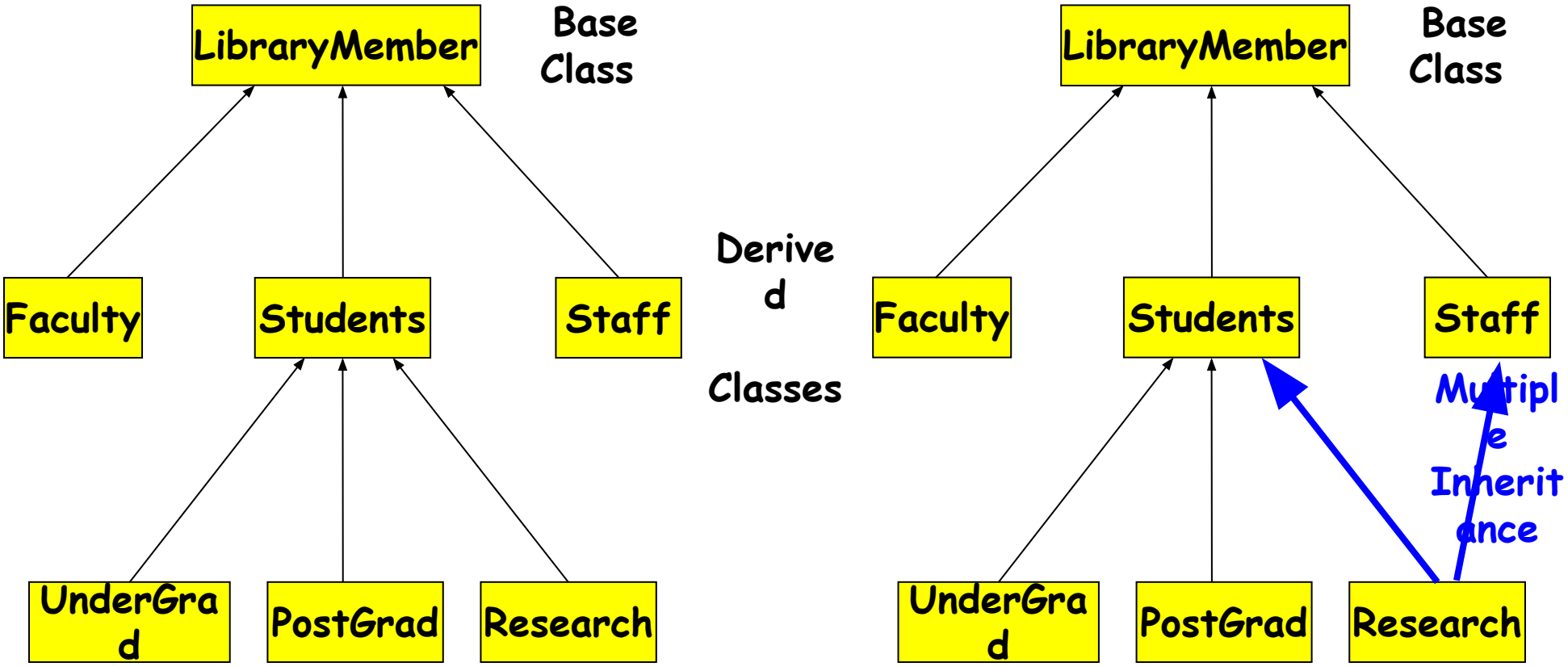


Inheritance Example



Representation of the inheritance relationship

Multiple Inheritance



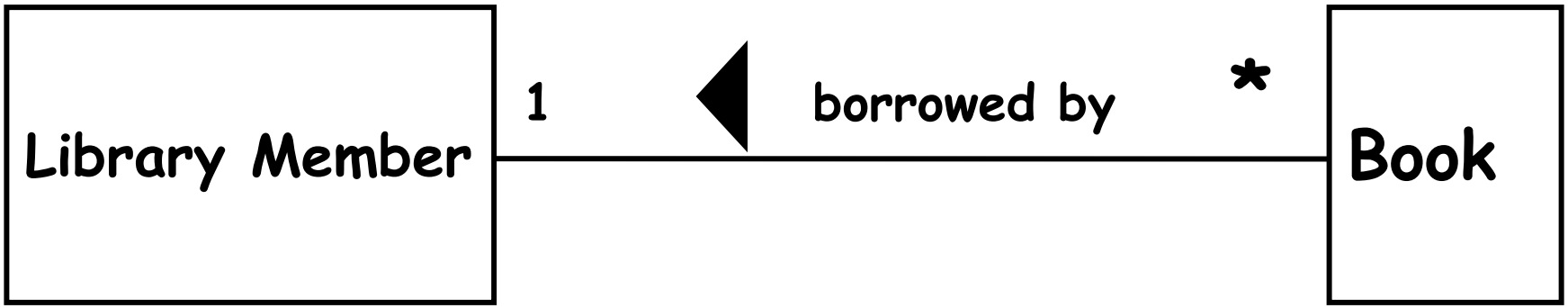
Association Relationship

- Enables objects to communicate with each other:
  - Thus one object must "know" the address of the corresponding object in the association.
- Usually binary:
  - But in general can be n-ary.

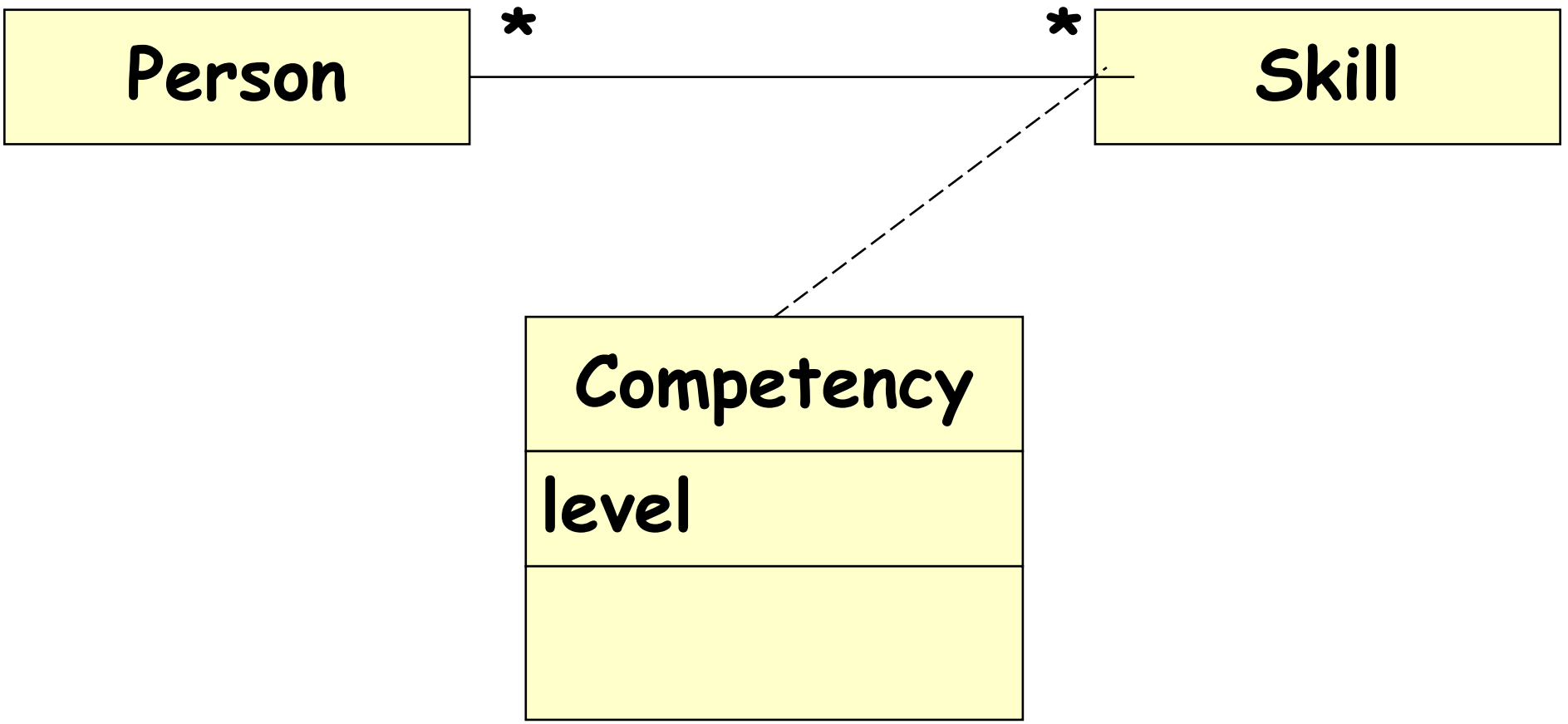
Association Relationship

- A class can be associated with itself (recursive association).
  - Give an example?
- An arrowhead used along with name, indicates direction of association.
- Multiplicity indicates # of instances taking part in the association.

Association Relationship



3-ary Association



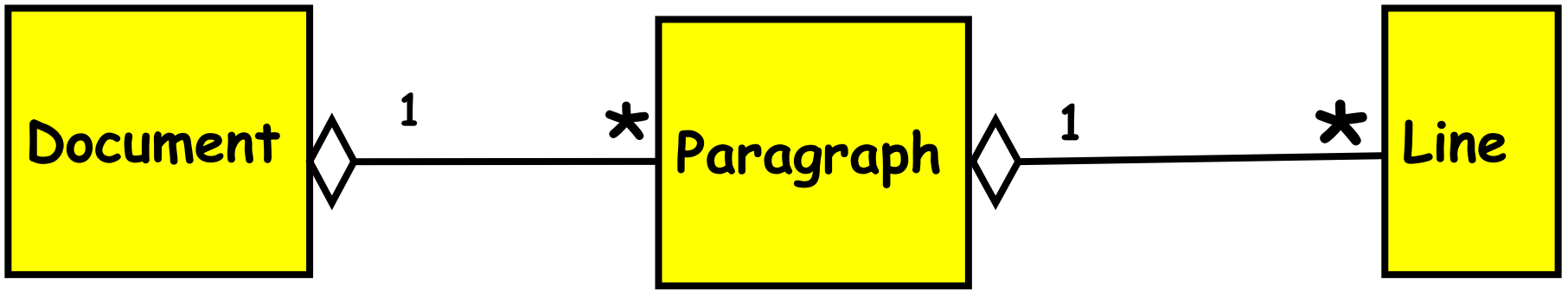
Association and Link

- A link:
  - An instance of an association
  - Exists between two or more objects
  - Dynamically created and destroyed as the run of a system proceeds
- For example:
  - An employee joins an organization,
  - Leaves that organization and joins a new organization etc.

Aggregation Relationship

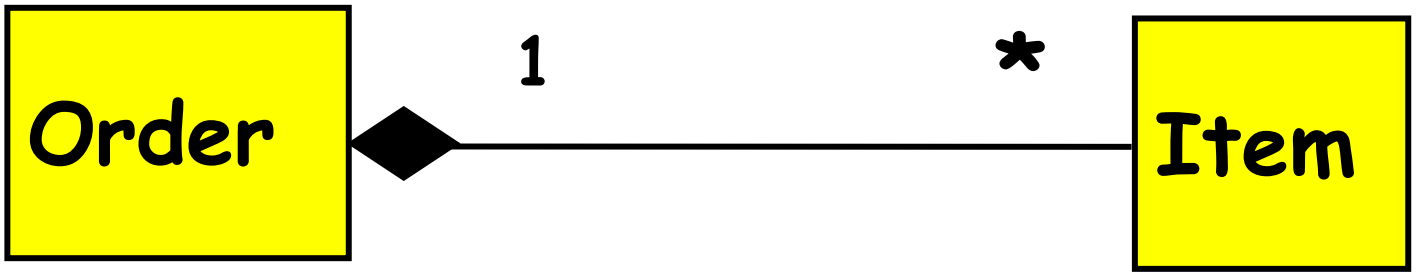
- Represents whole-part relationship
- Represented by a diamond symbol at the composite end
- Cannot be reflexive(i.e. recursive)
- Not symmetric
- It can be transitive

Aggregation Relationship



Composition Relationship

- Life of item is same as the order



Aggregation

cont…

A aggregate object contains other objects.

Aggregation limited to tree hierarchy:

No circular inclusion relation.

Aggregation vs. Inheritance

Cont…

Inheritance:

Different object types with similar features.

Necessary semantics for similarity of behavior is in place.

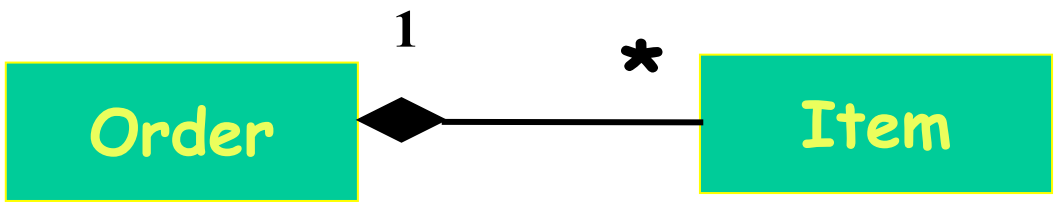
Aggregation:

Containment allows construction of complex objects.

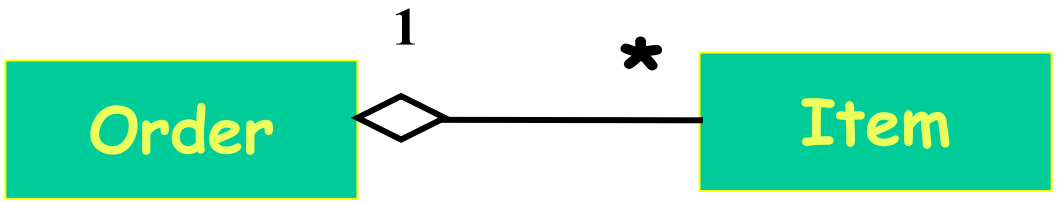
Aggregation vs. Composition

- Composition:
  - Composite and components have the same life.
- Aggregation:
  - Lifelines are different.
- Consider an order object:
  - Aggregation: If order items can be changed or deleted after placing the order.
  - Composition: Otherwise.

Composition versus Aggregation

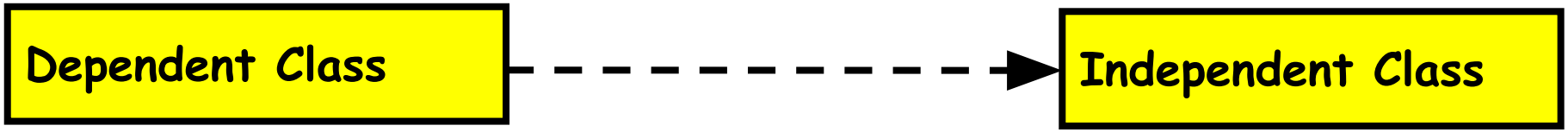


Composition



Aggregation

Class Dependency



Representation of dependence between classes

Abstraction

Consider aspects relevant for certain purpose

Suppress non-relevant aspects

Types of abstraction:

Data abstraction

Behaviour abstraction

Abstraction

cont…

Advantages of abstraction:

Reduces complexity of design

Enhances understandability

Increases productivity

It has been observed that:

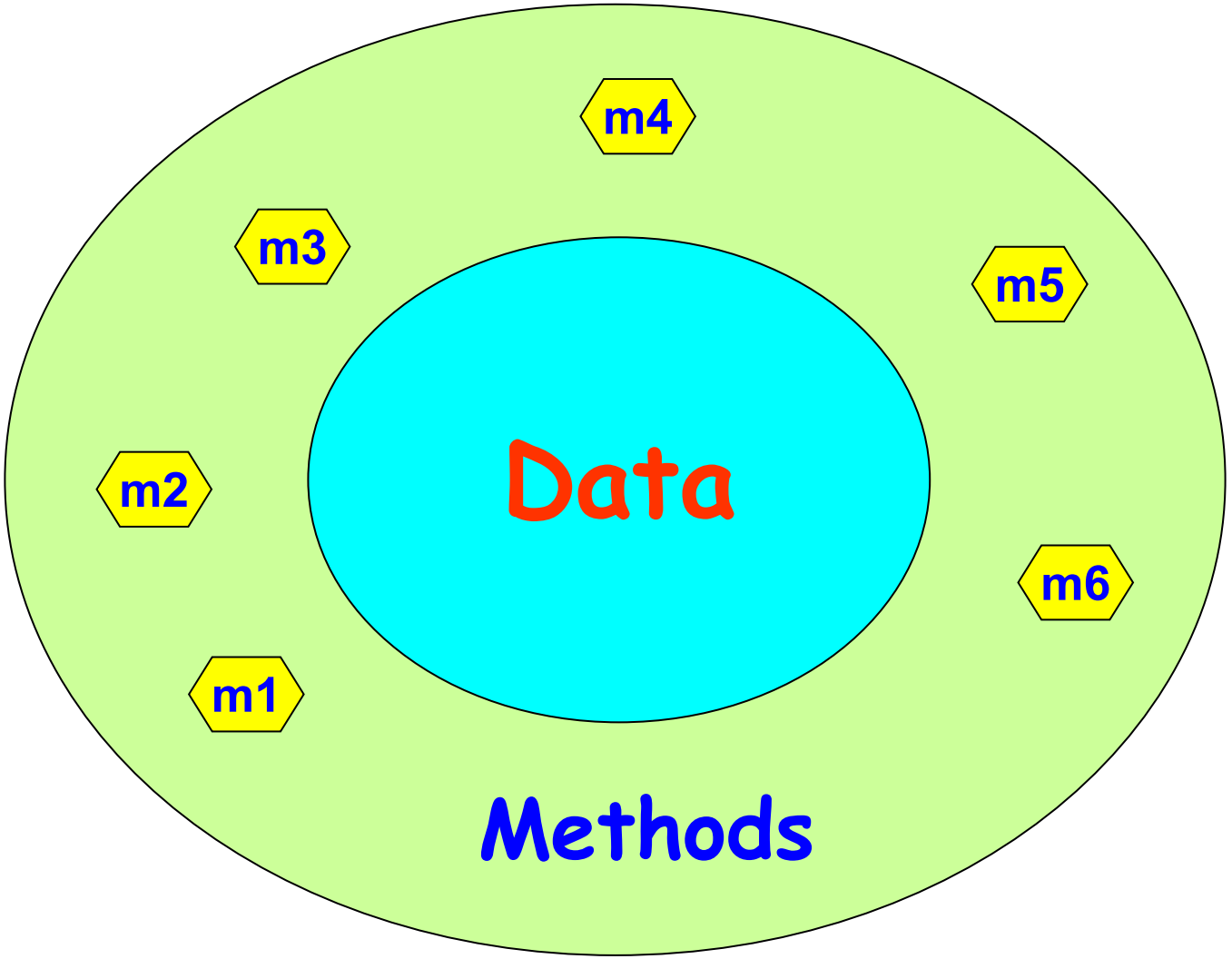
Productivity is inversely proportional to complexity.

Encapsulation

- Objects communicate with outside world through messages:
  - Data of objects encapsulated within its methods.
  - Data accessible only through methods.

Encapsulation

cont…



Concept of encapsulation

Polymorphism

Denotes poly (many) morphism (forms).

Under different situations:

Same message to the same object can result in different actions:

Static binding

Dynamic binding

An Example of Static Binding

```
Class Circle{
  private float x, y, radius;
  private int fillType;

    public create ();
   public create (float x,
float y, float centre);
    public create (float x,
float y, float centre, int
```

An Example of Static Binding

cont…

A class named Circle has three definitions for create operation

Without any parameter, default

Centre and radius as parameter

Centre, radius and fillType as parameter

Depending upon parameters, method will be invoked

Method create is said to be overloaded

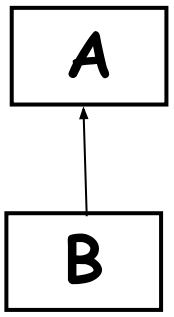
Dynamic Binding

- A method call to an object of an ancestor class:
  - Would result in the invocation of the method of an appropriate object of the derived class.
- Following principles are involved:
  - Inheritance hierarchy
  - Method overriding
  - Assignment to compatible types

Dynamic Binding

Principle of substitutability (Liskov's substitutability principle):

An object can be assigned to an object of its ancestor class, but not vice versa.



A a; B b;

a=b; (OK)

b=a; (not OK)

Dynamic Binding

Cont …

Exact method to be bound on a method call:

Not possible to determine at compile time.

