Chapter-11
Object- Oriented Mercis

What is Object-Orientation?

- ***Structure-oriented programming and Data-oriented programming*** *are* not enough to represent (dynamic) software behavior.
- ***Object-Orientation programming*** is a methodology for system analysis, design and implementation that supports integration of functional and data-oriented programming and system development.

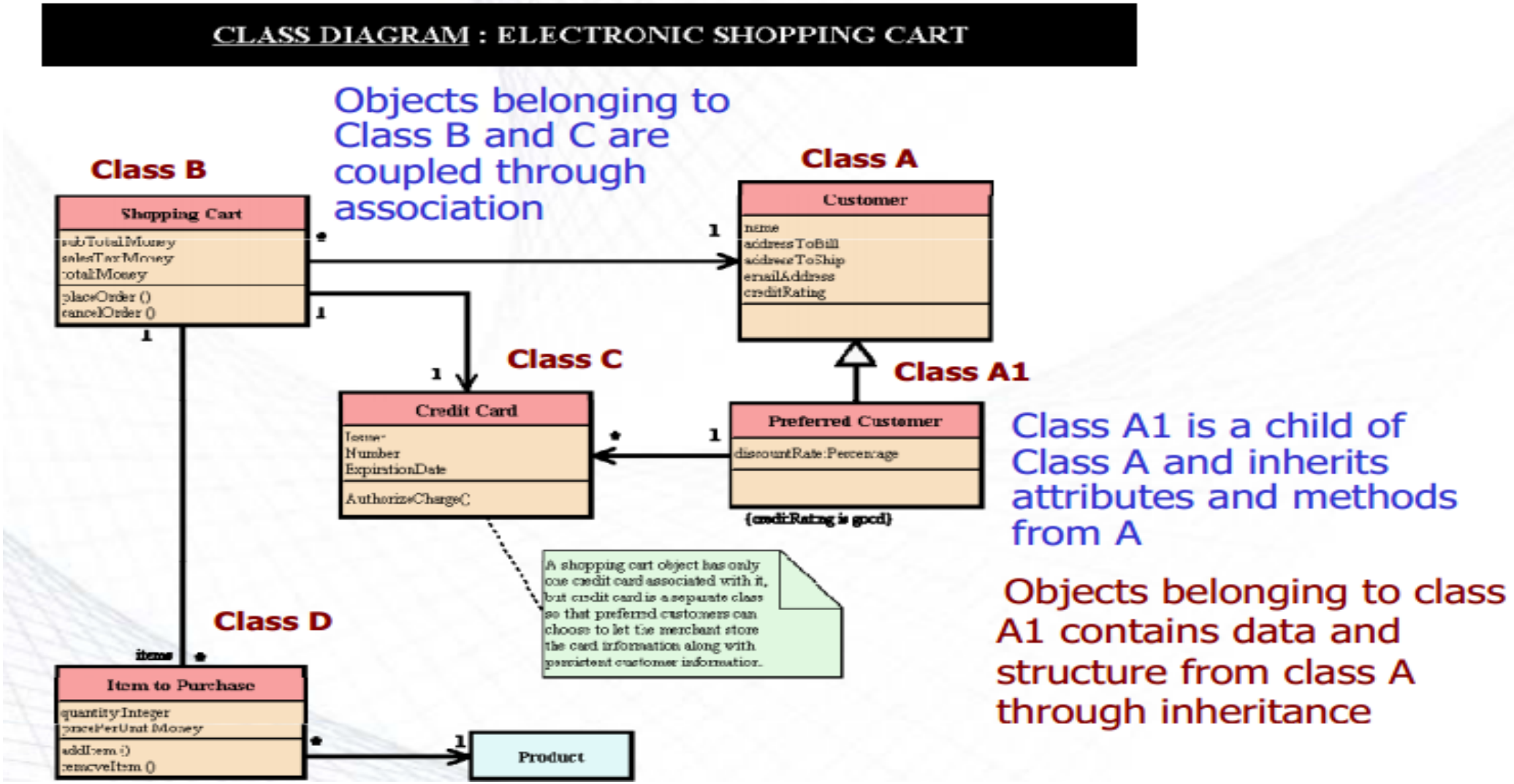
Terminology of OO

Class	A class is a description of a set of objects that share the same attributes, operations, relationships, and semantics.
Object	An instantiation of some class which is able to save a state (information) and which offers a number of operations to examine or affect this state.
Attribute **Variable**	An attribute is a named property of a class that describes a range of values instances of the property may hold.
Operation **Responsibility** **Method**	An operation is the implementation of a service that can be requested from any object of the class to affect behaviour.

Terminology of OO (cont.)

Package	A package is a general purpose mechanism for organizing elements into groups. Packages group functionally related classes.
Cohesion	The degree to which the methods within a class or classes in a package are related to one another.
Coupling	Object X is coupled to object Y if and only if X sends a message to Y.
Association	A semantic relationship between two or more classes that specifies connections among their instances.
Inheritance	A relationship among classes, wherein an object in a class acquires characteristics from one or more other classes.

Terminology of OO (cont.)



Similarities and differences

- Why Object-Oriented Software Engineering (OOSE) metrics are different from the conventional software metrics?
- OOSE metrics are different because of:
    1. Localization
    2. Encapsulation
    3. Information hiding
    4. Inheritance
    5. Reuse

1. Localization

- Localization means placing items in close (physical) proximity to each other.
  - ➢Functional decomposition (localize information around functions).
  - ➢Data localization (localize information around data).
  - ➢Object-oriented approaches (localize information around objects).
- In conventional software engineering, localization is based on functionality. Therefore:
  - ➢Metrics gathering has traditionally focused on functions and functionality
  - ➢Units of software were set to be functional, thus metrics focusing on component relationships emphasized functional interrelationships, e.g., module coupling and cohesion.

- In object-oriented software, , however, localization is based on ***objects***. This means:
  - Metrics identification and gathering effort must recognize the “object” as the basic unit of software.
  - Within systems of objects, the localization between functionality and objects is not a one-to-one relationship.
  - For example, one function may involve several objects, and one object may provide many functions.

2. Encapsulation

- Encapsulation is the packaging (or binding together) of a collection of items:
  - Low-level examples of encapsulation include records and arrays, procedures, subroutines.
  - OO programming languages allow higher-level encapsulating,

    e.g., classes in C++ and Java.
- Encapsulation has two major impacts on metrics:
  - The basic unit will no longer be the program, but rather the object.
  - We have to modify our thinking on characterizing and estimating systems.

3. Information hiding

- Information hiding is the suppression (or hiding) of details.
  - The general idea is that we show only that information which is necessary to accomplish our immediate goals.
  - There are degrees of information hiding ranging from , ranging from partially restricted visibility (e.g., public or private operations) to total invisibility (e.g., subsystems).
  - Encapsulation and information hiding may not be the same thing, e.g., an item can be encapsulated but may still be totally visible (e.g., a package).
  - Information hiding plays a direct role in such metrics as object coupling and the degree of information hiding.

4. Inheritance

- Inheritance is a mechanism whereby one object acquires characteristics from one, or more, other objects.
  - Some OO languages support single inheritance (e.g., Java), some support multiple inheritance (e.g., C++).
- Many OO software engineering metrics are based on inheritance, e.g.:
  - Number of children (number of immediate specializations)
  - Number of parents (number of immediate generalizations)
  - Class hierarchy nesting level (depth of a class in an inheritance hierarchy)

5. Reuse

- In OO development, reuse is a central issue
  - ➢ Reuse of libraries or frameworks
  - ➢ Reuse through inheritance
  - ➢ Meta-code level reuse:
    - ✓ Patterns
    - ✓ Business objects
- Reuse changes development process
  - ➢ Build reusable components
  - ➢ Find and reuse components

OO Project Metrics

- What we want to measure in an ***OO project***?
  - ➢Number of Classes, Operations (Methods), Attributes (Variables)
  - ➢Lines Of Code (LOC) and Statement Count
    - ✓Total and/or Averaged by class and/or method
- Structural measurement:
  - ➢Coupling, Cohesion

OO Package Metrics

- What we want to measure for a ***package***?
  - ➢Number of Classes, Operations (Methods), Attributes (Variables)
    - ✓Averaged by class and/or method
  - ➢Structural measurement:
    - ✓Coupling, Cohesion
    - ✓Maximum Inheritance Depth

OO Class Metrics

- What we want to measure for a ***class***?
  - ➢Number Attributes and Operations
  - ➢Lines of code (LOC) and statement count
  - ➢Inheritance related metrics
  - ➢Collaborators (Cohesion and Coupling related metrics)

OO Attribute Metrics

- What we want to measure for an ***attribute***?
  - ➢Instance variables
  - ➢How many times used

OO Operation Metrics

- What we want to measure for an ***operation***?
  - Number of local variables
  - Lines of code (LOC) and statement count
  - Cyclomatic Complexity

OO Metrics Suite

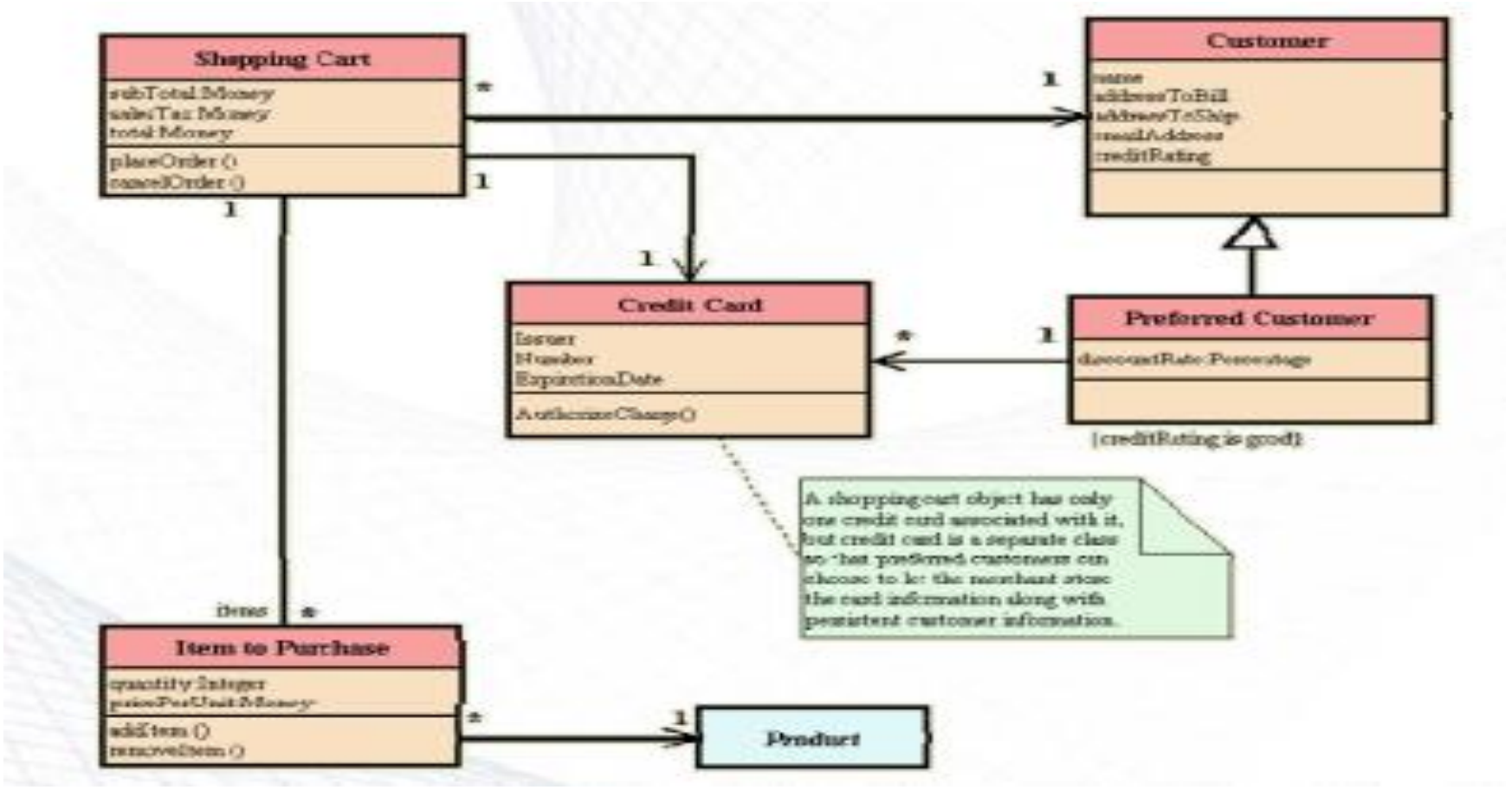
- Object Oriented Metrics seek to measure the unique attributes of Object Oriented design as opposed to software developed using other methods.
- Chidamber and Kemerer felt that software metrics developed with traditional methods in mind did not readily lend themselves to Object Oriented notions such as classes, inheritance, p g encapsulation and message passing (Chidamber & Kemerer, 1993).
- They proposed 6 metrics unique to Object Oriented systems. These metrics measure various attributes including size and complexity and are constructed with a strong degree of theoretical and mathematical rigor.