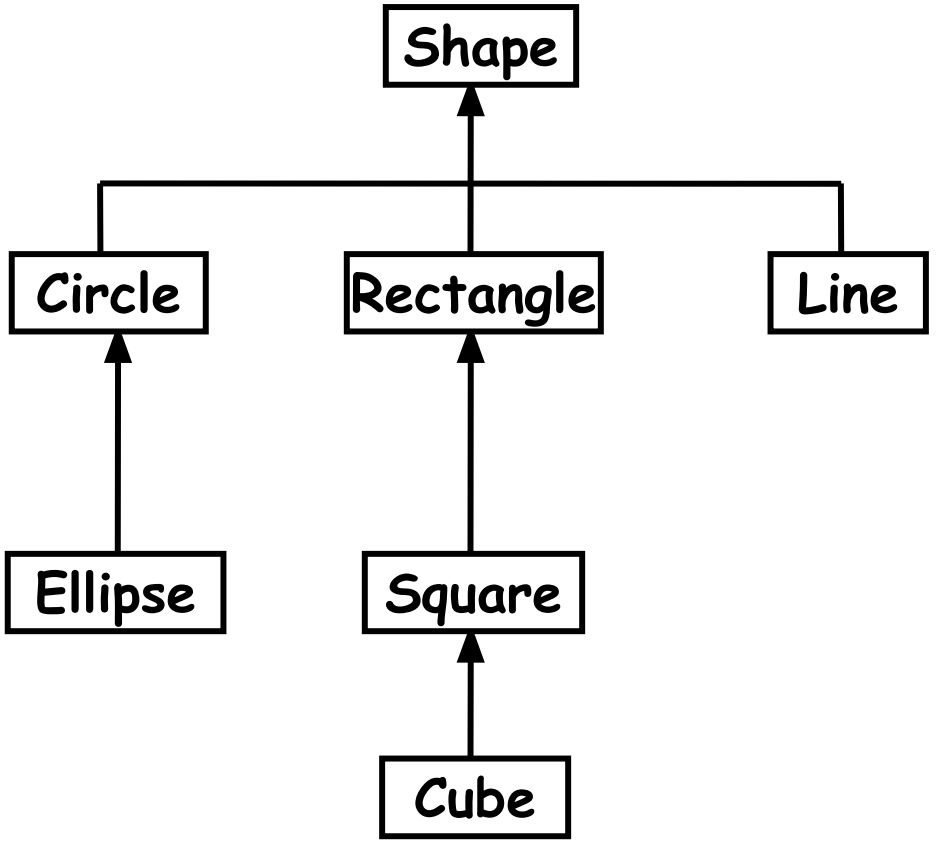
Dynamically decided at runtime.

An Example of Dynamic Binding

- Consider a class hierarchy of different geometric objects:
  - Display method is declared in the shape class and overridden in each derived class.
  - A single call to the display method for each object would take care of displaying the appropriate element.

An Example of Dynamic Binding

cont…



Class hierarchy of geometric objects

An Example

cont…

Traditional code

```
Shape s[1000];
For(i=0;i<1000;i++){
   If (s[i] == Circle)    then
         draw_circle();
    else if (s[i]== Rectangle)
then
         draw_rectangle();
        -

}
```

Object-oriented code

```
Shape s[1000];
For(i=0;i<1000;i++)
        Shape.draw();

     -
     -
     -
     -
```

Traditional code and OO code using dynamic binding

Genericity

Ability to parameterize class definitions.

Example: class stack of different types of elements:

Integer stack

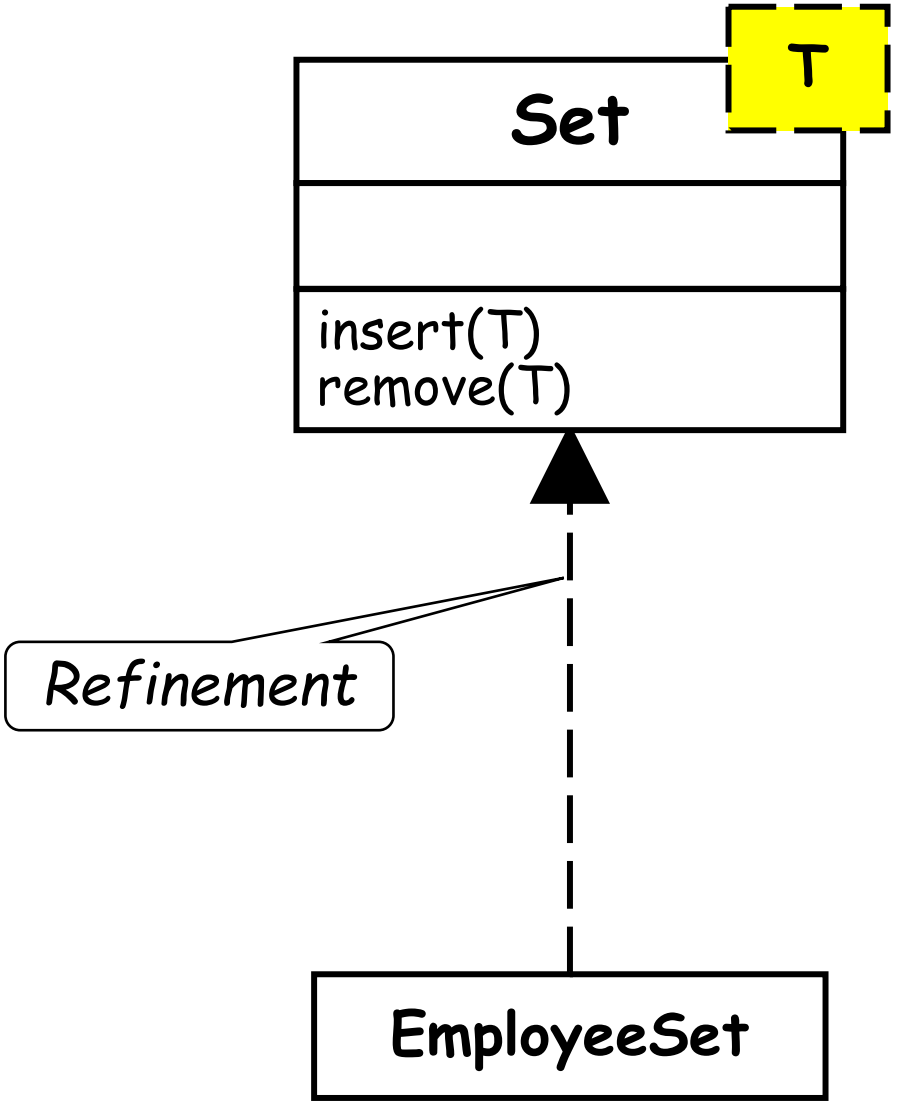
Character stack

Floating point stack

Define generic class stack:

Later instantiate as required

Genericity



Advantages of Object-Oriented Development

Code and design reuse

Increased productivity

Ease of testing (?) and maintenance

Better understandability

Elegant design:

Loosely coupled, highly cohesive objects:

Essential for solving large problems.

Advantages of Object-Oriented Development cont…

Initially incurs higher costs

After completion of some projects reduction in cost become possible

Using well-established OO methodology and environment:

Projects can be managed with 20% -- 50% of traditional cost of development.

Object Modelling Using UML

UML is a modelling language

- Not a system design or development methodology

Used to document object-oriented analysis and design results.

Independent of any specific design methodology.

UML Origin

OOD in late 1980s and early 1990s:

- Different software development houses were using different notations.
- Methodologies were tied to notations.

UML developed in early 1990s to:

- Standardize the large number of object-oriented modelling notations

UML Lineology

Based Principally on:

OMT [Rumbaugh 1991]

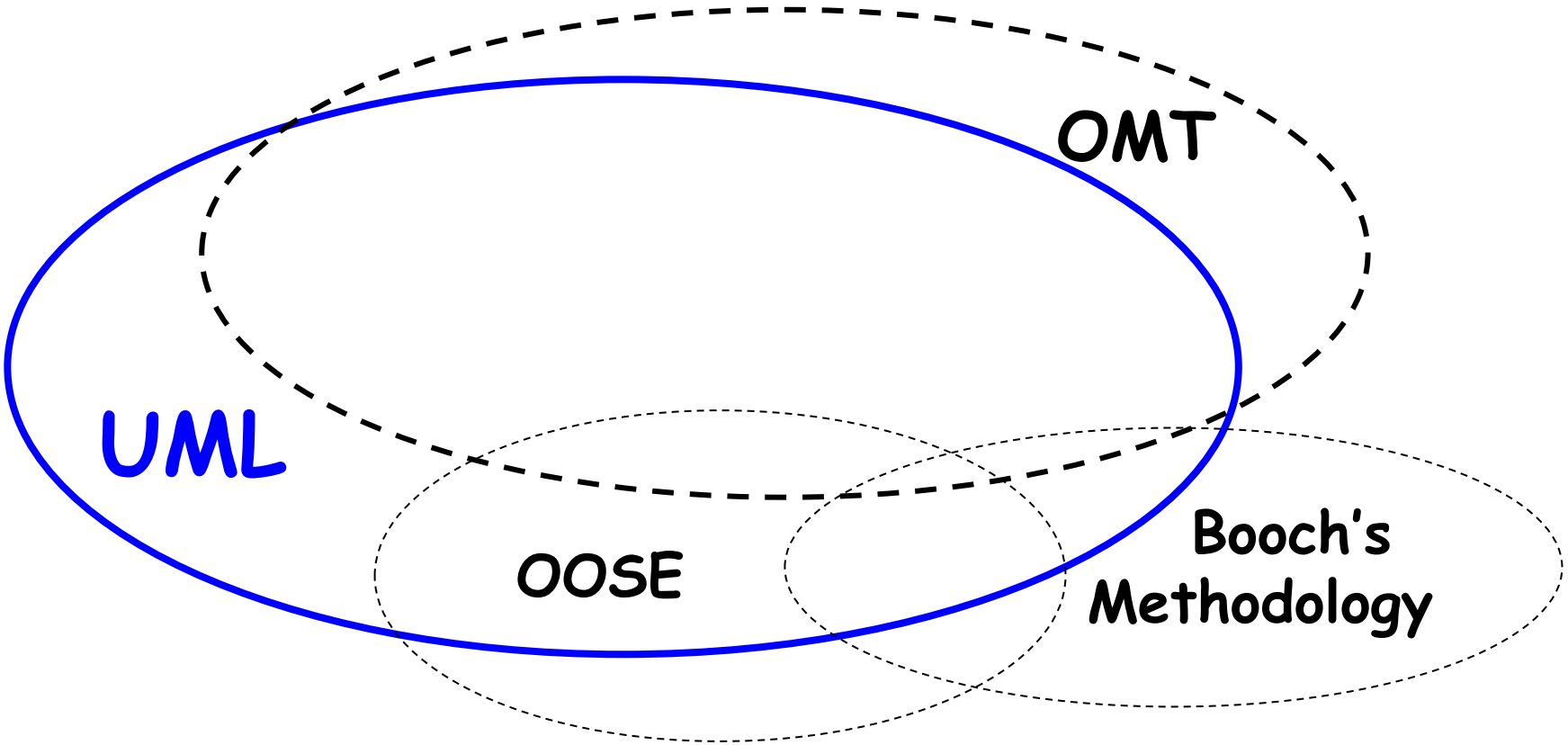
Booch's methodology[Booch 1991]

OOSE [Jacobson 1992]

Odell's methodology[Odell 1992]

Shlaer and Mellor [Shlaer 1992]

Different Object Modeling Techniques in UML



UML as A Standard

Adopted by Object Management Group (OMG) in 1997

OMG is an association of industries

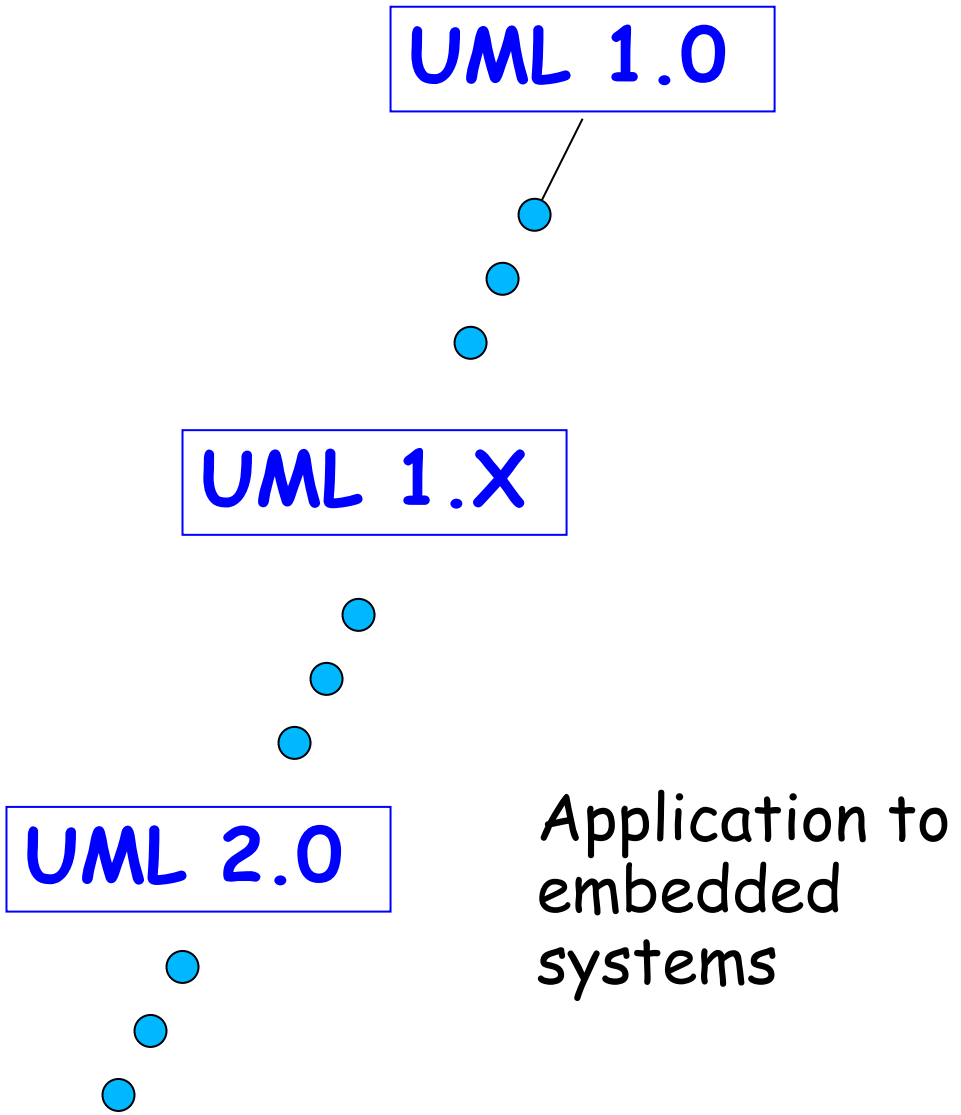
Promotes consensus notations and techniques

Used outside software development

Example car manufacturing

Developments to UML

- **UML continues to develop:**
  - **Refinements**
  - **Making it applicable to new contexts**



Why are UML Models Required?

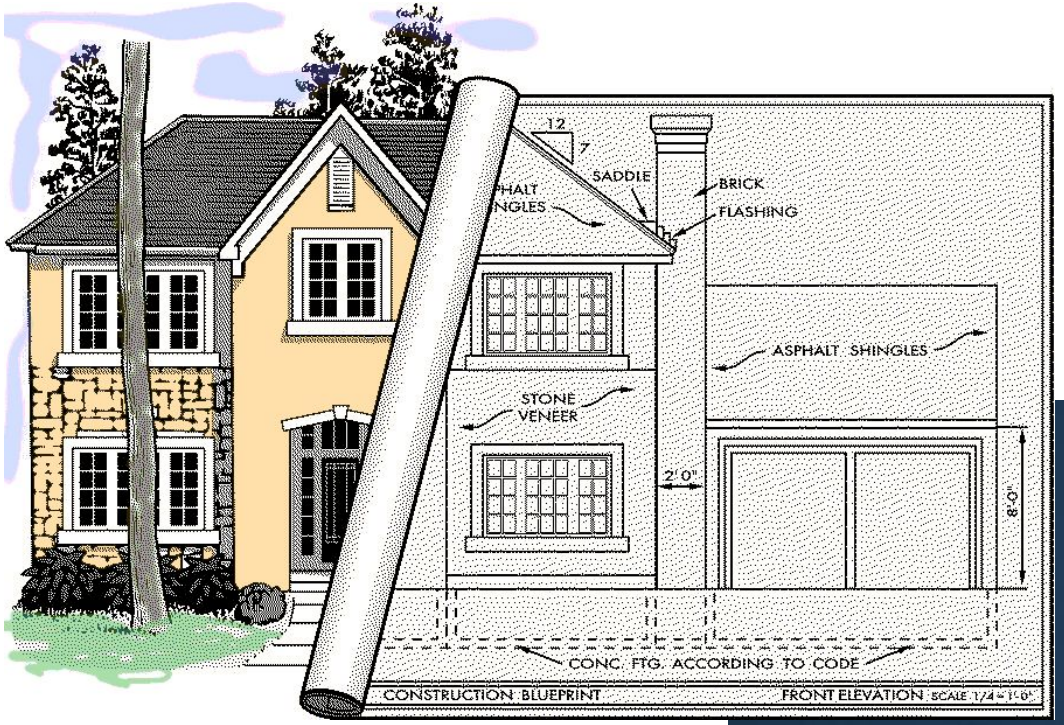
A model is an abstraction mechanism:

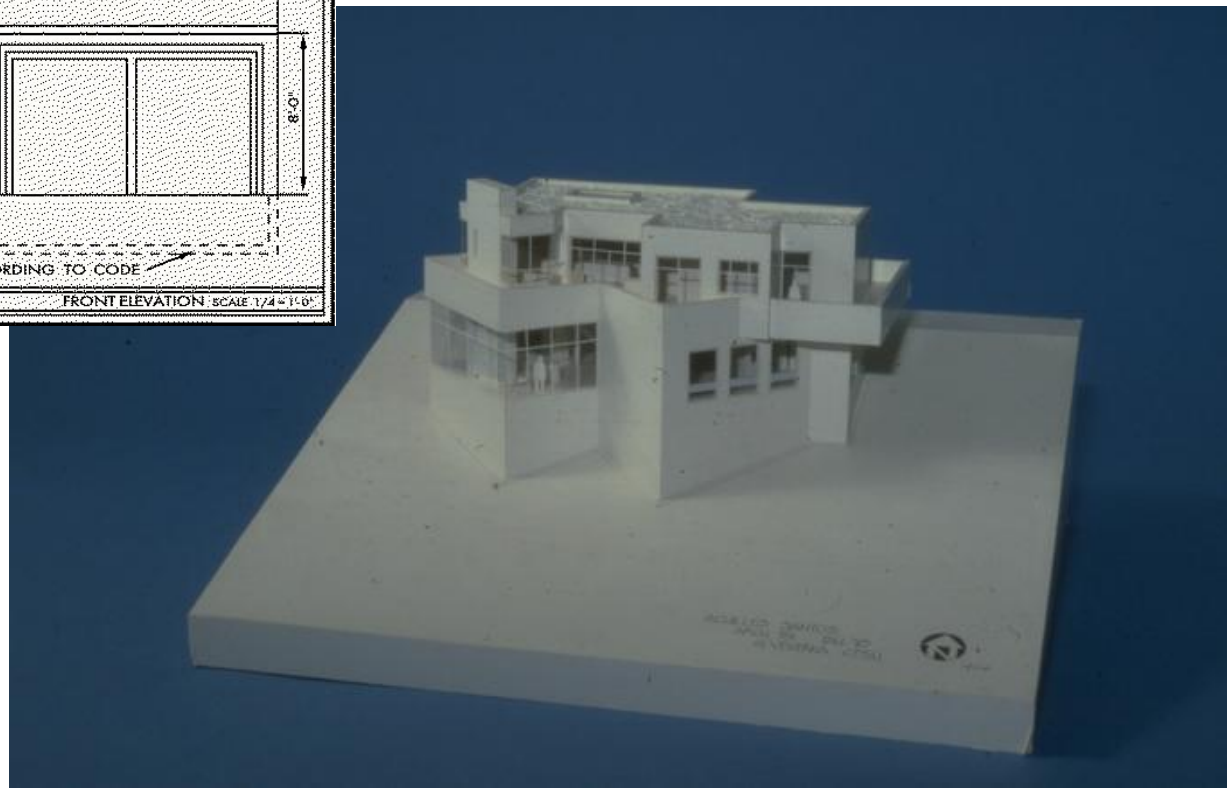
- Capture only important aspects and ignores the rest.
- Different models result when different aspects are ignored.
- An effective mechanism to handle complexity.

UML is a graphical modelling tool

Easy to understand and construct

Modeling a House





UML Diagrams

Nine diagrams are used to capture different views of a system.

Views:

Provide different perspectives of a software system.