Basic Metrics for OO Systems

- Proposed originally by Chidamber & Kemerer 1993, expanded by Soft assurance Technology Center (SATC) at NASA.

SOURCE	METRIC	O-O CONSTRUCT
Traditional	Cyclomatic Complexity (CC)	Operation
Traditional	Lines of Code (LOC)	Class/Operation
Traditional	Comment Percentage (CP)	Class/Operation
NEW	Weighted Methods per Class (WMC)	Class/Operation
NEW	Response For a Class (RFC)	Class/Operation
NEW	Lack of COhesion (LCOM)	Class/Operation
NEW	Coupling Between Objects (CBO)	Coupling
NEW	Depth of Inheritance Tree (DIT)	Inheritance
NEW	Number of Children (NoC)	Inheritance

Working Example: Shoppin Cart



Weighted Methods per Class (WMC)

- WMC is a metric of size and complexity. It is defined as: WMC = Σc_i
- where c_i is the complexity of each different method C_1, C_2, … C_n in class C.
- If each method were assigned a complexity of 1then the WMC for class C would equal the number of methods in the class.
- Chidamber and Kemerer deliberately did not define “complexity” more specifically in order to permit the most general application of the metric possible.

Weighted Methods per Class (WMC) (cont.)

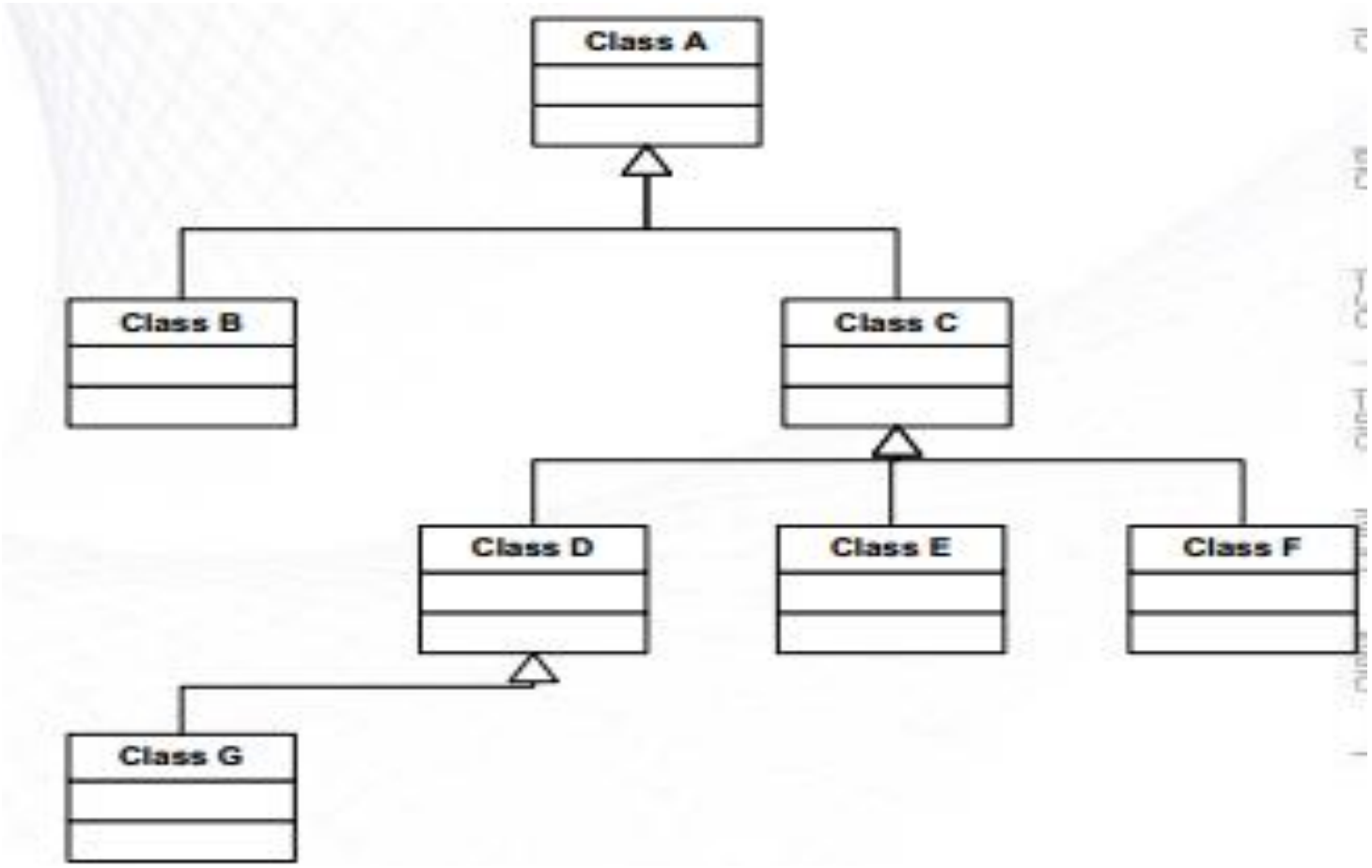
- The number of methods and the complexity of the methods involved is a predictor of how much time and effort is required to develop and maintain the class.
- The larger the number of methods in a class, the greater the potential impact on children; children inherit all of the methods defined in the parent class.
- Classes with large numbers of methods are likely to be more application specific, limiting the possibility of reuse.
  - **Example:** WMC is calculated by counting the number of method in each class, therefore:
    - ✓WMC for *Shopping_Cart* = 2
    - ✓WMC for *Credit Card* = 1

Depth of Inheritance Tree (DIT)

- The depth of a class within the inheritance hierarchy is the maximum number of steps from the class node to the root of the tree and is measured by the number of ancestor classes.
- The deeper a class is within the hierarchy, the greater the number of methods it is likely to inherit making it more complex to predict its behavior.
- Deeper trees constitute greater design complexity, since more methods and classes are involved but the greater the , but the greater the potential for reuse of inherited methods.
  - **E.g 1:** *Customer* is the root and has a DIT of 0. The DIT for *Preferred_Customer* is 1.

Depth of Inheritance Tree (DIT) (cont.)

- E.g. 2
  - DIT(A)=0
  - DIT(B C) =1
  - DIT(D,E,F)=2
  - DIT(G)=3

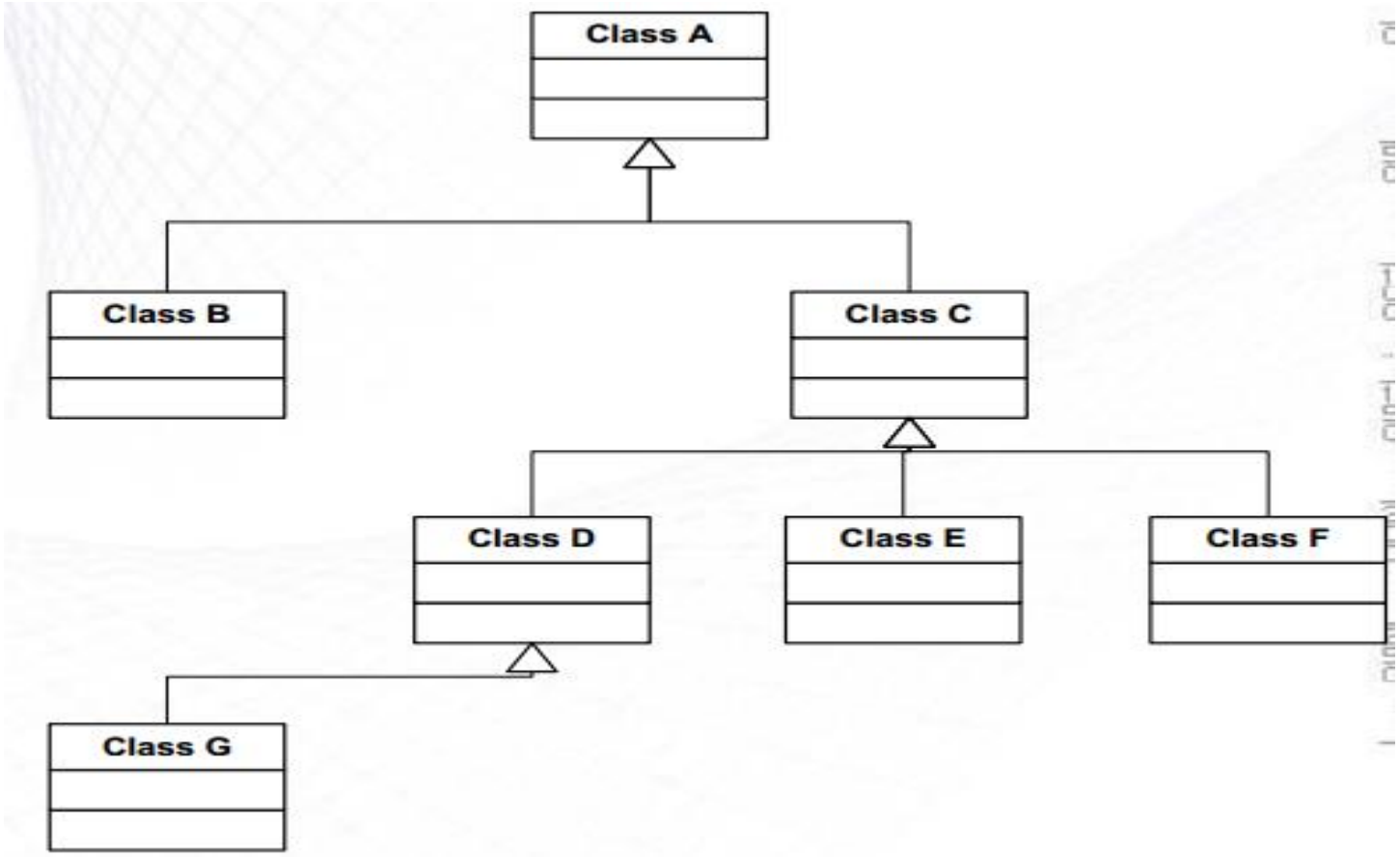


Number of Children (NoC)

- The number of children is the number of immediate subclasses subordinate to a class in the hierarchy.
- It is an indicator of the potential influence a class can have on the design and on the system.
- The greater the NoC, gives an idea of the potential influence a parent class has on design. If a class has a large number of sub-classes, it could require more testing of its methods.
- The greater the NoC, the greater the reuse since inheritance is a form of reuse.
  - **E.g:** *Customer* has an NOC of 2. NOC for *Preferred_Customer* is 0 since it is a terminating or leaf node in the tree structure.

Number of Children (NoC) (cont.)