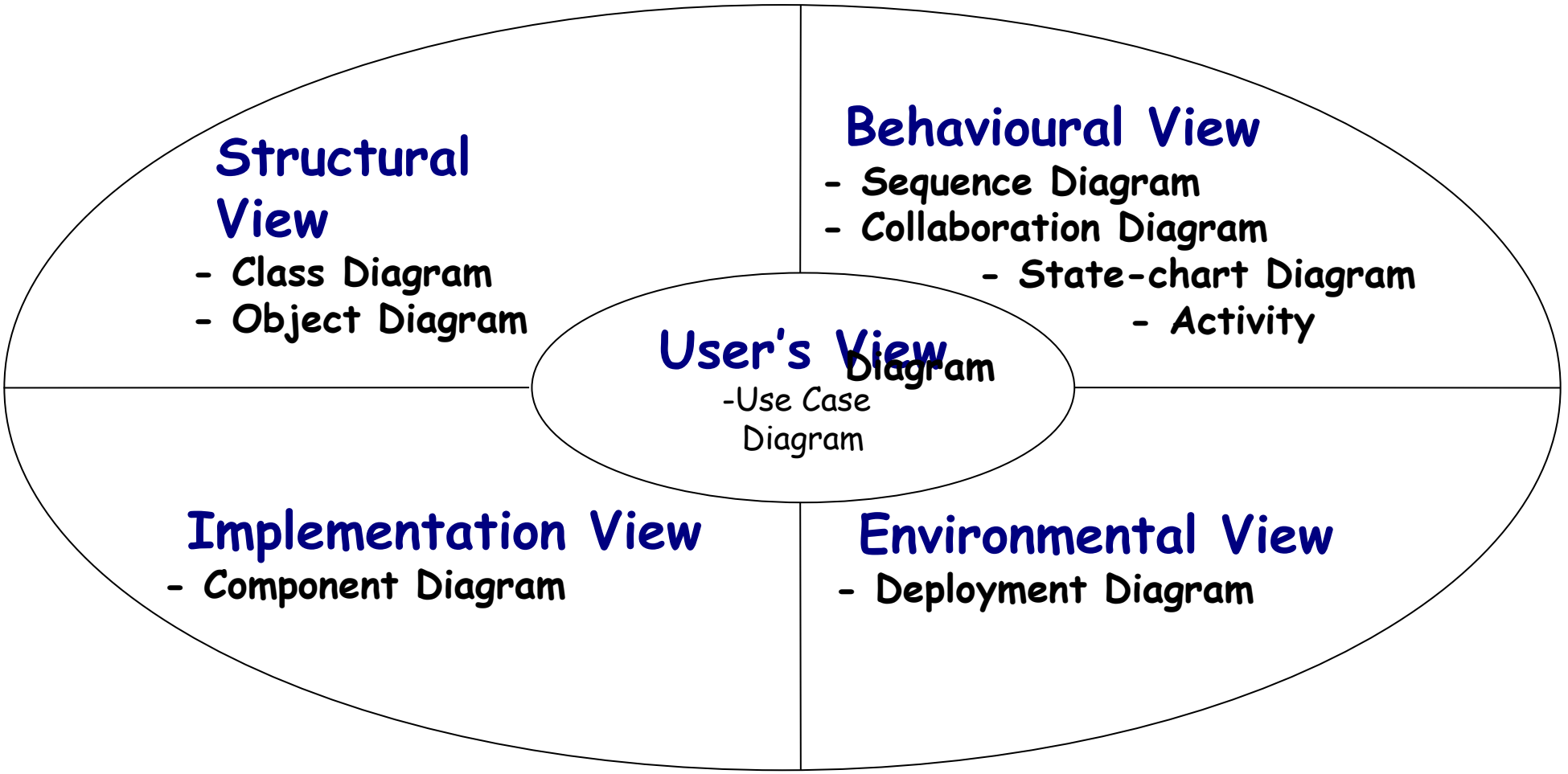
Diagrams can be refined to get the actual implementation of a system.

UML Model Views

Views of a system:

- User's view
- Structural view
- Behavioral view
- Implementation view
- Environmental view

UML Diagrams



Diagrams and views in UML

Are All Views Required for Developing A Typical System?

NO

Use case diagram, class diagram and one of the interaction diagram for a simple system

State chart diagram required to be developed when a class state changes

However, when states are only one or two, state chart model becomes trivial

Deployment diagram in case of large number of hardware components used to develop the system

Use Case Model

- Consists of set of "use cases"
- An important analysis and design artifact
- The central model:
  - 📫 Other models must confirm to this model
  - 📫 Not really an object-oriented model
  - 📫 Represents a functional or process model

Use Cases

- Different ways in which a system can be used by the users
- Corresponds to the high-level requirements
- Represents transaction between the user and the system
- Defines external behavior without revealing internal structure of system
- Set of related scenarios tied together by a common goal.

Use Cases

Cont…

- Normally, use cases are independent of each other
- Implicit dependencies may exist
- Example: In Library Automation System, renew-book & reserve-book are independent use cases.

  📫 But in actual implementation of renew-book: a check is made to see if any book has been reserved using reserve-book.

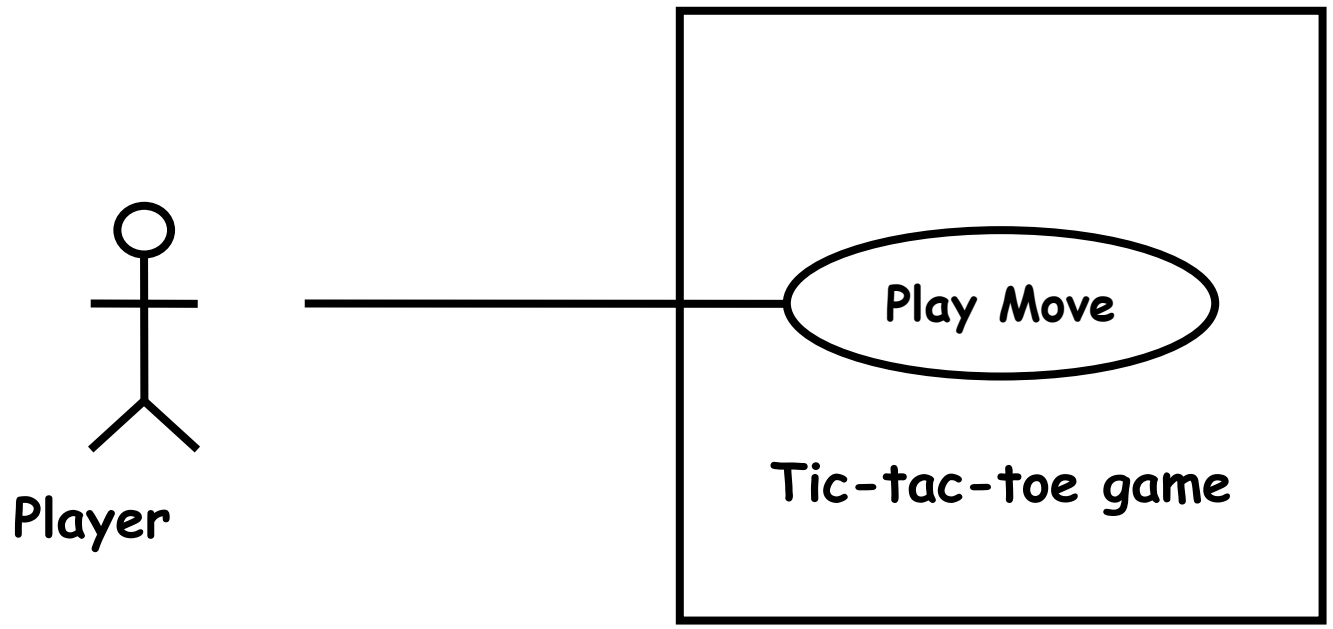
Example Use Cases

- For library information system
  - issue-book
  - query-book
  - return-book
  - create-member
  - add-book, etc.

Representation of Use Cases

- Represented by use case diagram
- A use case is represented by an ellipse
- System boundary is represented by a rectangle
- Users are represented by stick person icons (actor)
- Communication relationship between actor and use case by a line
- External system by a stereotype

An Example Use Case Diagram



Use case model

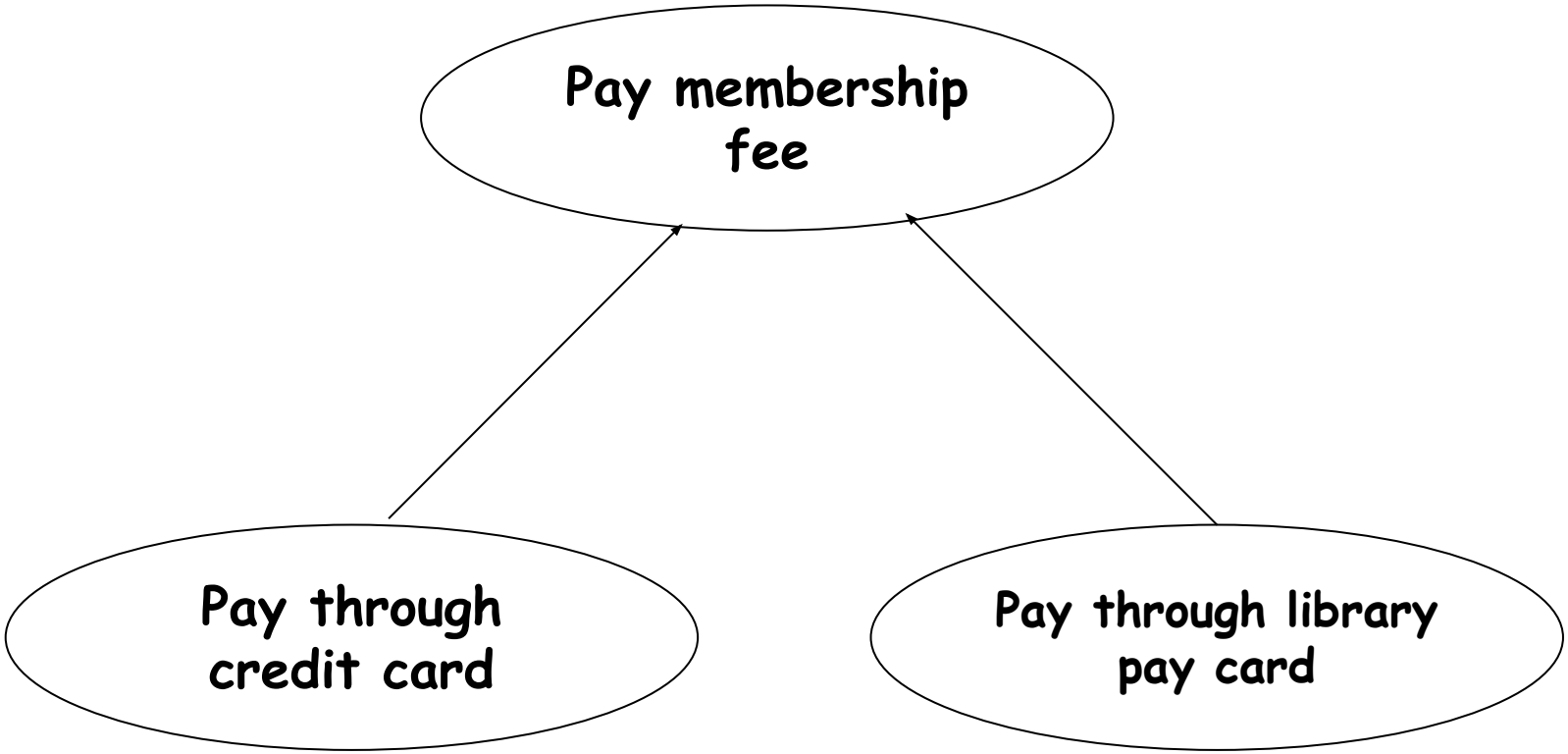
Why Develop A Use Case Diagram?

- Serves as requirements specification
- How are actor identification useful in software development:
  - User identification helps in implementing appropriate interfaces for different categories of users
  - Another use in preparing appropriate documents (e.g. user's manual).

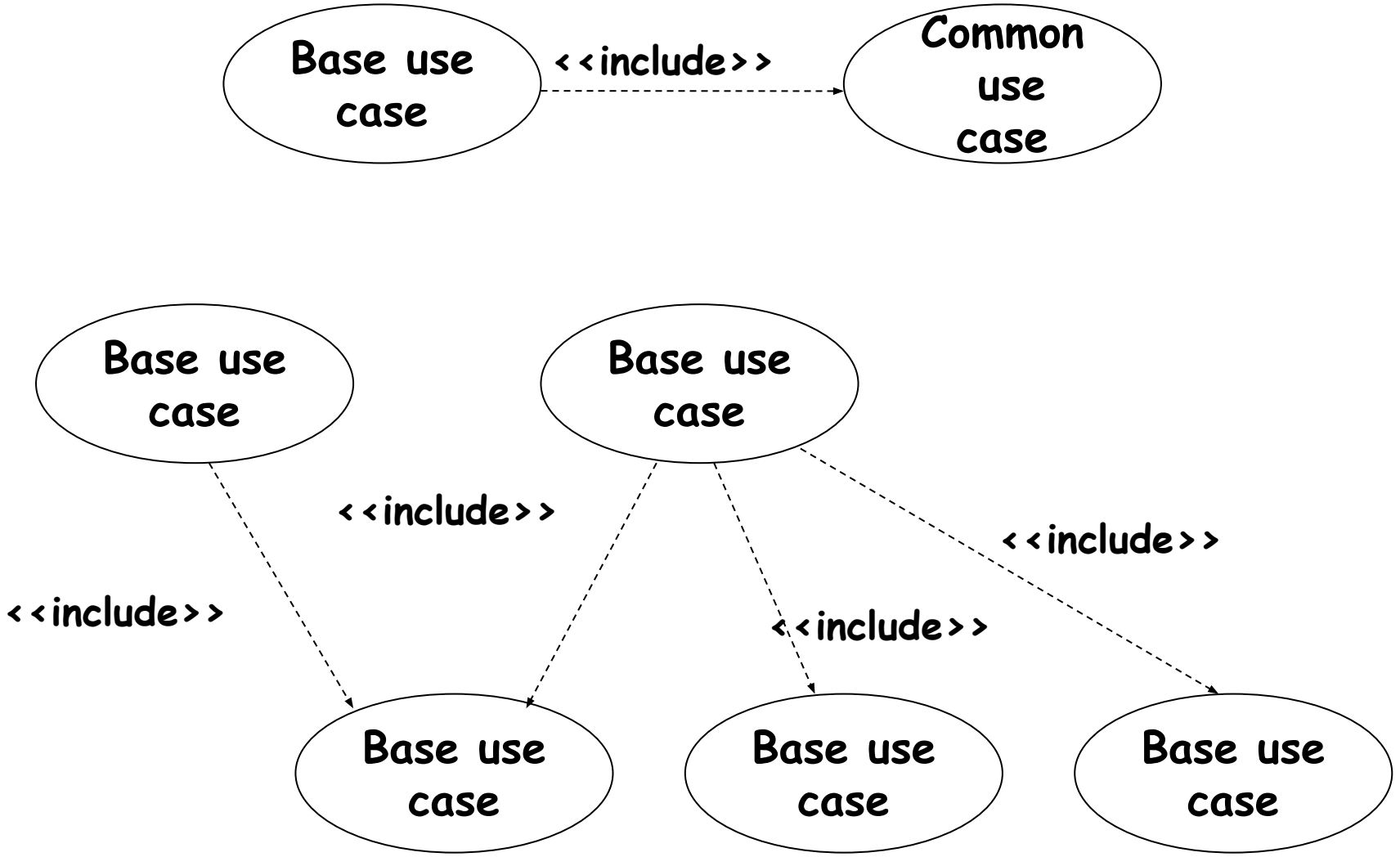
Factoring Use Cases

- Two main reasons for factoring:
  - Complex use cases need to be factored into simpler use cases
  - To represent common behavior across different use cases
- Three ways of factoring:
  - Generalization
  - Includes
  - Extends

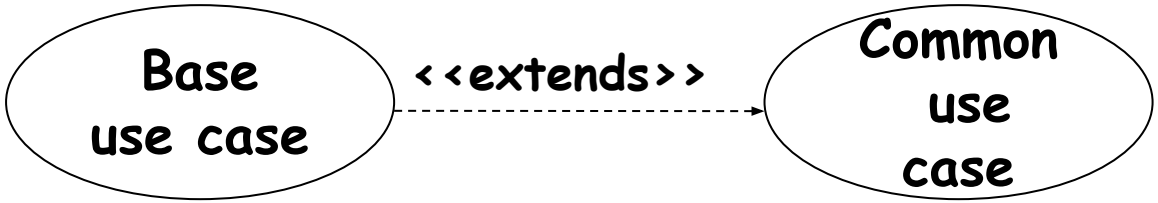
Factoring Use Cases Using Generalization



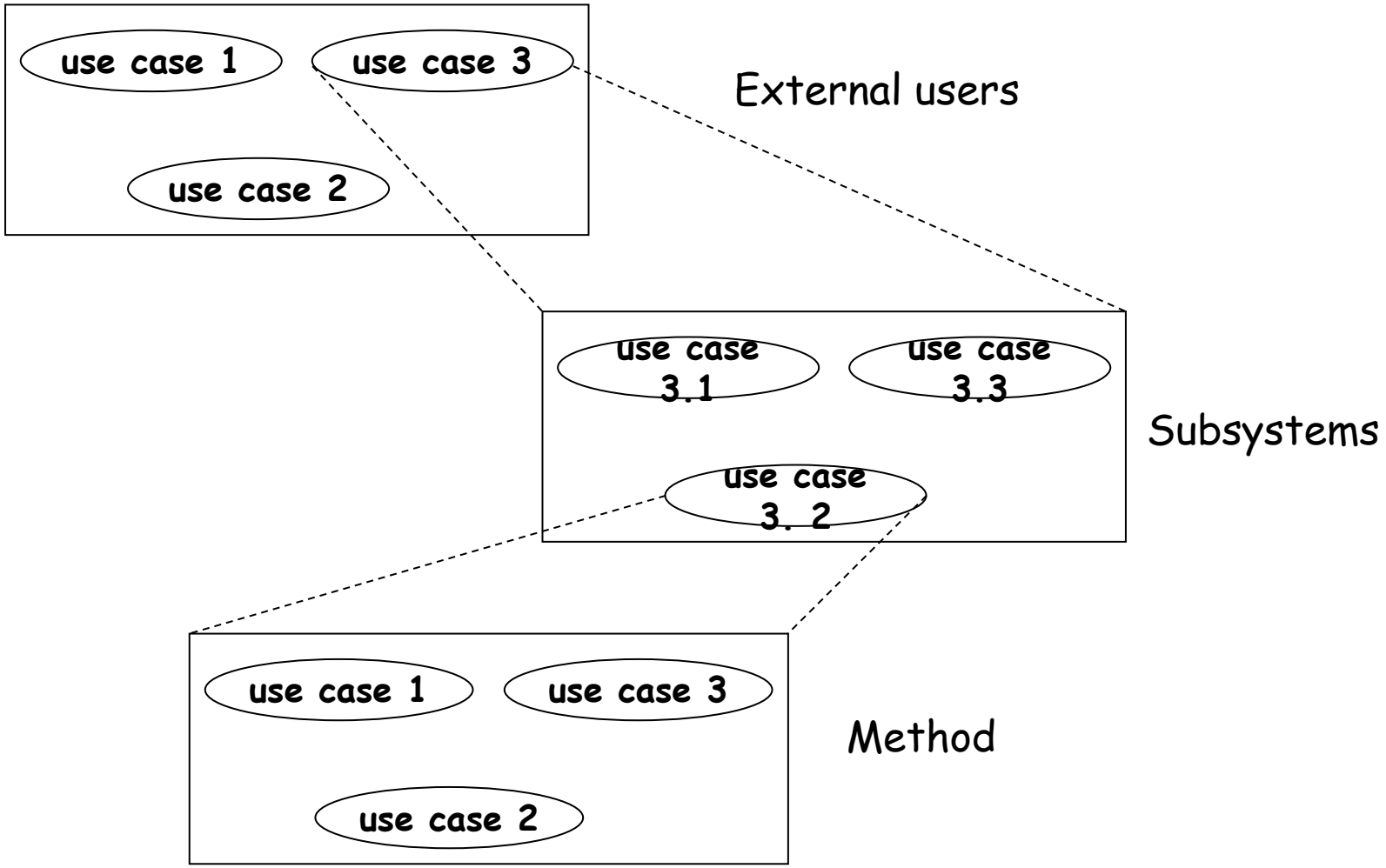
Factoring Use Cases Using Includes



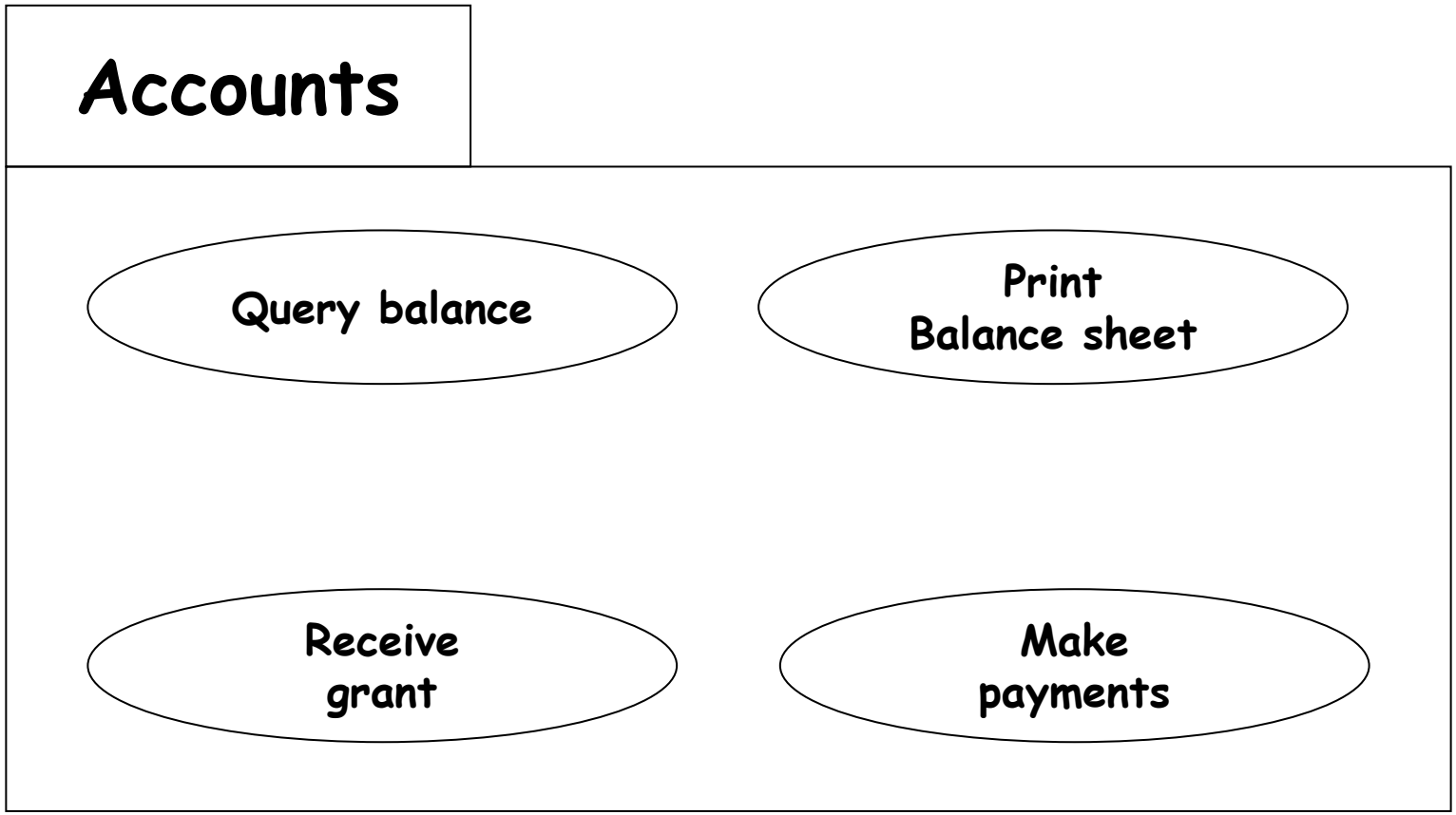
Factoring Use Cases Using Extends



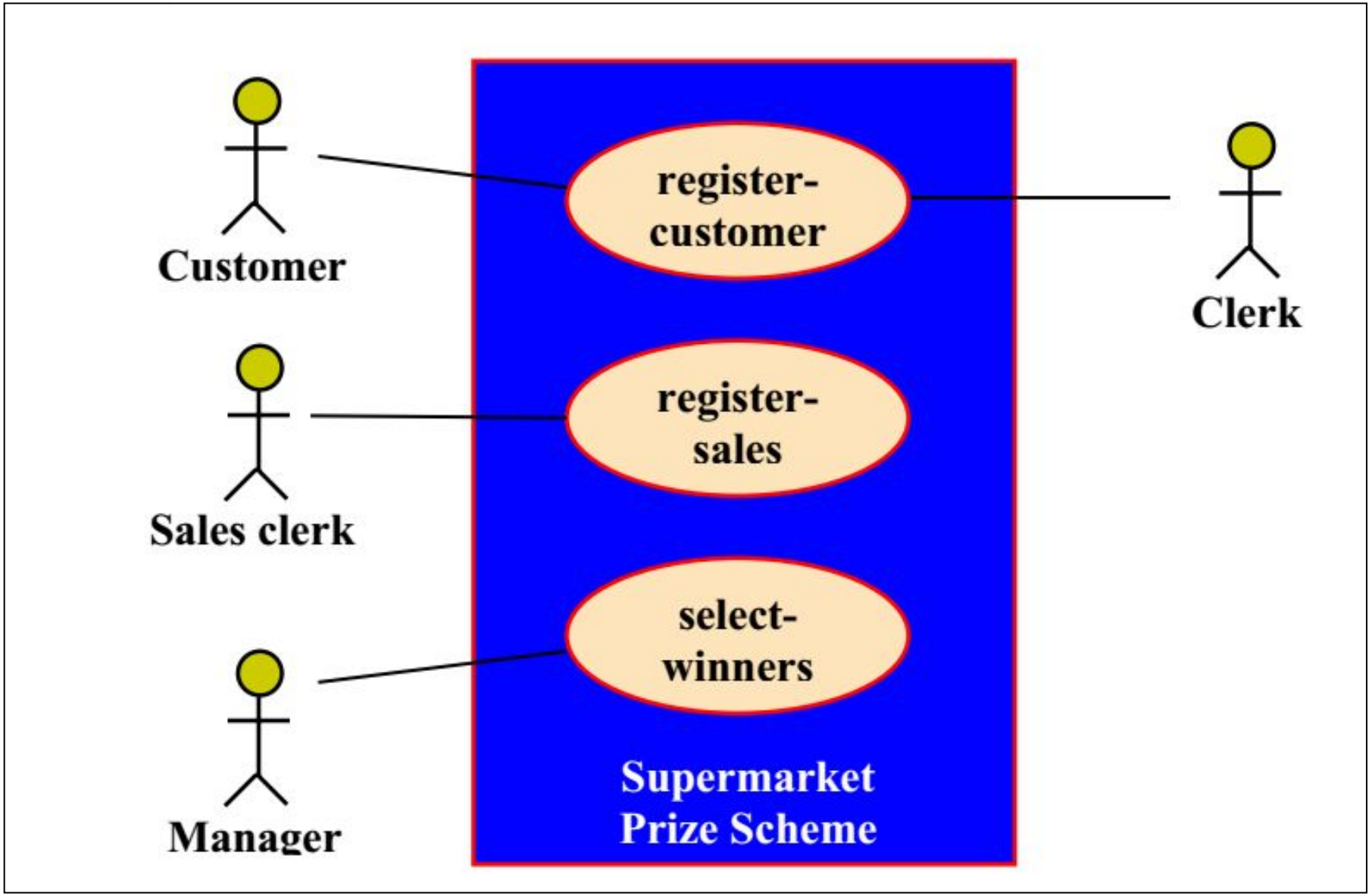
Hierarchical Organization of Use Cases



Use Case Packaging



Use Case Diagram for Supermarket Prize scheme



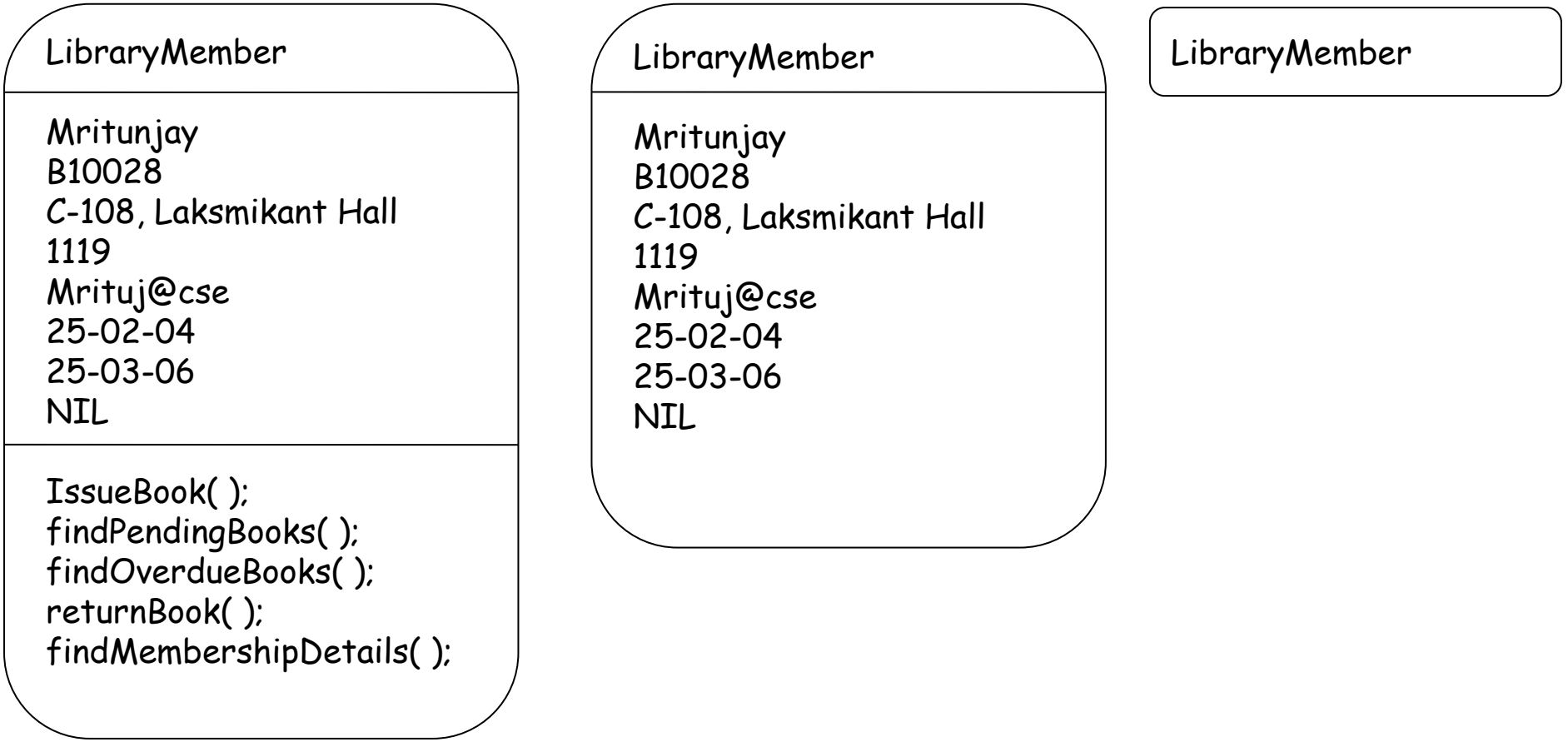
Class Diagram

- Describes static structure of a system
- Main constituents are classes and their relationships:
  - 📫 Generalization
  - 📫 Aggregation
  - 📫 Association
  - 📫 Various kinds of dependencies

Class Diagram

- Entities with common features, i.e. attributes and operations
- Classes are represented as solid outline rectangle with compartments
- Compartments for name, attributes, and operations.
- Attribute and operation compartments are optional depending on the purpose of a diagram.

Object Diagram



Different representations of the LibraryMember object

Interaction Diagram

- Models how groups of objects collaborate to realize some behaviour.
- Typically each interaction diagram realizes behaviour of a single use case.

Interaction Diagram

- Two kinds: Sequence and Collaboration diagrams.
- Two diagrams are equivalent
  - 📬 Portray different perspectives
- These diagrams play a very important role in the design process.

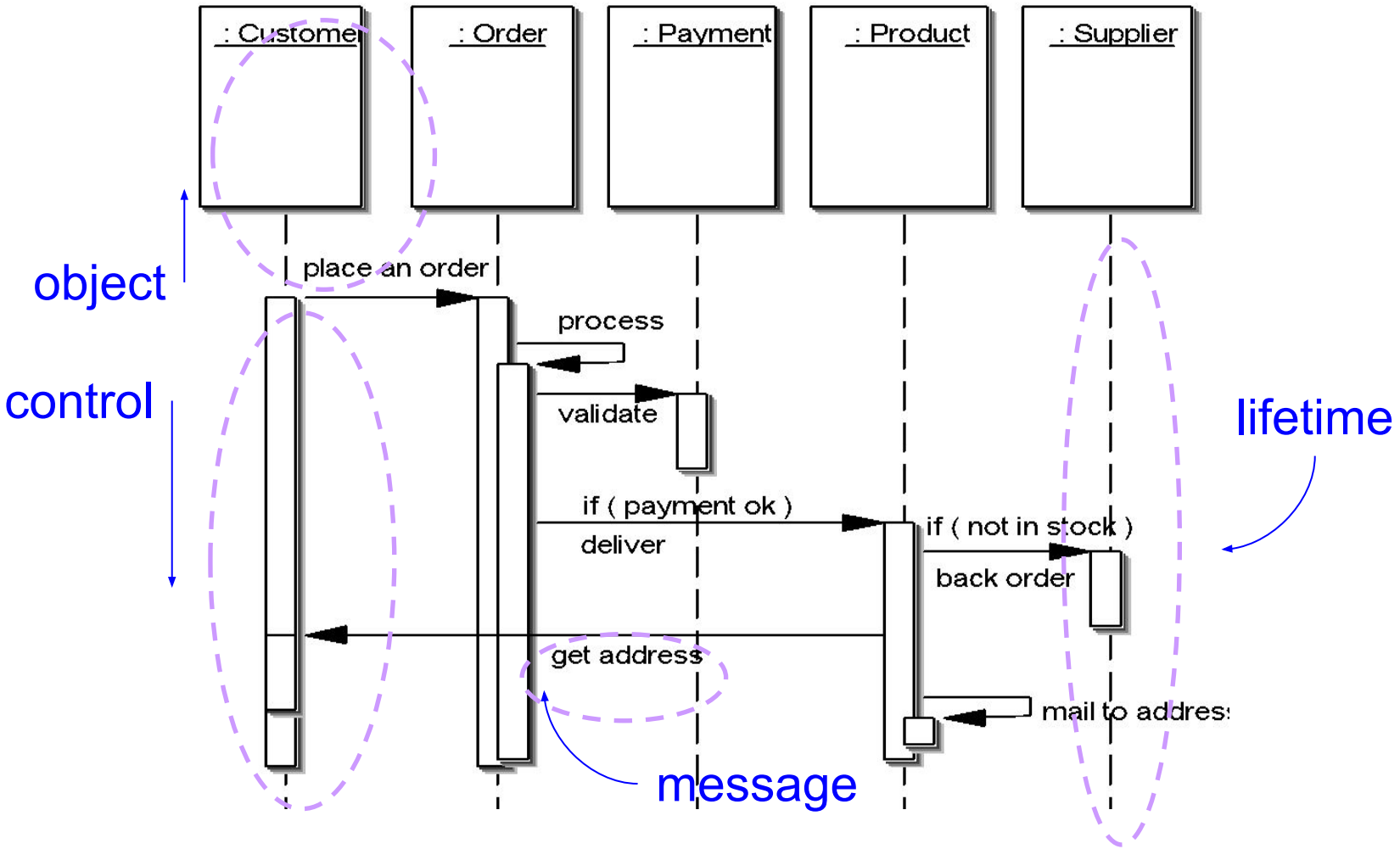
Sequence Diagram

- Shows interaction among objects as a two-dimensional chart
- Objects are shown as boxes at top
- If object created during execution then shown at appropriate place
- Objects existence are shown as dashed lines (lifeline)
- Objects activeness, shown as a rectangle on lifeline

Sequence Diagram Cont…

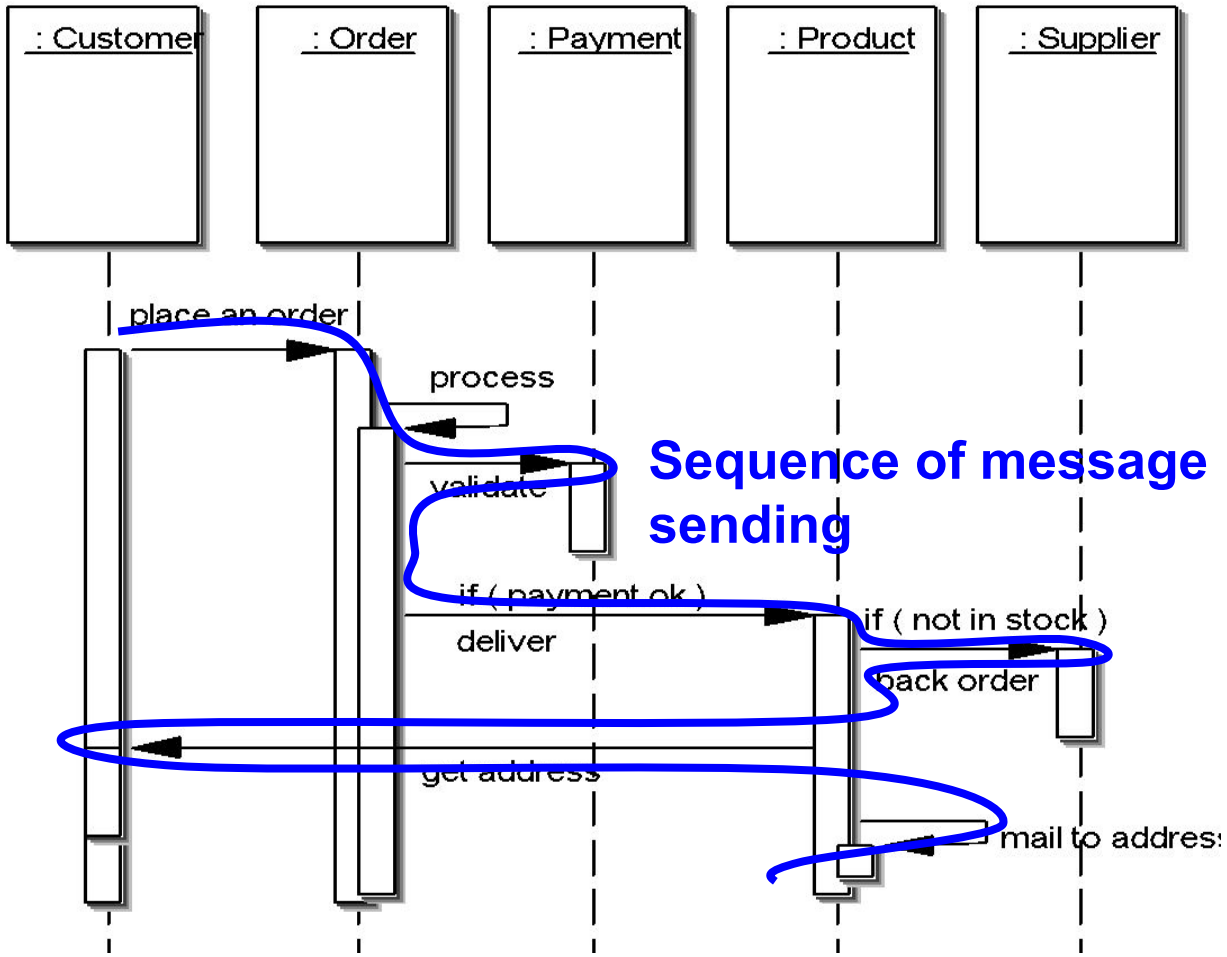
- Messages are shown as arrows
- Each message labelled with corresponding message name
- Each message can be labelled with some control information
- Two types of control information
  - condition ([])
  - iteration (*)

Elements of a Sequence Diagram

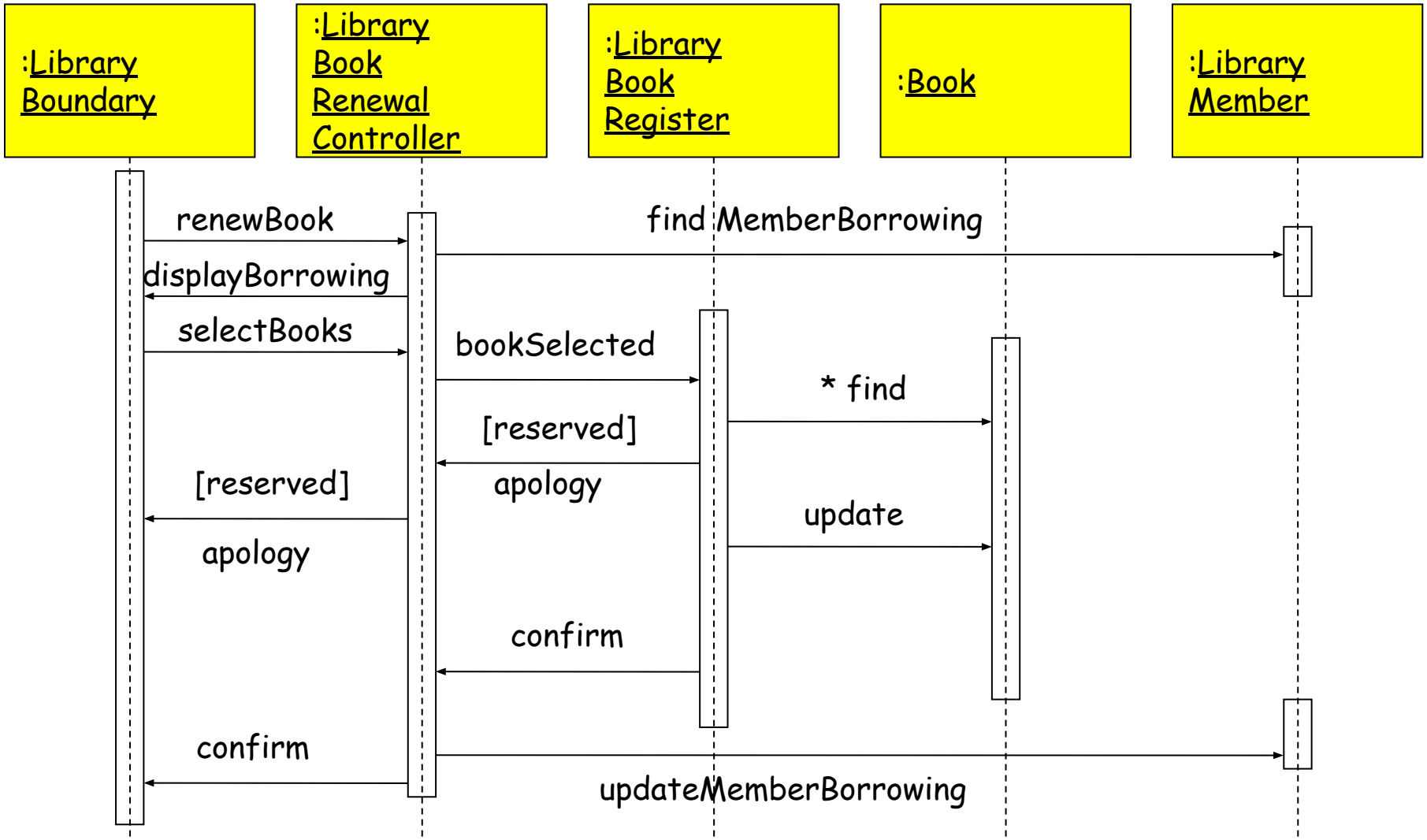


Example

Cont...