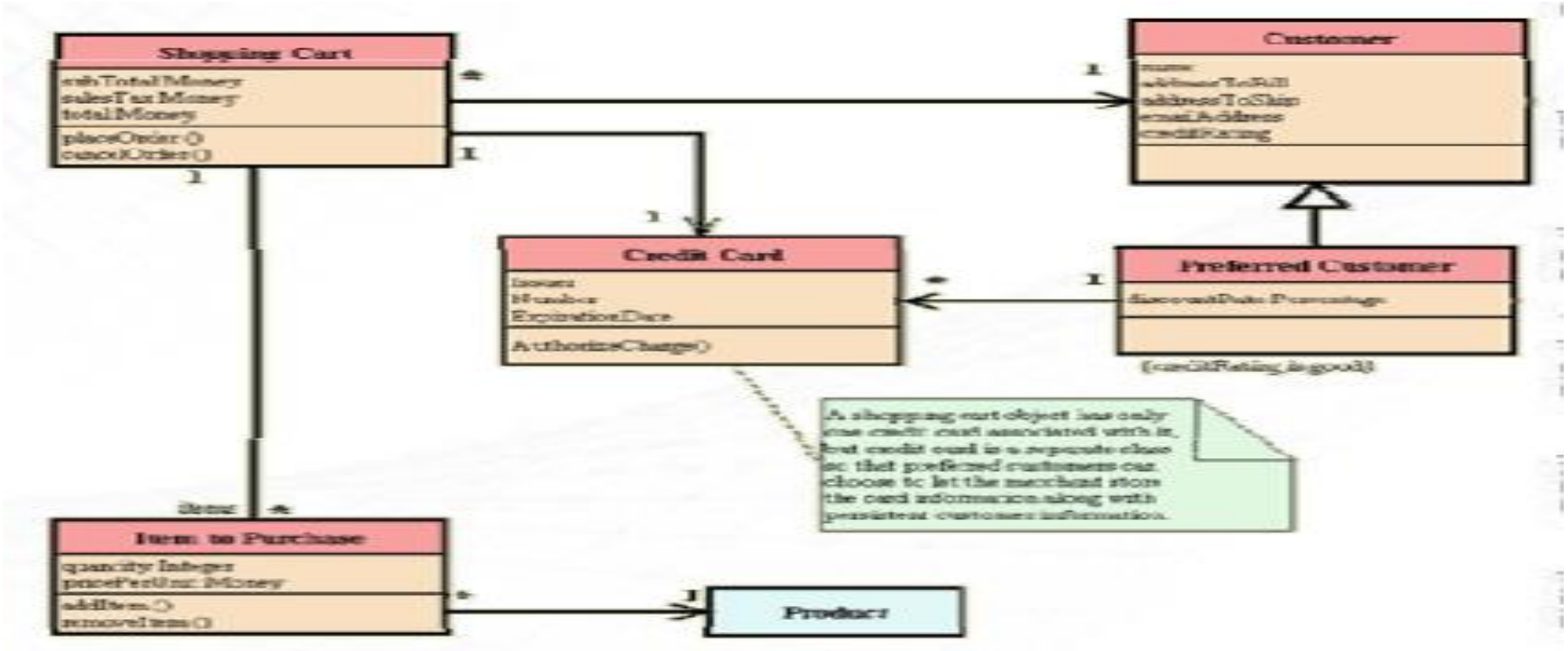
- E.g. 2
  - NoC(A)=2
  - NoC(C) =3
  - NoC(D)=1
  - NoC(B E F G)=0



Coupling Between Objects (CBO)

- CBO metric is a measure of non inherited interactions between classes.
- CBO is a count of the number of other classes to which a class is coupled.
- It is measured by counting the number of distinct non-inheritance related class hierarchies on which a class depends.
- Excessive coupling is detrimental to modular design and prevents reuse.
- The more independent a class is, the easier it is reuse in another application.

Example: Two classes may have excessive coupling (too many messages passing between them). This implies that those classes should be combined into one class.



Response for a Class (RFC)

- RFC is the count of the set of all methods that can be invoked in response to a message to an object of the class or by some method in the class.
- This metric looks at combination of the complexity of a class through the number of methods and the amount of communication with other classes.
- The larger the number of methods that can be invoked from a class through messages the greater the complexity of the , the greater the complexity of the class.

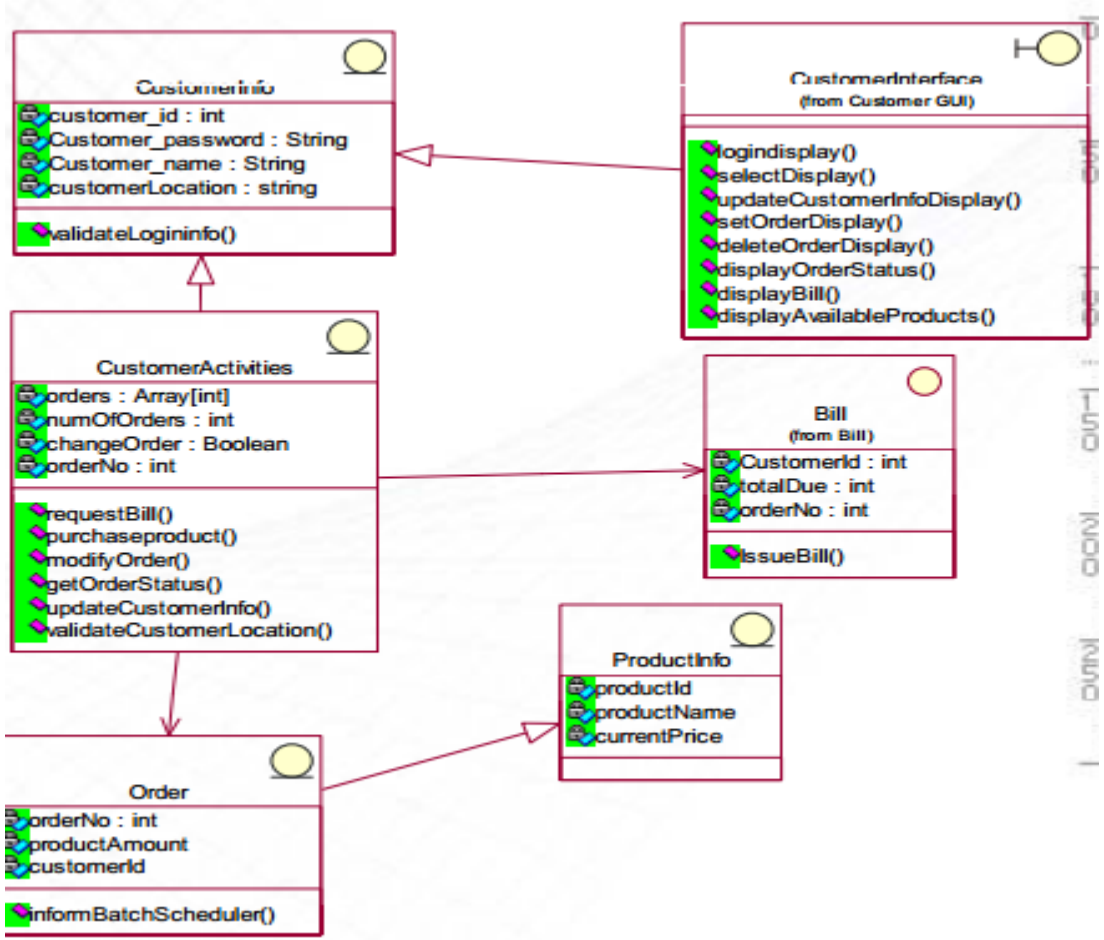
  E.g: RFC for *Preferred_Customer* = 0 (*self*) + 0 (*Customer*) + 1 (*Credit_Card*)= 1