An Example of A Sequence Diagram

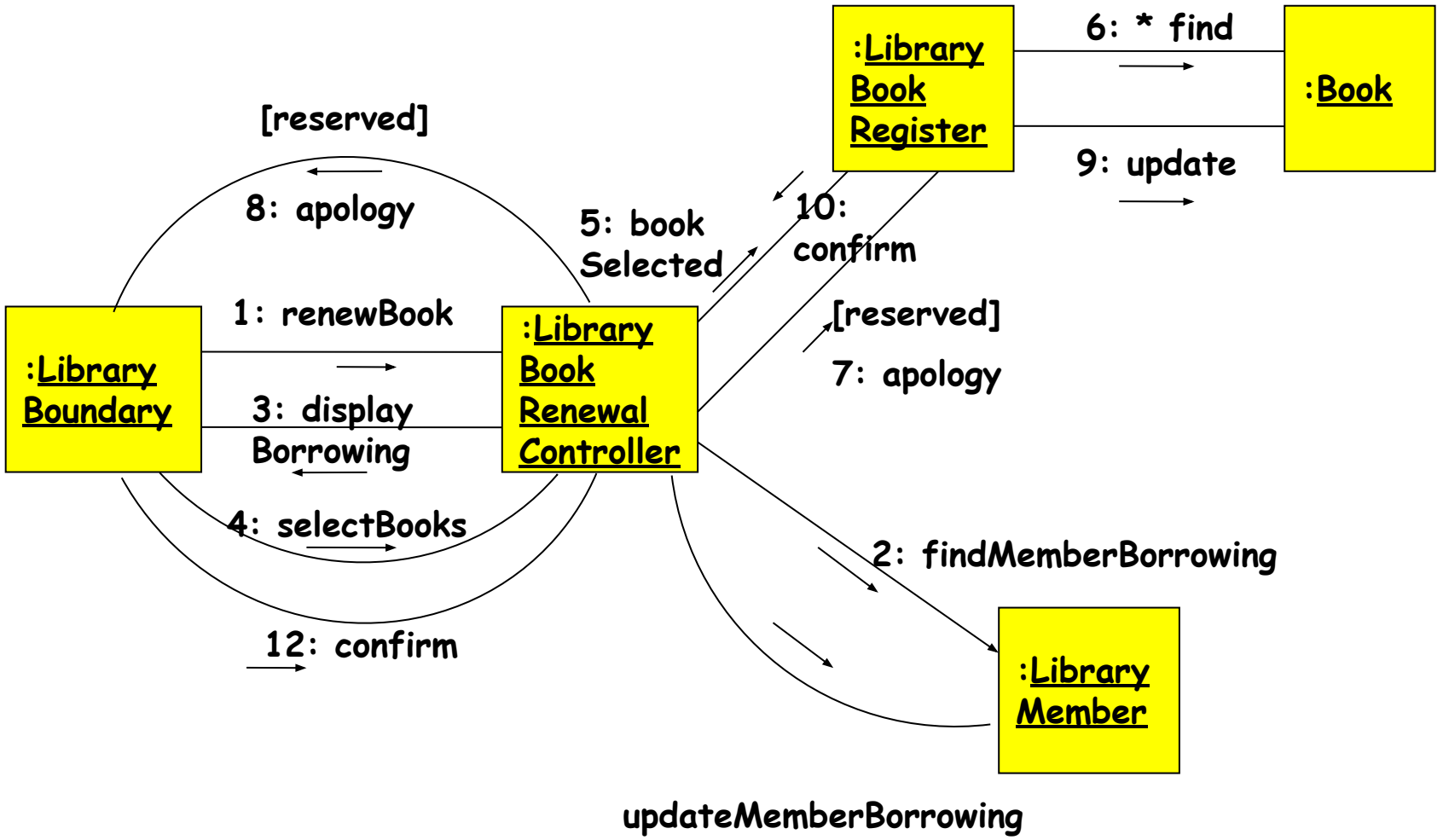


Sequence Diagram for the renew book use case

Collaboration Diagram

- Shows both structural and behavioural aspects
- Objects are collaborator, shown as boxes
- Messages between objects shown as a solid line
- A message is shown as a labelled arrow placed near the link
- Messages are prefixed with sequence numbers to show relative sequencing

An Example of A Collaboration Diagram



Collaboration Diagram for the renew book use case

Activity Diagram

- Not present in earlier modelling techniques:
  - Possibly based on event diagram of Odell [1992]
- Represents processing activity, may not correspond to methods
- Activity is a state with an internal action and one/many outgoing transitions
- Somewhat related to flowcharts

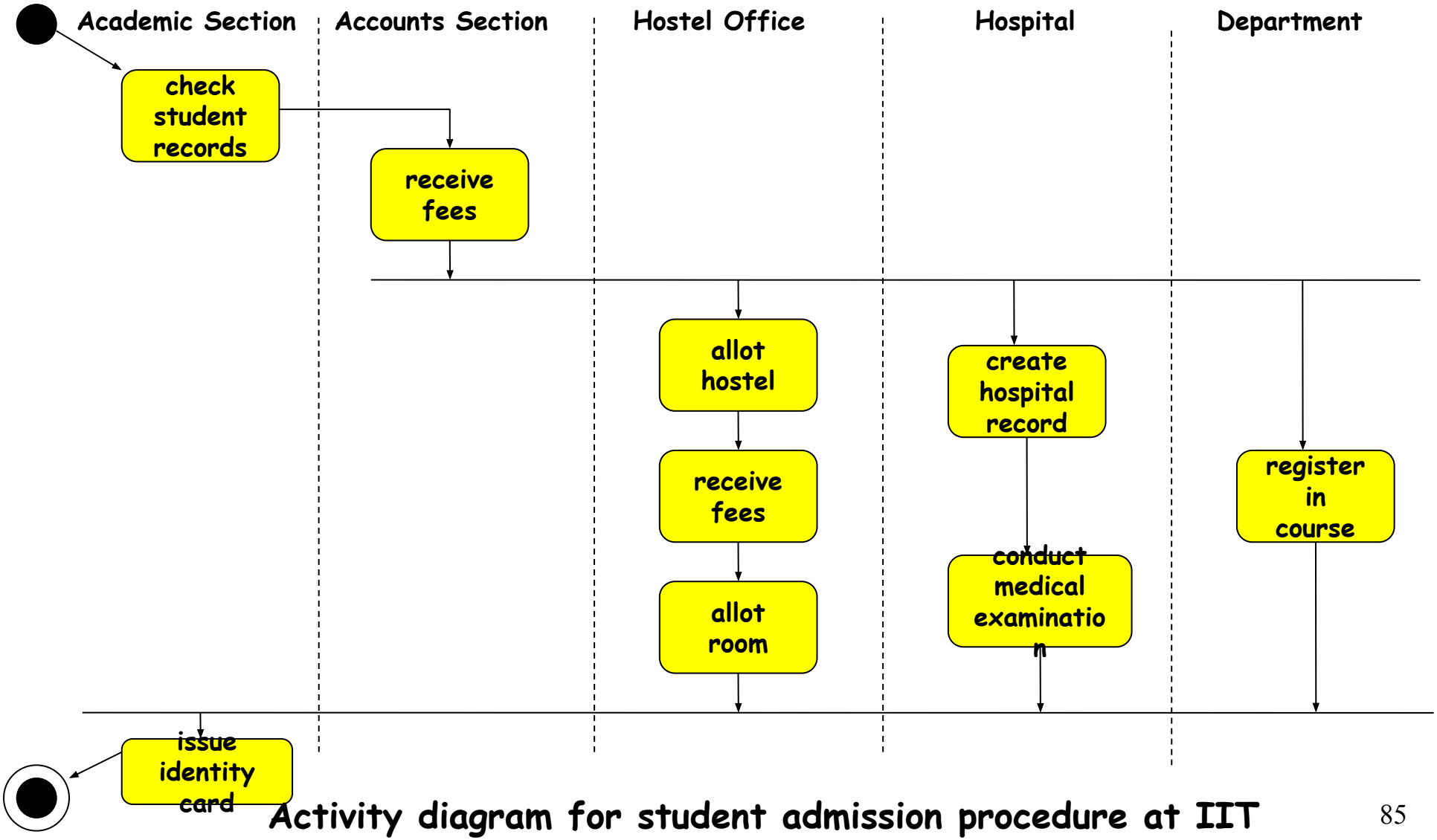
Activity Diagram vs Flow Chart

- Can represent parallel activity and synchronization aspects
- **Swim lanes** can be used to group activities based on who is performing them
- Example: academic department vs. hostel

Activity Diagram

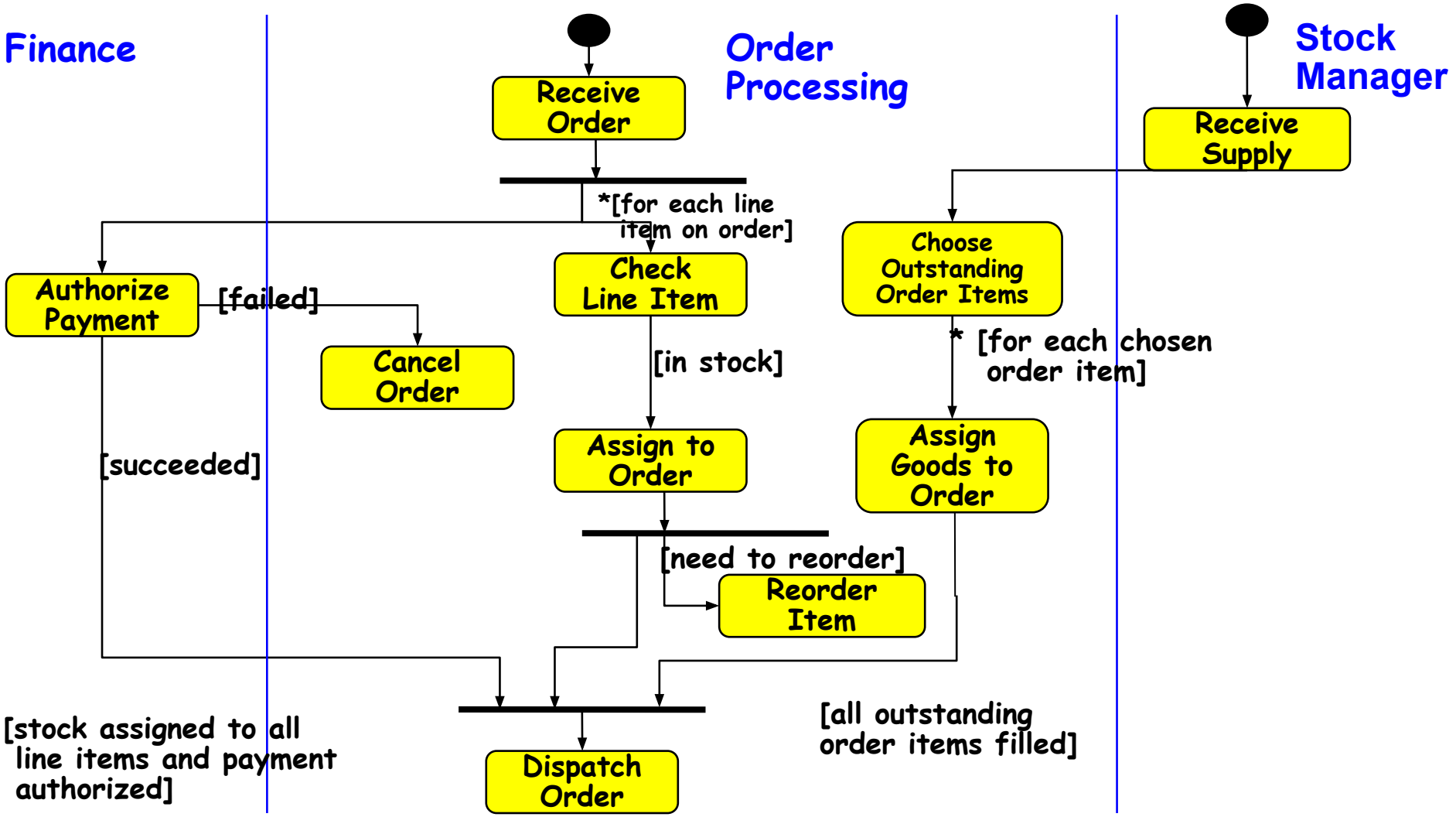
- Normally employed in business process modelling.
- Carried out during requirements analysis and specification stage.
- Can be used to develop interaction diagrams.

An Example of An Activity Diagram



Activity diagram for student admission procedure at IIT

Activity Diagram: Example 2



State Chart Diagram

- Based on the work of **David Harel** [1990]
- Model how the state of an object changes in its lifetime
- Based on finite state machine (FSM) formalism

State Chart Diagram

Cont…

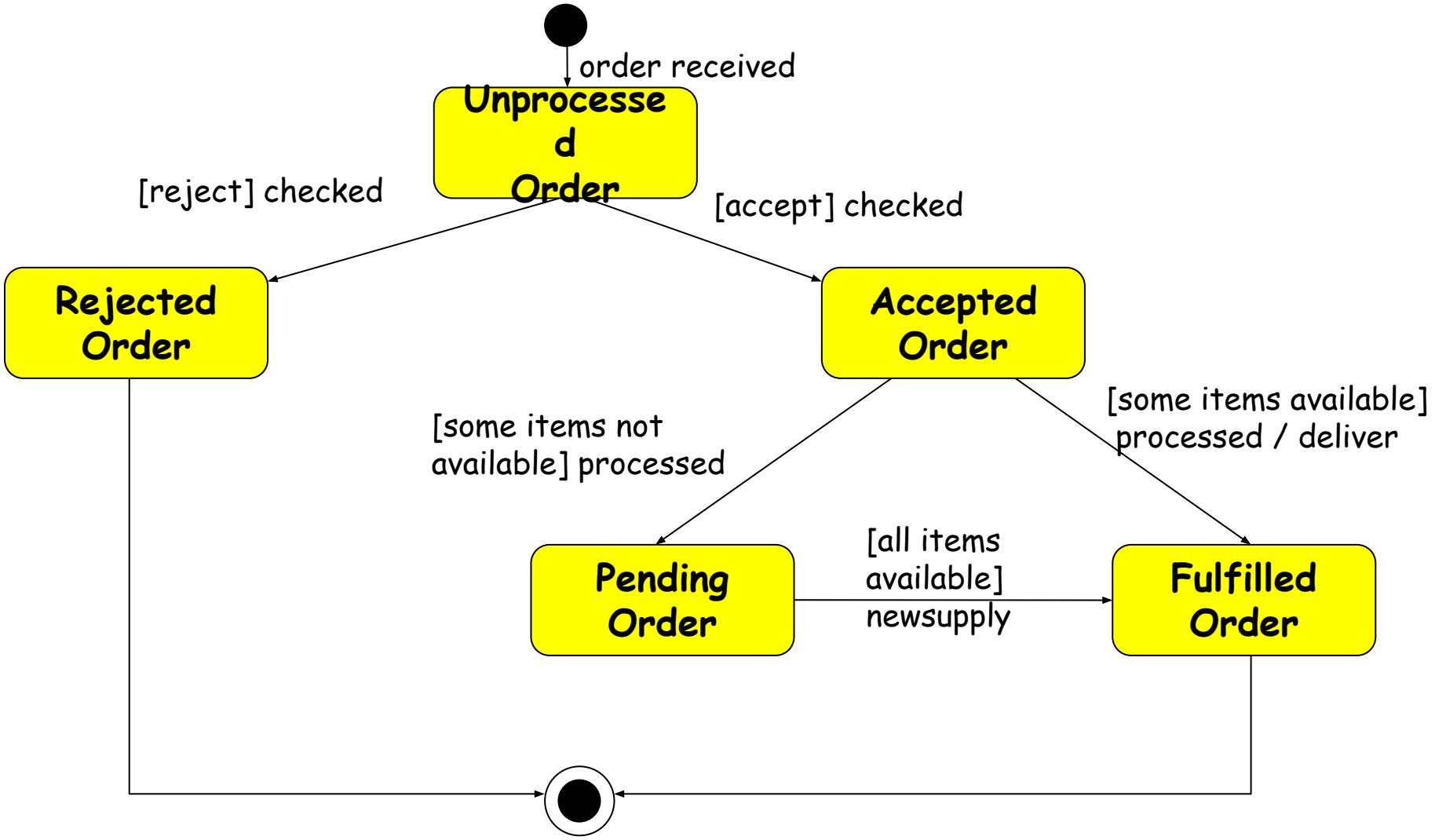
- State chart avoids the problem of state explosion of FSM.
- Hierarchical model of a system:
  - 📫 Represents composite **nested** states

State Chart Diagram

Cont…

- Elements of state chart diagram
- Initial State: A filled circle
- Final State: A filled circle inside a larger circle
- State: Rectangle with rounded corners
- Transitions: Arrow between states, also boolean logic condition (guard)

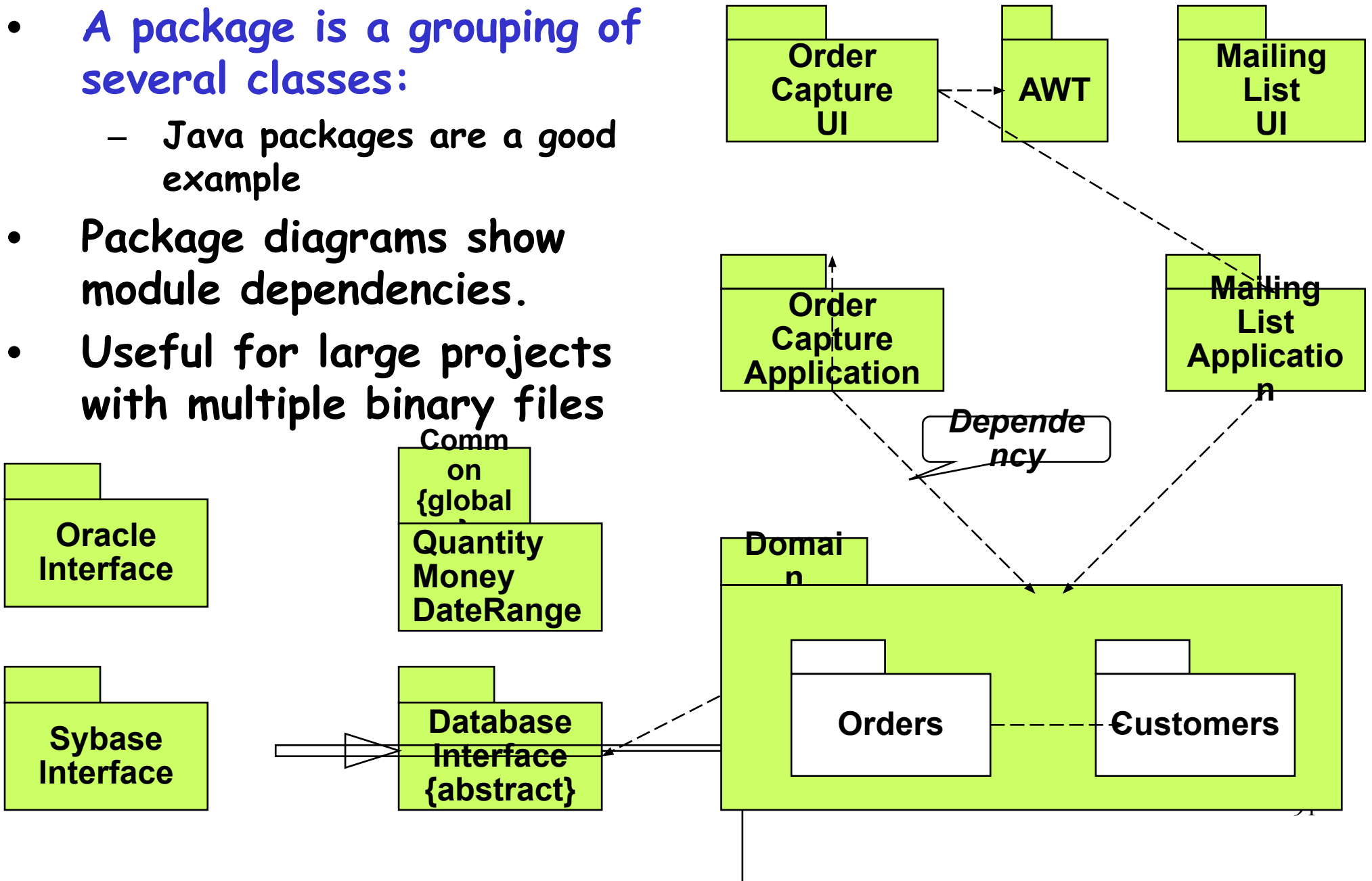
An Example of A State Chart Diagram



Example: State chart diagram for an order object

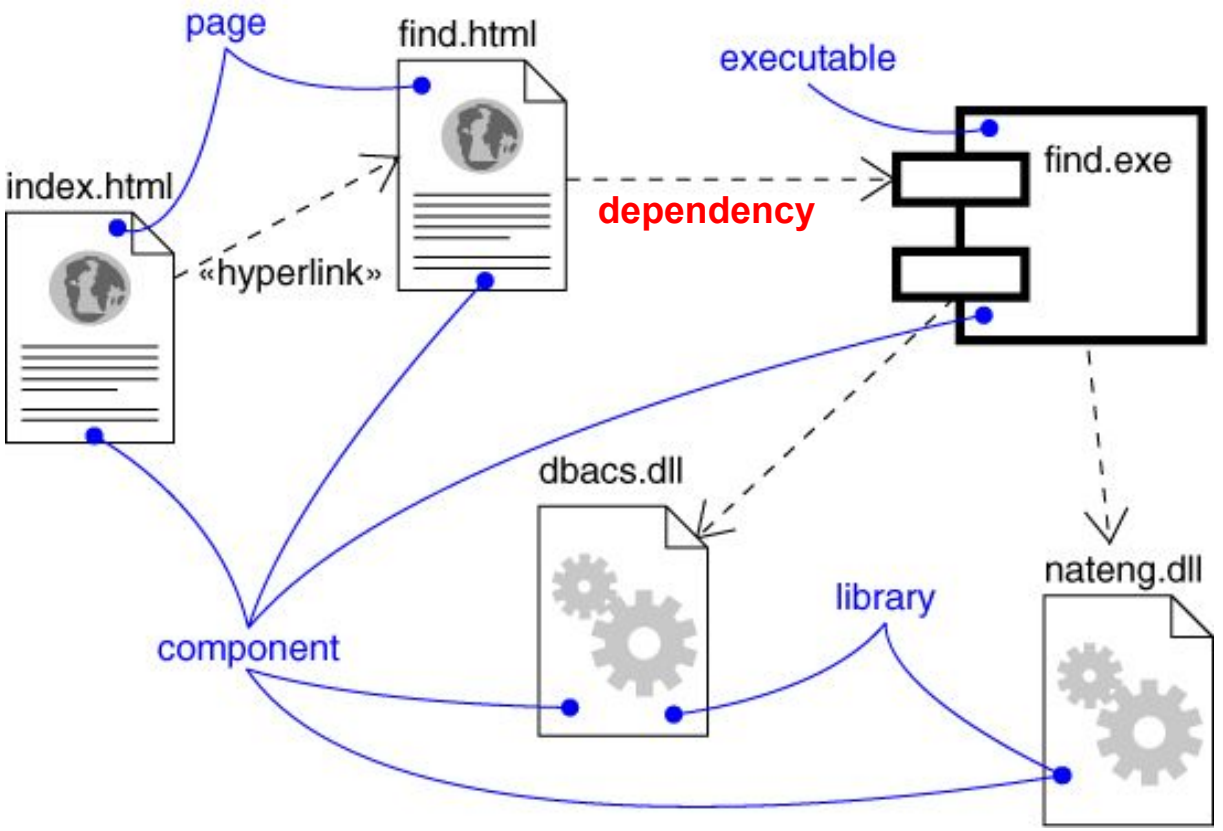
Package Diagrams

- *A package is a grouping of several classes:*
  - Java packages are a good example
- Package diagrams show module dependencies.
- Useful for large projects with multiple binary files



Component Diagram

- Captures the physical structure of the implementation (code components)



Components:

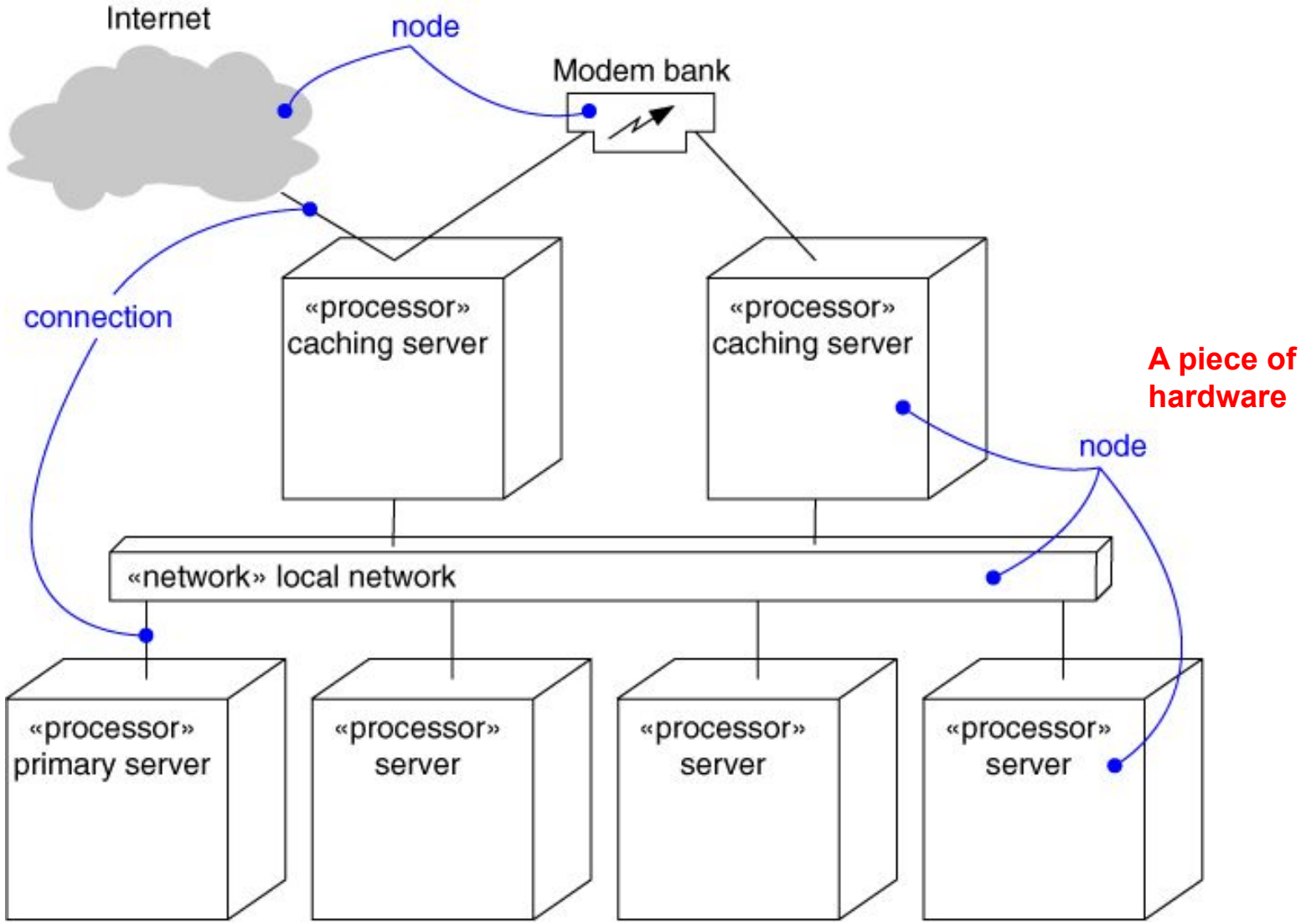
- **Executables**
- **Library**
- **Table**
- **File**
- **Document**

Component Diagram

- Captures the physical structure of the implementation
- Built as part of architectural specification
- Purpose
  - 📫 Organize source code
  - 📫 Construct an executable release
  - 📫 Specify a physical database
- Developed by architects and programmers

Deployment Diagram

- Captures the topology of a system's hardware

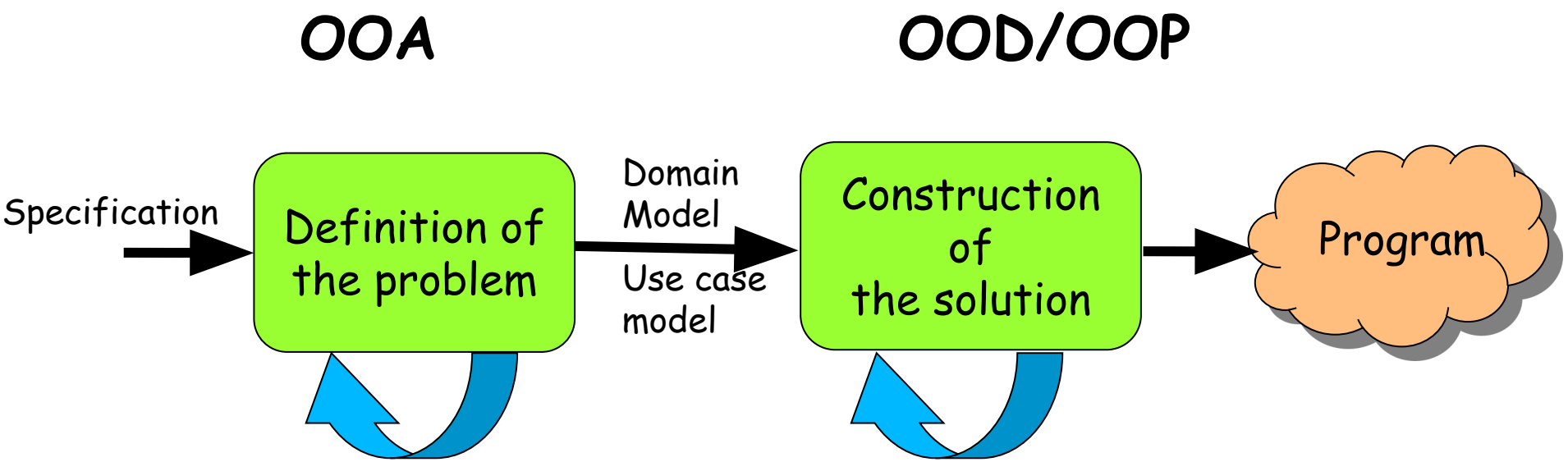


A Design Process

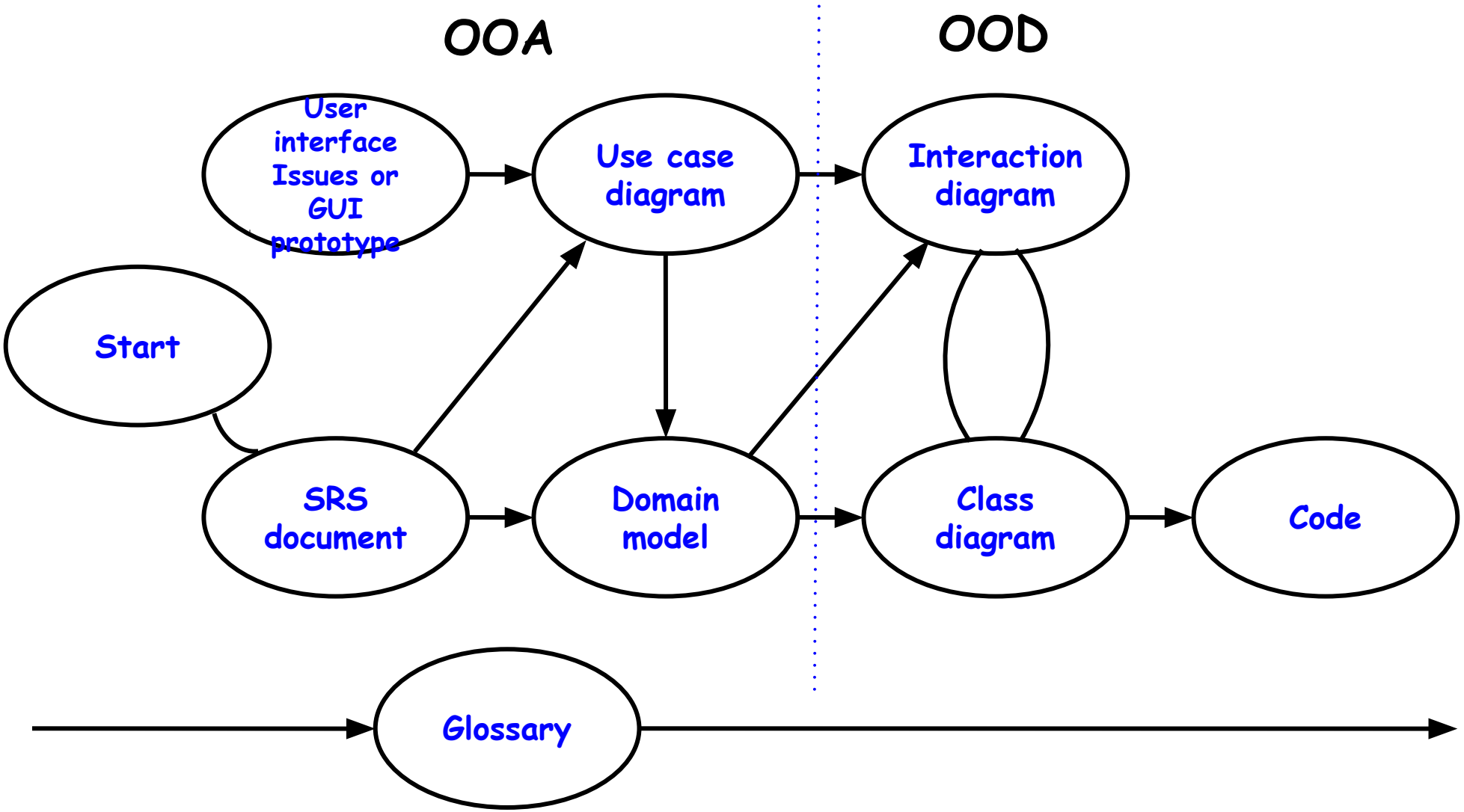
- Developed from various methodologies.
  - However, UML has been designed to be usable with any design methodology.
- From requirements specification, initial model is developed (OOA)
  - Analysis model is iteratively refined into a design model
- Design model is implemented using OO concepts

OOAD

Iterative and Incremental



Unified Development Process Cont…



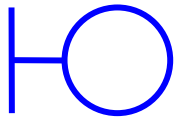
Domain Modelling

- Represents concepts or objects appearing in the problem domain.
- Also captures relationships among objects.
- Three types of objects are identified
  - Boundary objects
  - Entity objects
  - Controller objects

Class Stereotypes

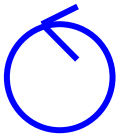
Three different stereotypes on classes are used: <<boundary>>, <<control>>, <<entity>>.

Boundary



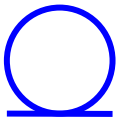
Cashier Interface

Control



Withdrawal

Entity



Account

Boundary Objects

- Interact with actors:
  - User interface objects
- Include screens, menus, forms, dialogs etc.
- Do not perform processing but validates, formats etc.

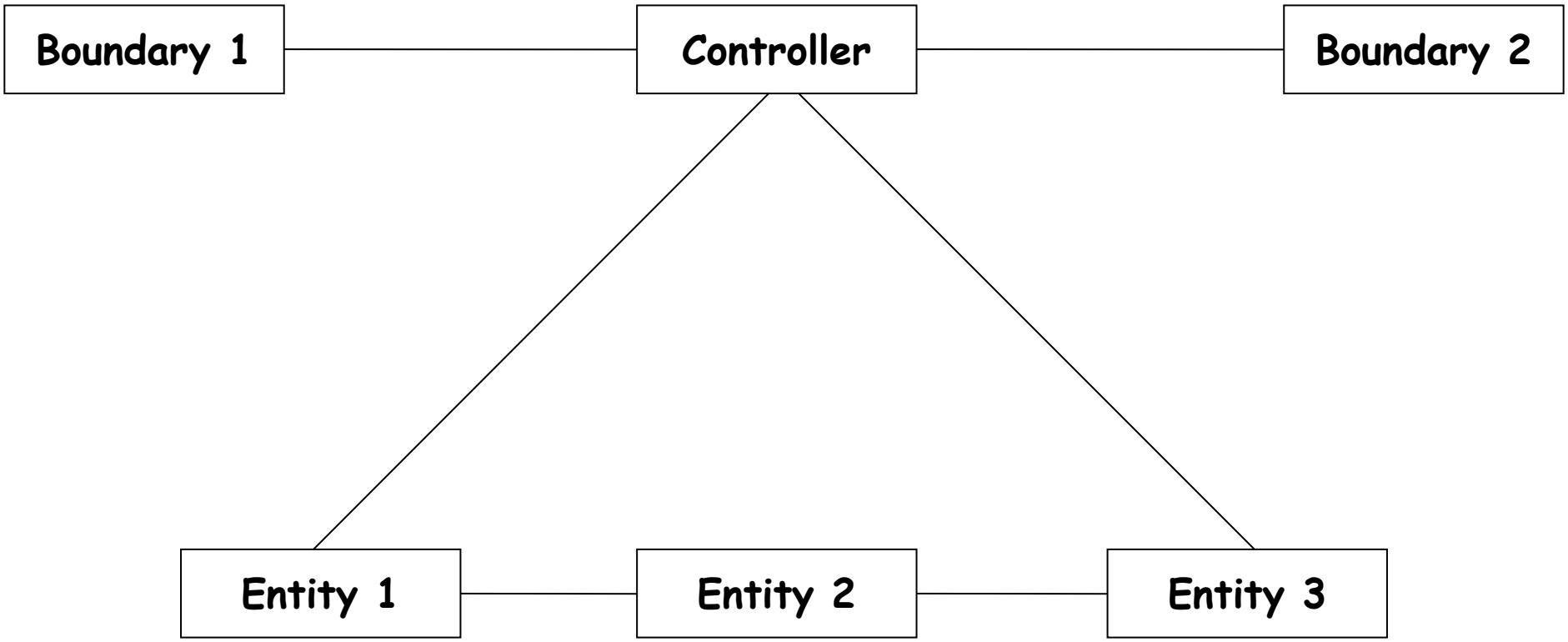
Entity Objects

- Hold information:
  - Such as data tables & files, e.g. Book, BookRegister
- Normally are dumb servers
- Responsible for storing data, fetching data etc.
- Elementary operations on data such as searching, sorting, etc.
- Entity Objects are identified by examining nouns in problem description

Controller Objects

- Coordinate the activities of a set of entity objects
- Interface with the boundary objects
- Realizes use case behavior
- Embody most of the logic involved with the use case realization
- There can be more than one controller to realize a single use case

Use Case Realization



Realization of use case through the collaboration of Boundary, controller and entity objects

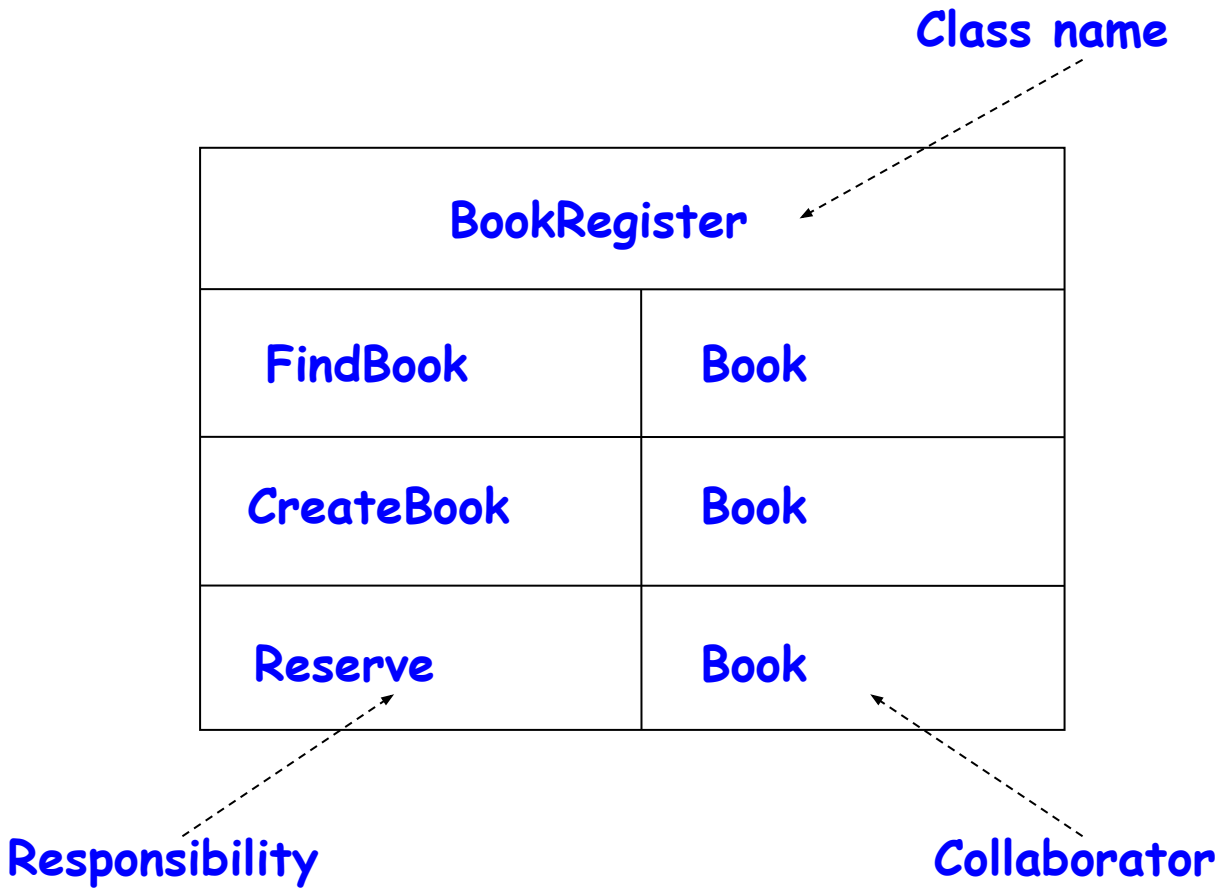
Class-Responsibility-Collaborator(CRC) Cards

- Pioneered by Ward Cunningham and Kent Beck
- Index cards prepared one each per class
- Class responsibility is written on these cards
- Collaborating object is also written

CRC Cards Cont…

- Required for developing interaction diagram of complex use cases
- Team members participate to determine:
  - The responsibility of classes involved in the use case realization

An Example of A CRC Card



CRC card for the BookRegister class

Patterns versus Idioms

- A pattern:
  - Describes a recurring problem
  - Describes the *core* of a solution
  - Is capable of generating many distinct designs

- An Idiom is more restricted
  - Still describes a recurring problem
  - Provides a more specific solution, with fewer variations
  - Applies only to a narrow context
    - e.g., the C++ language

Patterns

- The essential idea:
  - If you can master a few important patterns, you can easily spot them in application development and use the pattern solutions.