Lack of Cohesion (LCOM)

- Lack of Cohesion (LCOM) measures the dissimilarity of methods in a class by instance variable or attributes.
- If a class has different methods performing different operations on the same set of instance variables, the class has cohesion.
- A highly cohesive module should stand alone; high cohesion indicates good class subdivision.
- Lack of cohesion or low cohesion increases complexity, thereby increasing the likelihood of errors during the development process.
- High cohesion implies simplicity and high reusability.
- Example: Alternative design with high LCOM: Assume that the *Credit_Card* and *Preferred_Customer* classes are merged. There will be relatively few common attributes and methods among the objects that may belong to this class.

- Determine the value of
  - "Average method per class";
  - "Response for a Class (RFC)" for CustomerActivities and CustomerInterface classes

Average method per class = 17/6 = 2.83
For* `CustomerActivities` *RFC = 9
For* `CustomerInterface` *RFC = 9

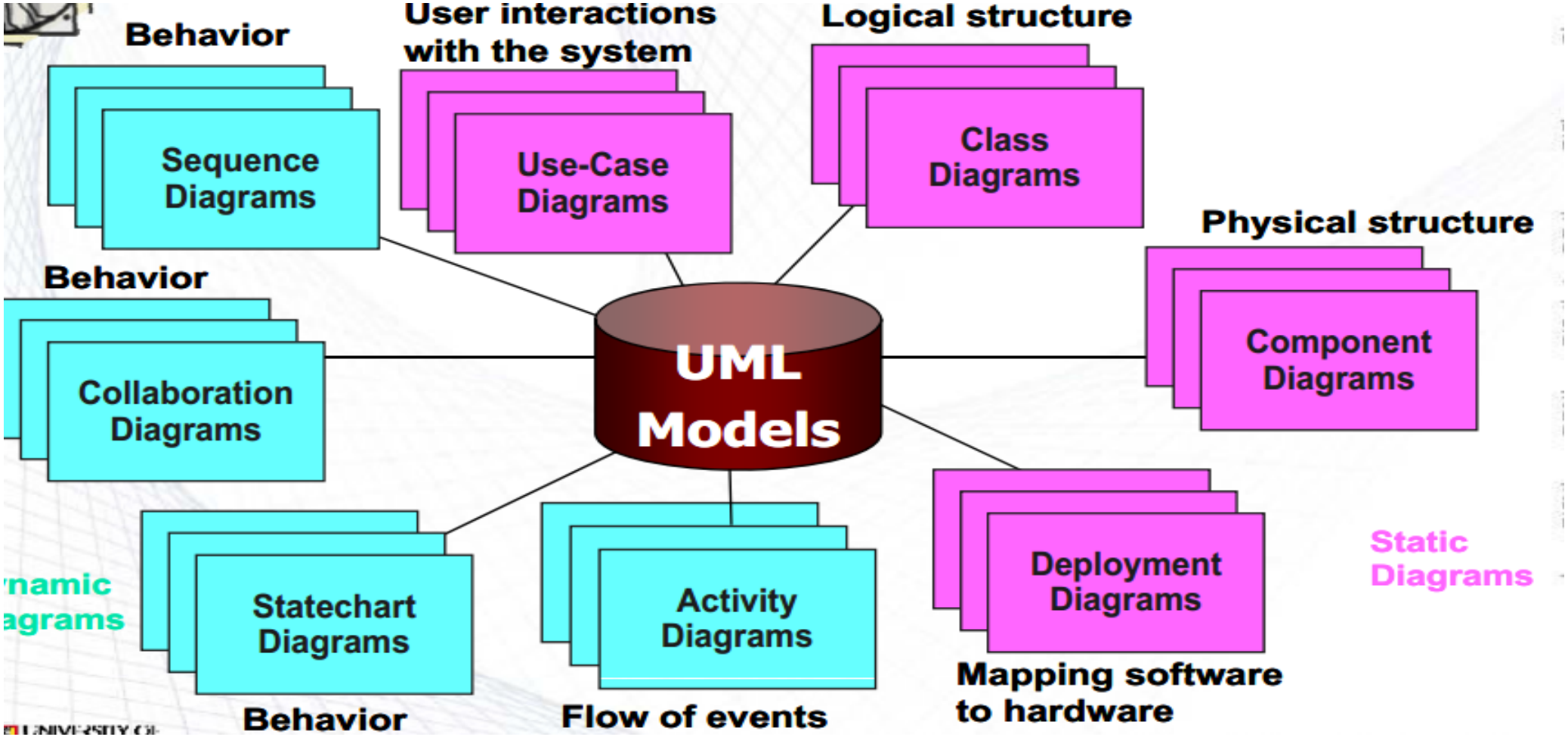


Interpretation

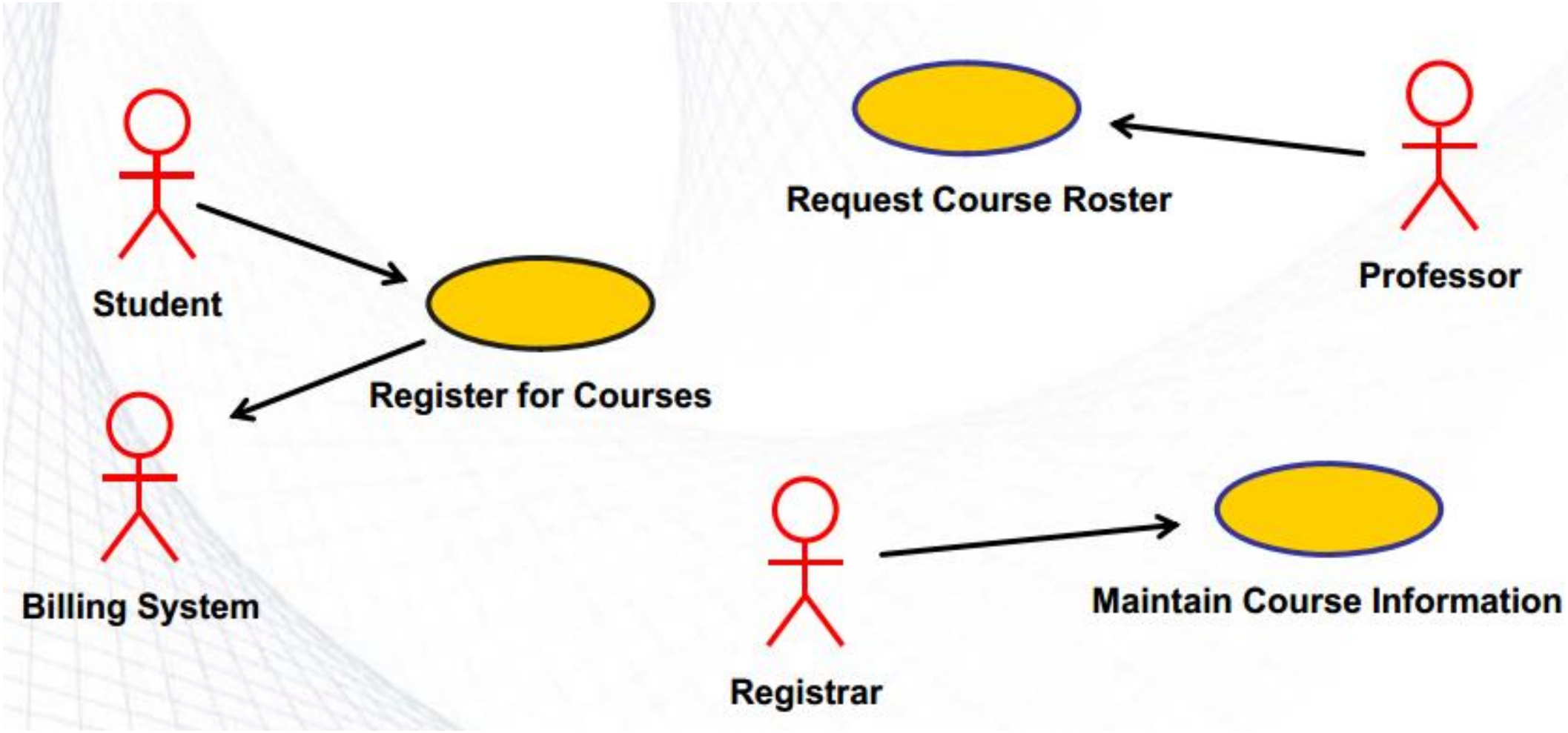
METRICS	OBJECTIVE
Cyclomatic Complexity	Low
Lines of Code/Executable Statements	Low
Comment Percentage	~ 20 – 30 %
Weighted Methods per Class (WMC)	Low
Response for a Class (RFC)	Low
Lack of Cohesion of Methods (LCOM) Cohesion of Methods	Low High
Coupling Between Objects (CBO)	Low
Depth of Inheritance (DIT)	Low (trade-off)
Number of Children (NoC)	Low (trade-off)