Idioms

- In English:
  - A group of words that has meaning different from a simple juxtaposition of the meanings of the individual words.
  - "Raining cats and dogs"
- A C idiom:
  - `for(i=0;i<1000;i++){`
  - `}`

Antipattern

- If a pattern represents a best practice:
  - Antipattern represents lessons learned from a bad design.
- Antipatterns help to recognise deceptive solutions:
  - That appear attractive at first, but turn out to be a liability later.

Design Patterns

- Standard solutions to commonly recurring problems
- Provides good solution based on common sense
- Pattern has four important parts
  - The problem
  - The context
  - The solution
  - The context in which it works or does not work

Example Pattern: Expert

- **Problem**: Which class should be responsible for doing certain things
- **Solution**: *Assign* responsibility to the class that has the information necessary to fulfil the required responsibility

Example Pattern: Expert Cont…

Class Diagram

Collaboration Diagram

Example Pattern: Creator

- Problem: Which class should be responsible for creating a new instance of some class?
- Solution: Assign a class C1 the responsibility to create class C2 if
  - C1 is an aggregation of objects of type C2
  - C1 contains object of type C2

Example Pattern: Controller

- Problem: Who should be responsible for handling the actor requests?
- Solution: Separate controller object for each use case.

Example Pattern: Facade

- Problem: How should the services be requested from a service package?
- Context (problem): A package (cohesive set of classes), example: RDBMS interface package
- Solution: A class (DBfacade) can be created which provides a common interface to the services of the package

Example Pattern: MVC

- Model-View-Controller
- How should the user interface (Boundary) objects interact with the other objects?
- Solution 1: Pull from Above
  - Boundary object invokes other objects.
  - Does not work when data needs to be asynchronously displayed, simulation experiment, stock market alert, network monitor, etc.

Example Pattern: MVC

- Solution 2: Publish-Subscribe
  - The boundary objects register themselves with an event manager object.
  - Other objects, notify the event manager object as and when an event of interest occurs.
  - The event manager notifies those boundary objects that have registered with it by using a call back.

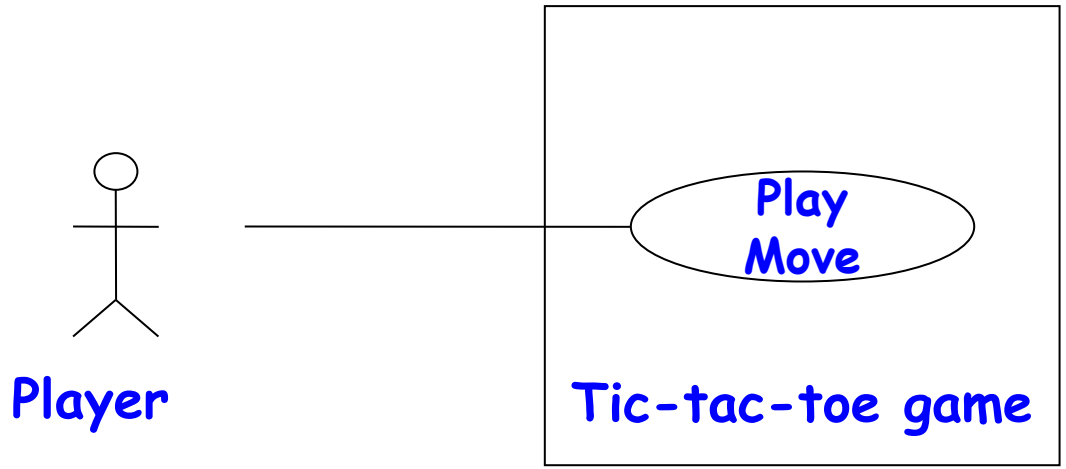
Example 1: Tic-Tac-Toe Computer Game

- A human player and the computer make alternate moves on a 3 3 square.
- A move consists of marking a previously unmarked square.
- The user inputs a number between 1 and 9 to mark a square
- Whoever is first to place three consecutive marks along a straight line (i.e., along a row, column, or diagonal) on the square wins.

Example 1: Tic-Tac-Toe Computer Game

- As soon as either of the human player or the computer wins,
  - A message announcing the winner should be displayed.
- If neither player manages to get three consecutive marks along a straight line,
  - And all the squares on the board are filled up,
  - Then the game is drawn.
- The computer always tries to win a game.

Example 1: Use Case Model

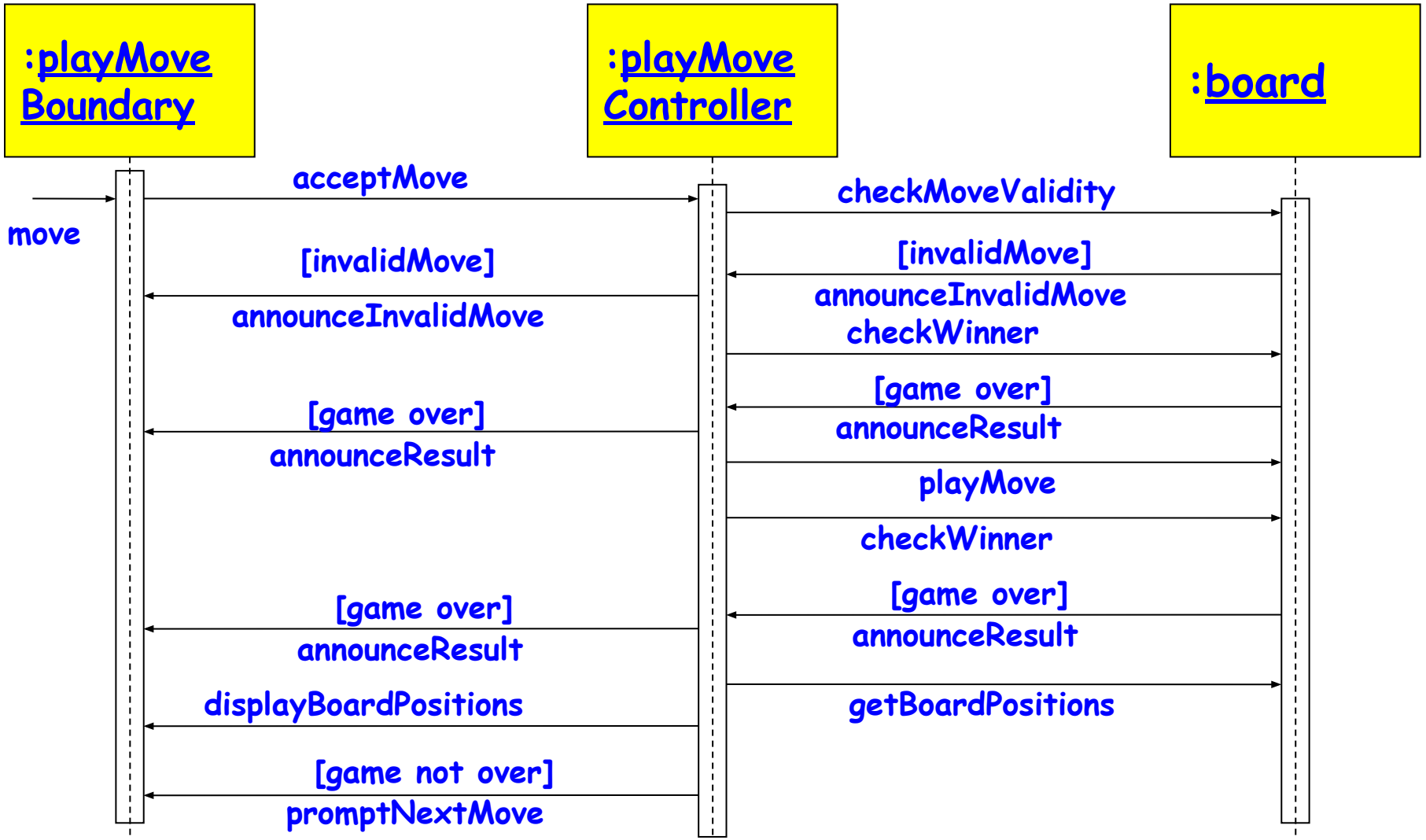


Example 1: Initial and Refined Domain Model

Initial domain model

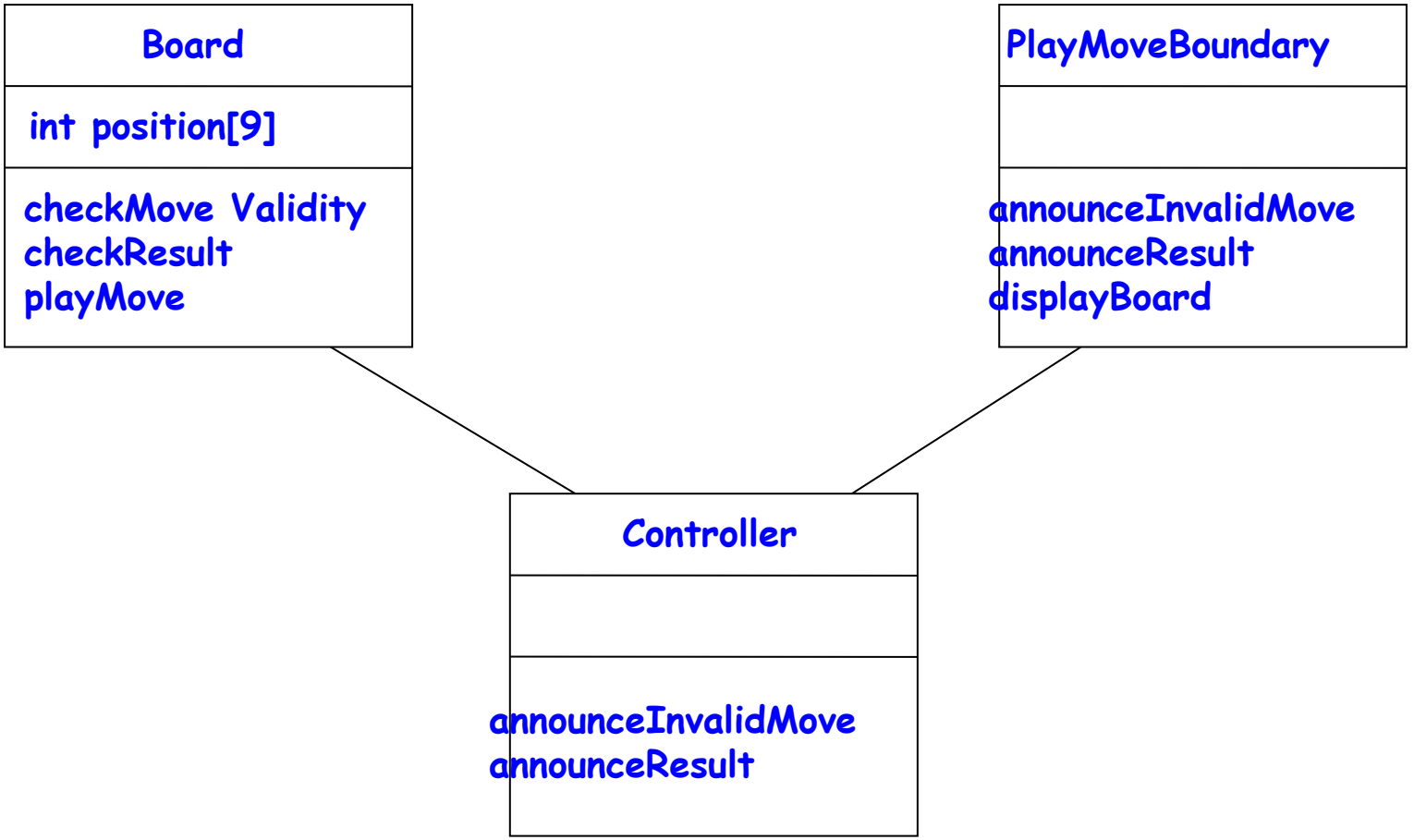
Refined domain model

Example 1: Sequence Diagram



Sequence Diagram for the play move use case

Example 1: Class Diagram



Example 2: Supermarket Prize Scheme

- Supermarket needs to develop software to encourage regular customers.
- Customer needs to supply his:
  - Residence address, telephone number, and the driving licence number.
- Each customer who registers is:
  - Assigned a unique customer number (CN) by the computer.

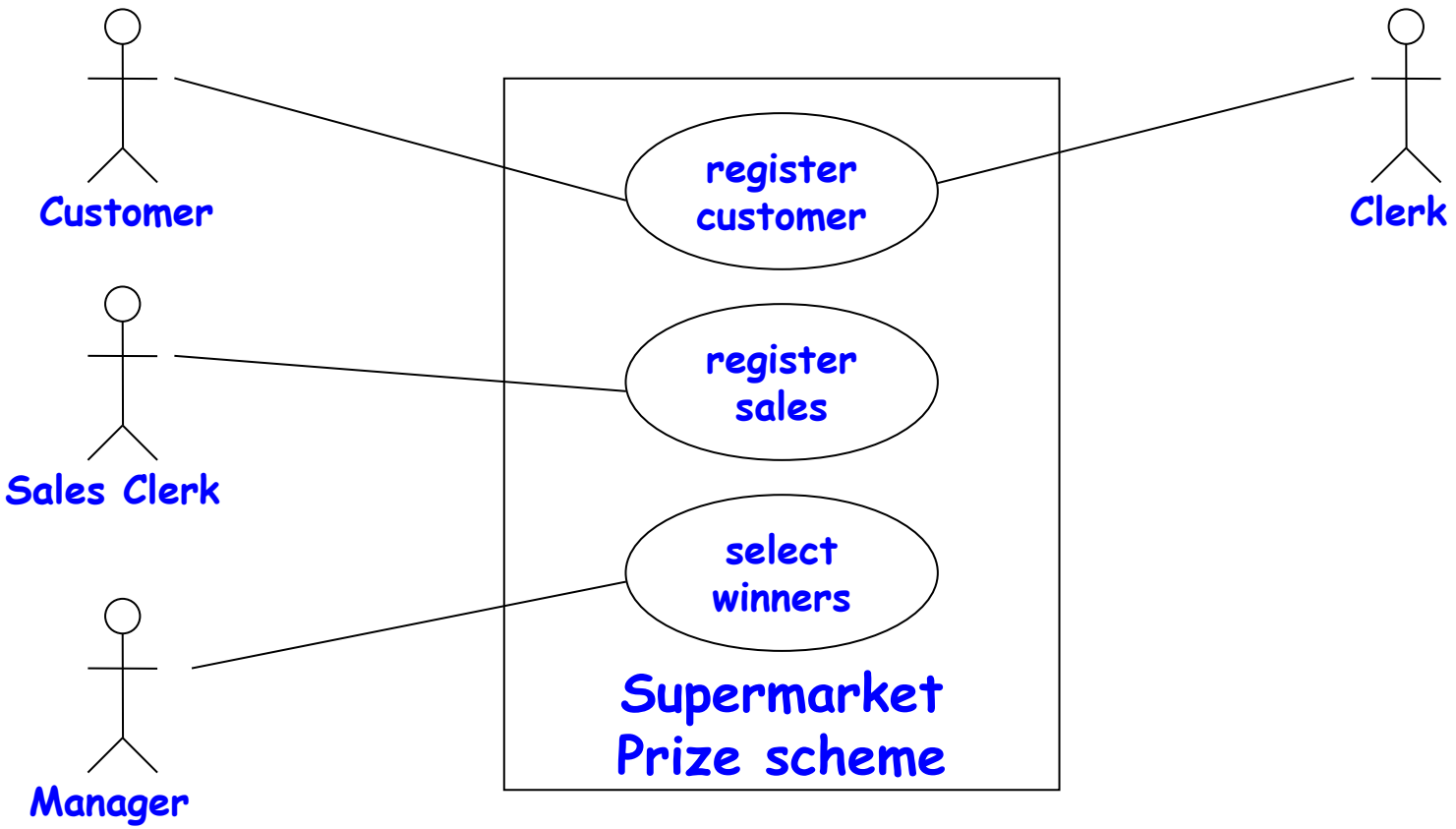
Example 2: Supermarket Prize Scheme

- A customer can present his CN to the staff when he makes any purchase.
- The value of his purchase is credited against his CN.
- At the end of each year:
  - The supermarket awards surprise gifts to ten customers who make highest purchase.

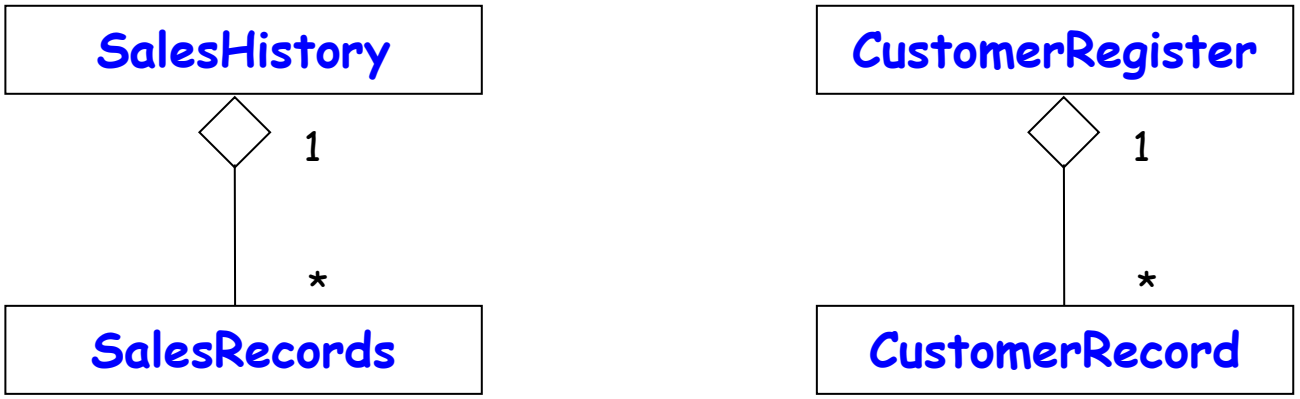
Example 2: Supermarket Prize Scheme

- Also, it awards a 22 carat gold coin to every customer:
  - Whose purchases exceed Rs. 10,000.
- The entries against the CN are reset:
  - On the last day of every year after the prize winner's lists are generated.

Example 2: Use Case Model

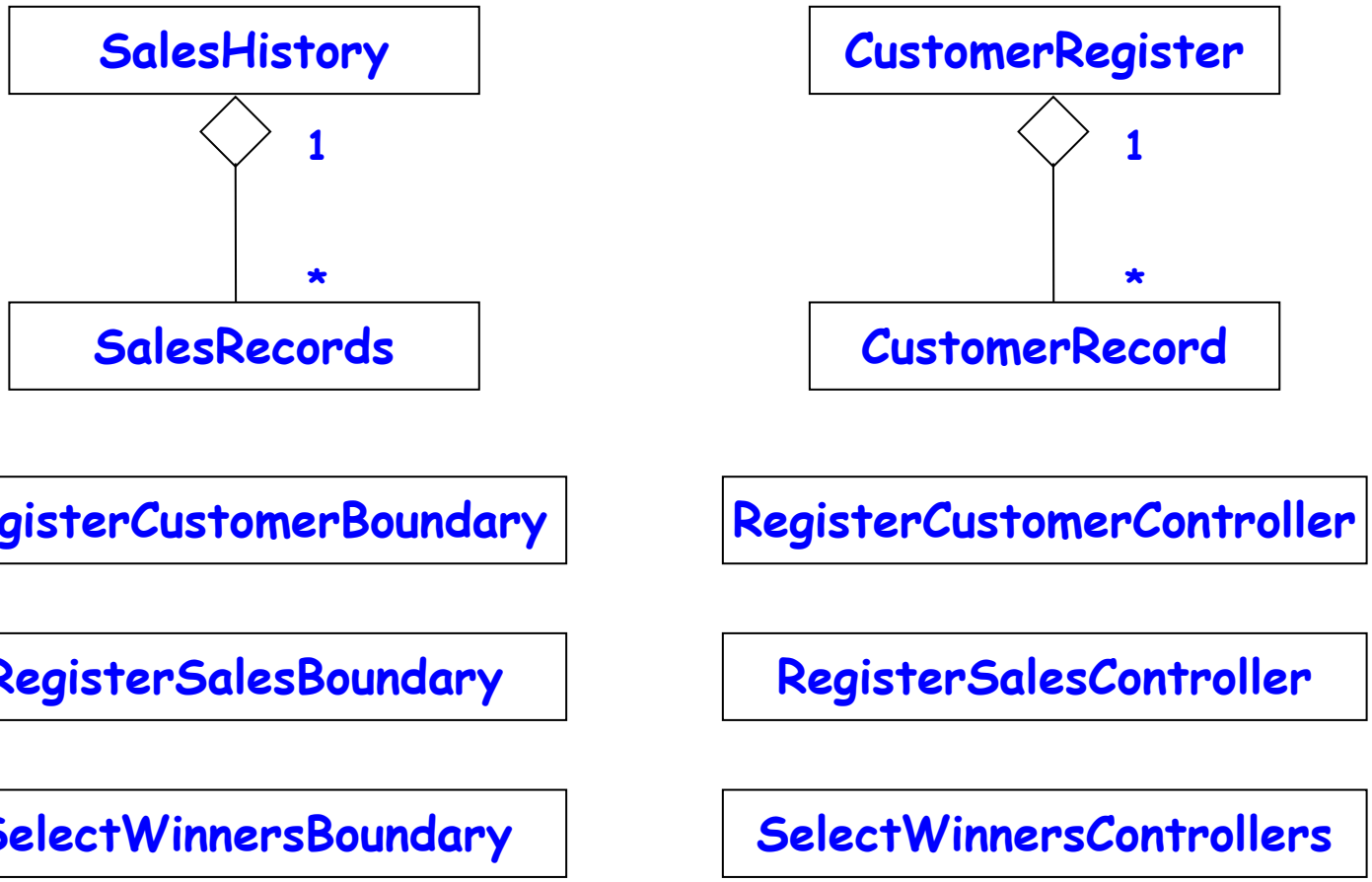


Example 2: Initial Domain Model



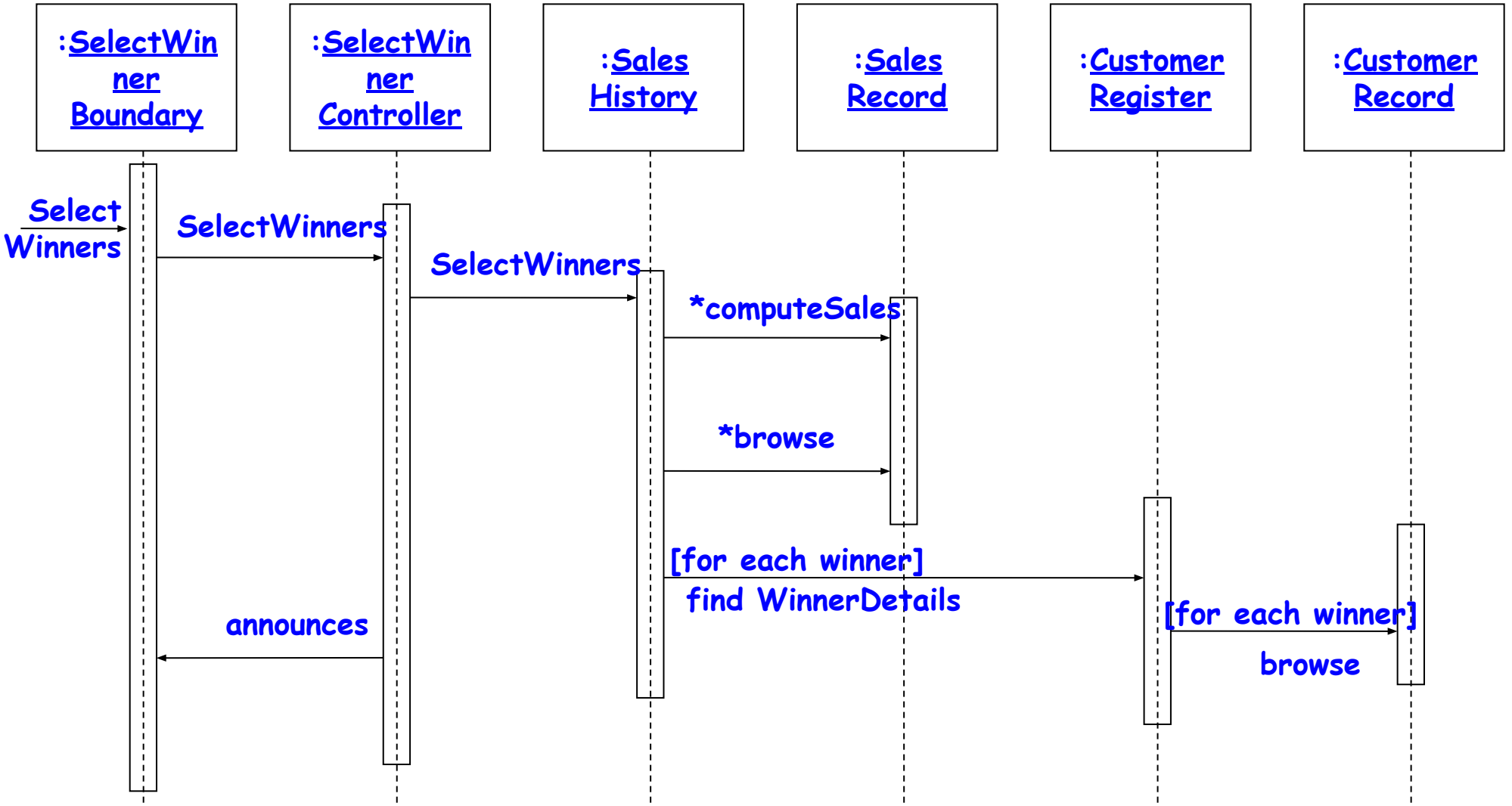
Initial domain model

Example 2: Refined Domain Model



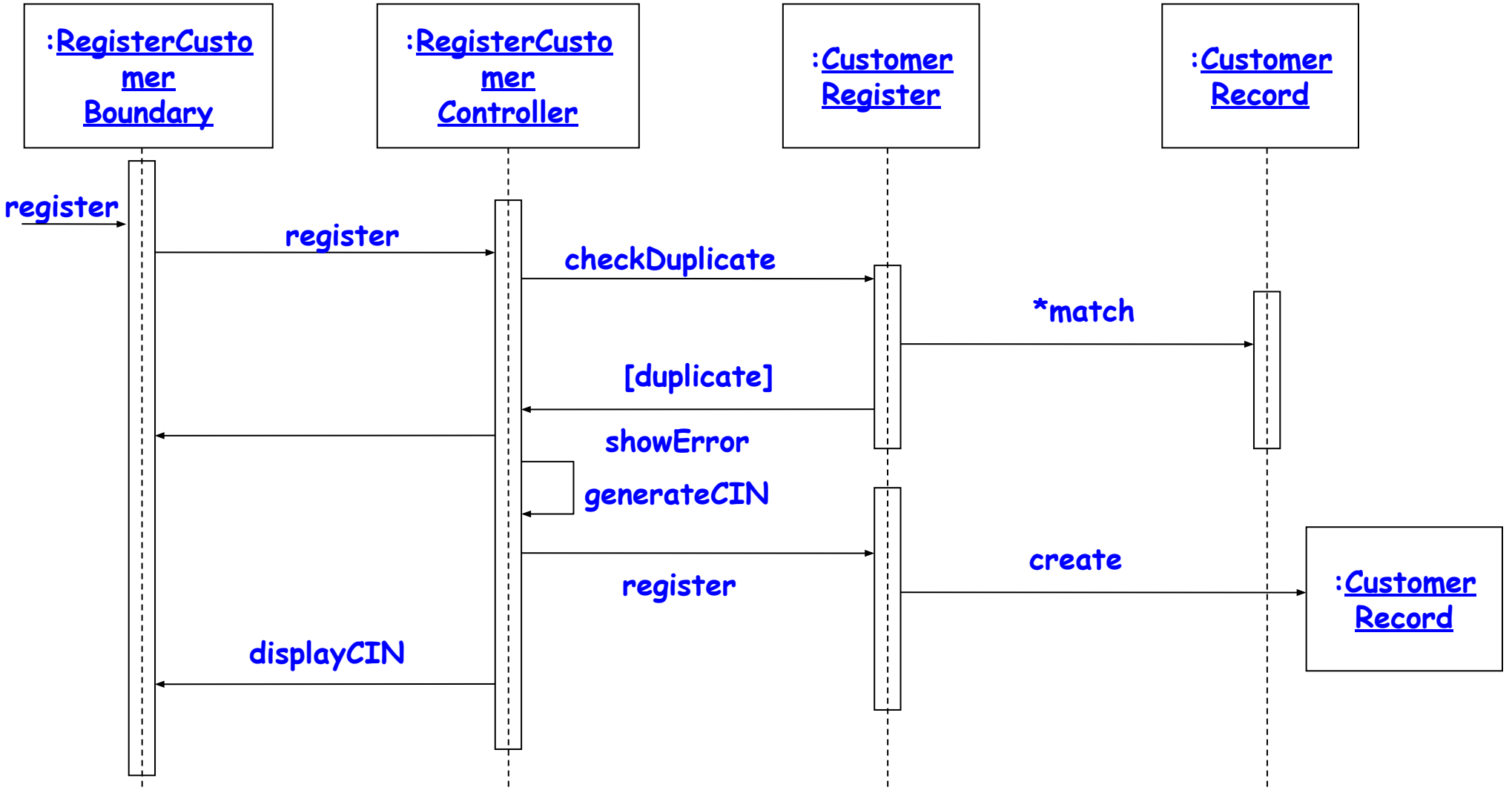
Refined domain model

Example 2: Sequence Diagram for the Select Winners Use Case



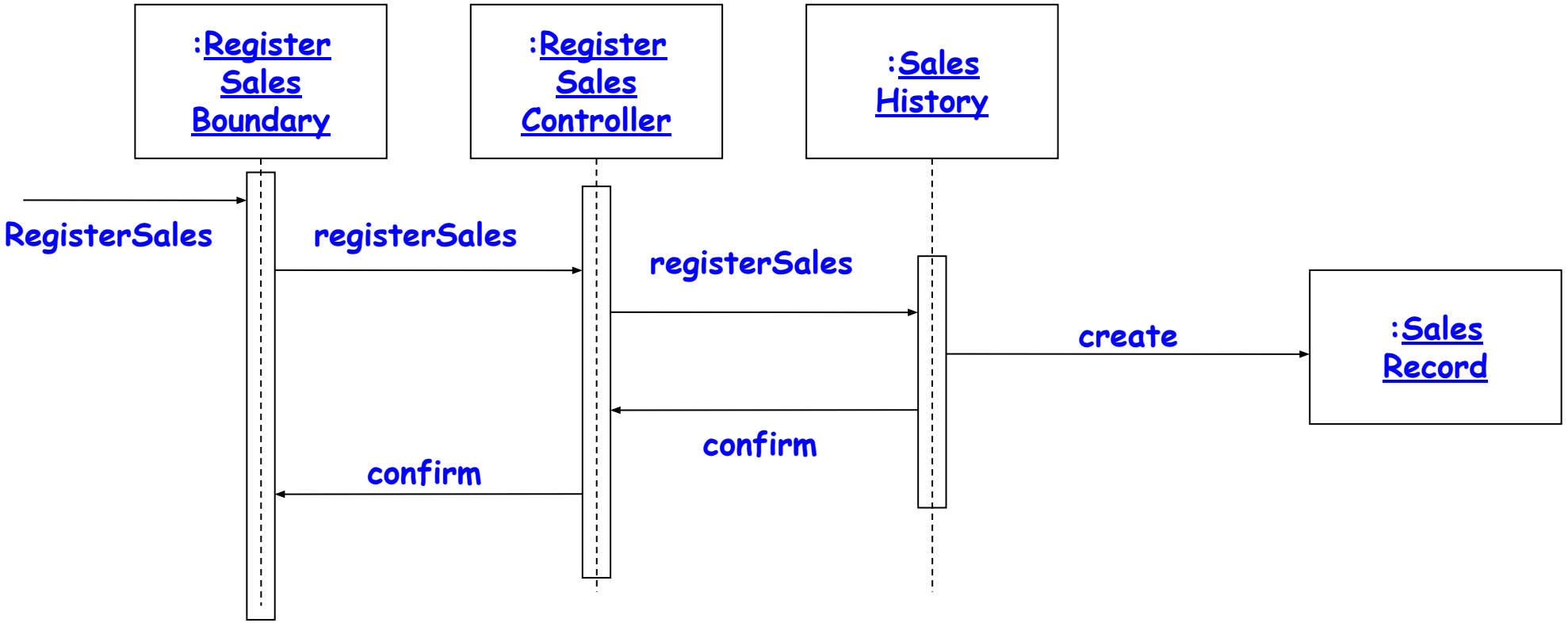
Sequence Diagram for the select winners use case

Example 2: Sequence Diagram for the Register Customer Use Case



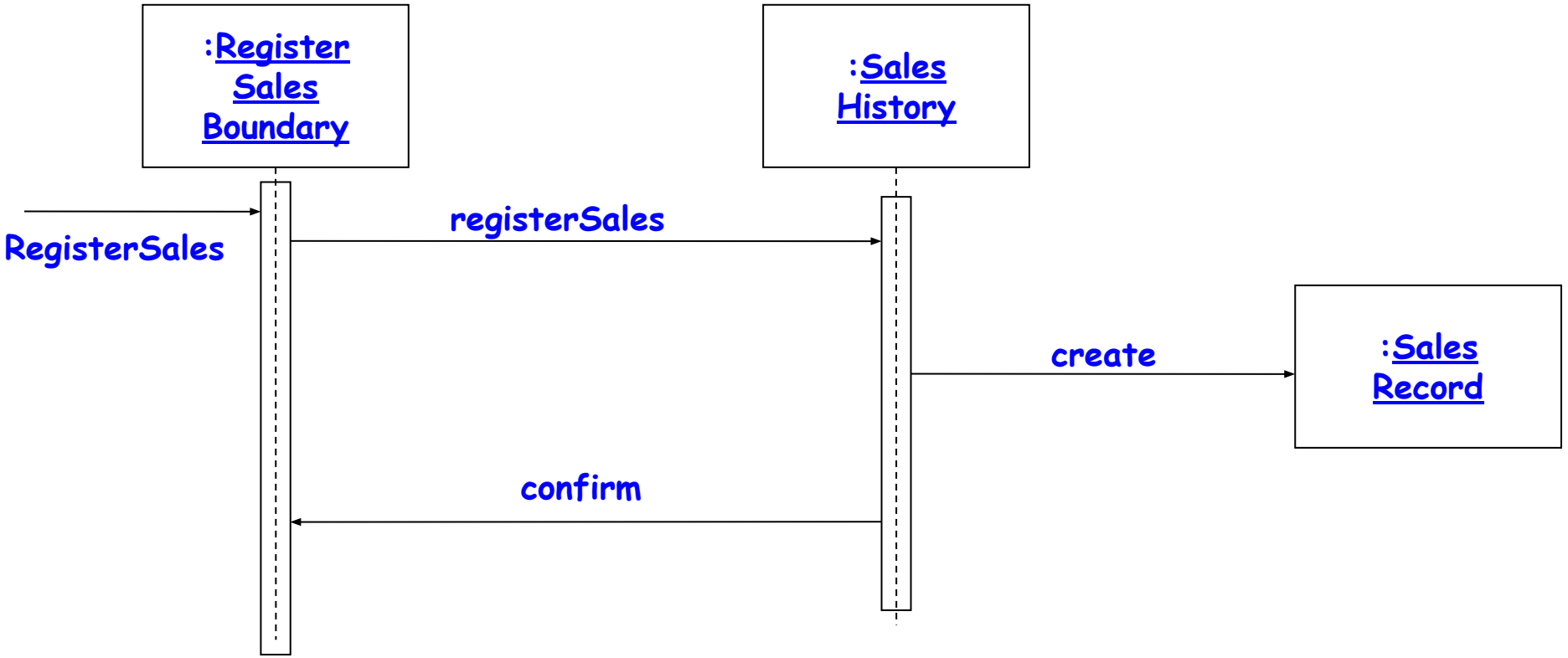
Sequence Diagram for the register customer use case

Example 2: Sequence Diagram for the Register Sales Use Case



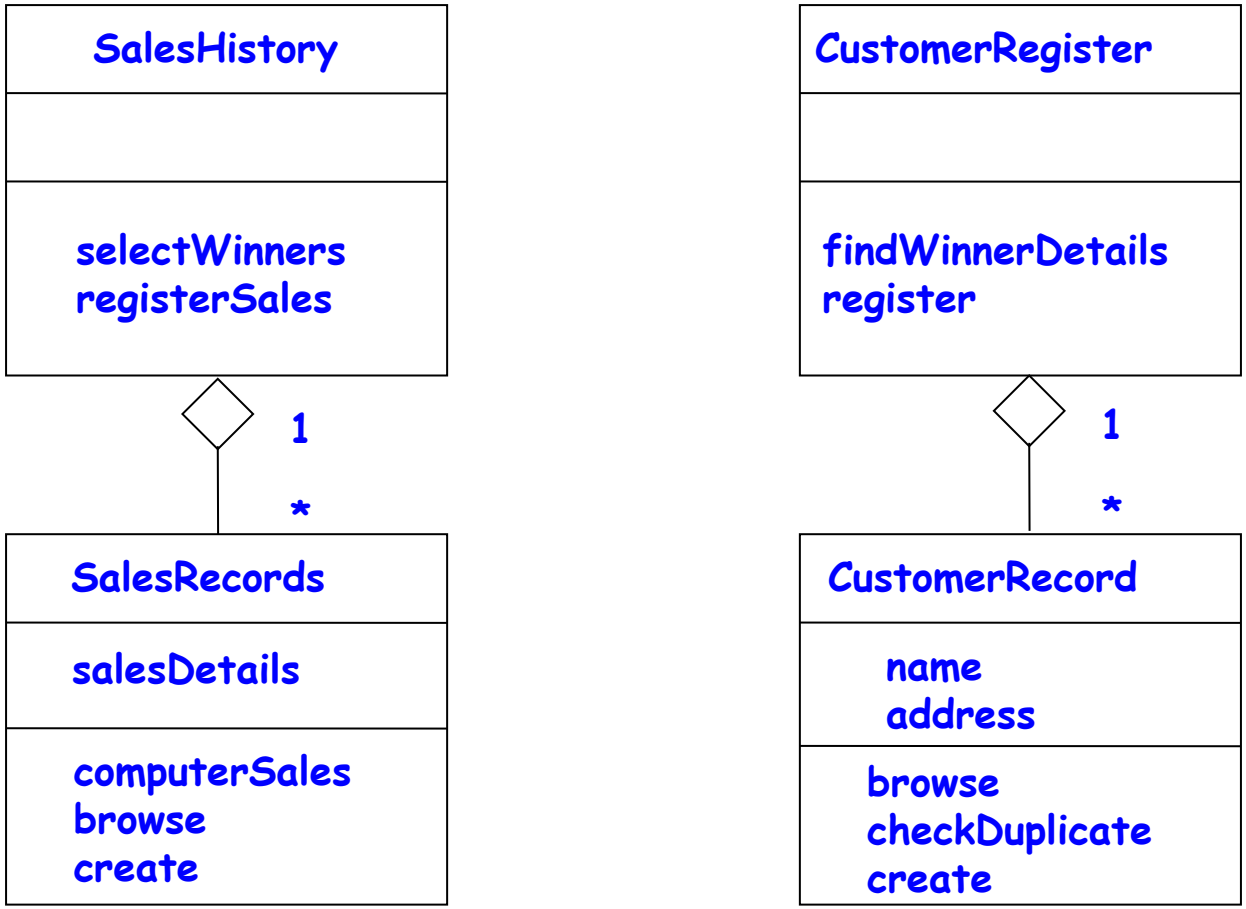
Sequence Diagram for the register sales use case

Example 2: Sequence Diagram for the Register Sales Use Case



Refined Sequence Diagram for the register sales use case

Example 2: Class Diagram



Summary

- We discussed object-oriented concepts
  - Basic mechanisms: Such as objects, class, methods, inheritance etc.
  - Key concepts: Such as abstraction, encapsulation, polymorphism, composite objects etc.

Summary

- We discussed an important OO language UML:
  - Its origin, as a standard, as a model
  - Use case representation, its factorisation such as generalization, includes and extends
  - Different diagrams for UML representation
  - In class diagram we discussed some relationships association, aggregation, composition and inheritance

Summary

- Other UML diagrams: cont…
  - Interaction diagrams (sequence and collaboration),
  - Activity diagrams,
  - State chart diagrams.
- We discussed OO software development process:
  - Use of patterns lead to increased productivity and good solutions.