OO Metrics: Metrics Using UML

Here are the Various UML Diagrams

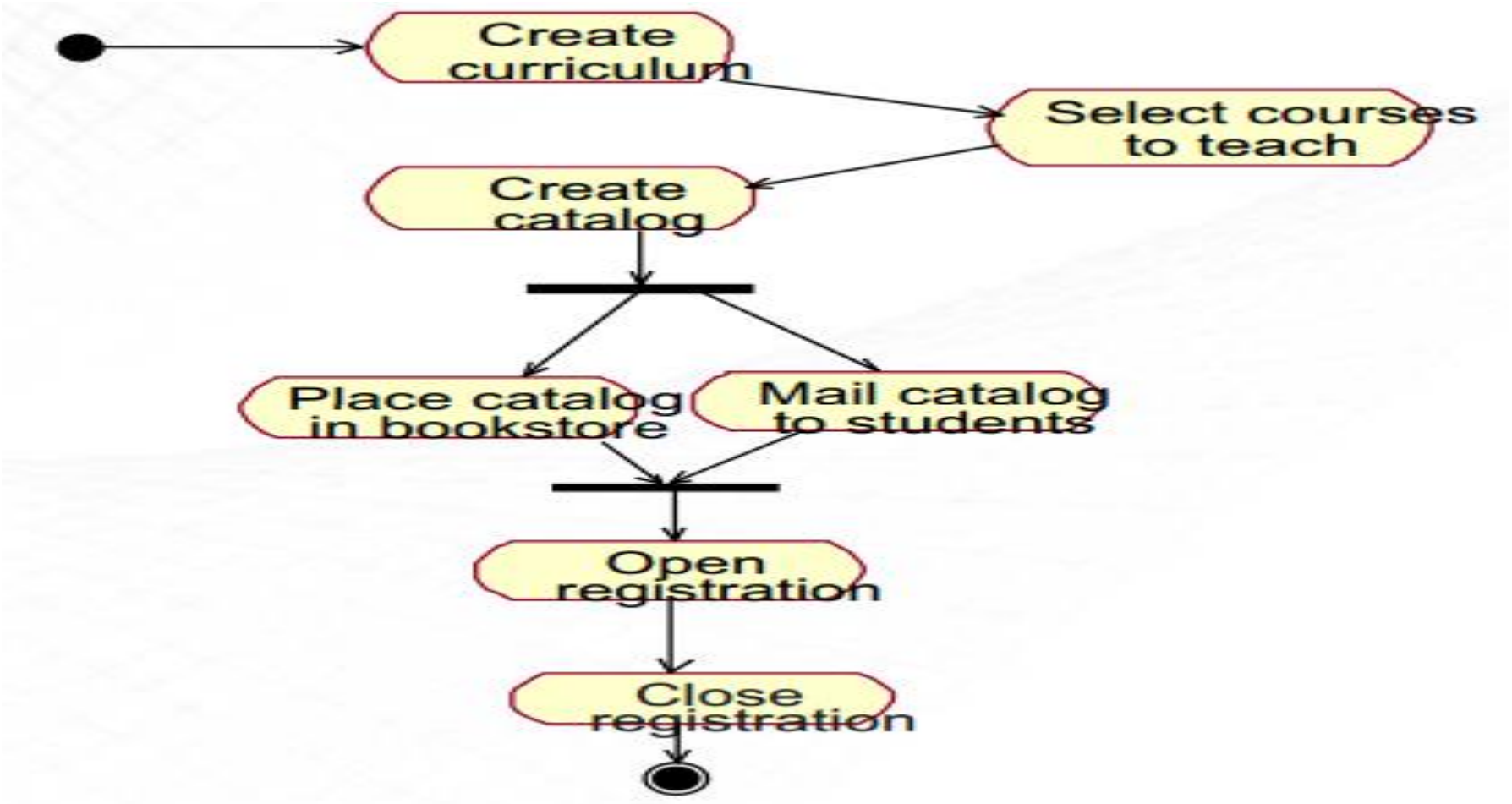


Example: UML Use-Case Diagram



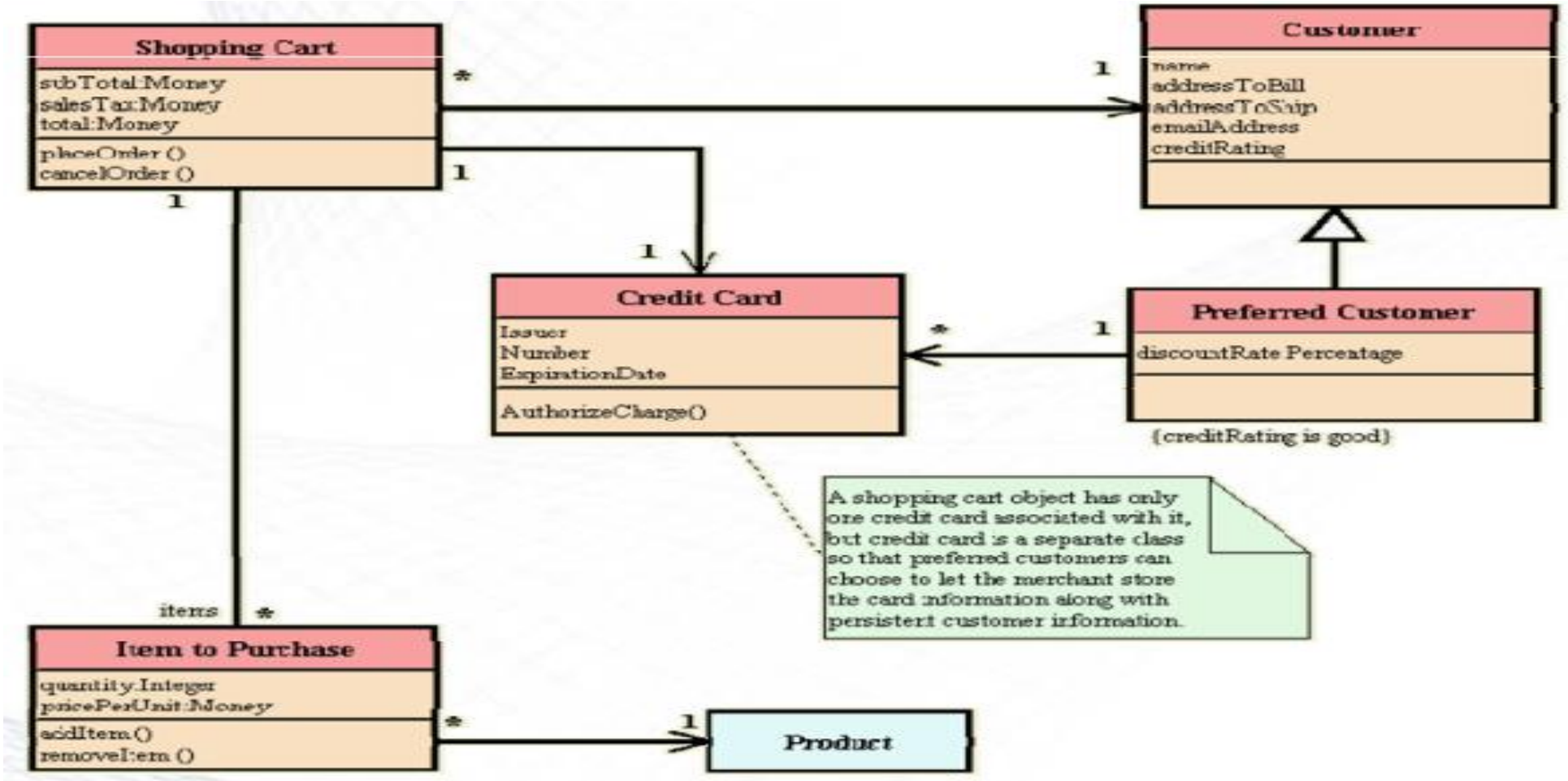
Example: UML Activity Diagram

- An activity diagram shows the flow of events within the use-case

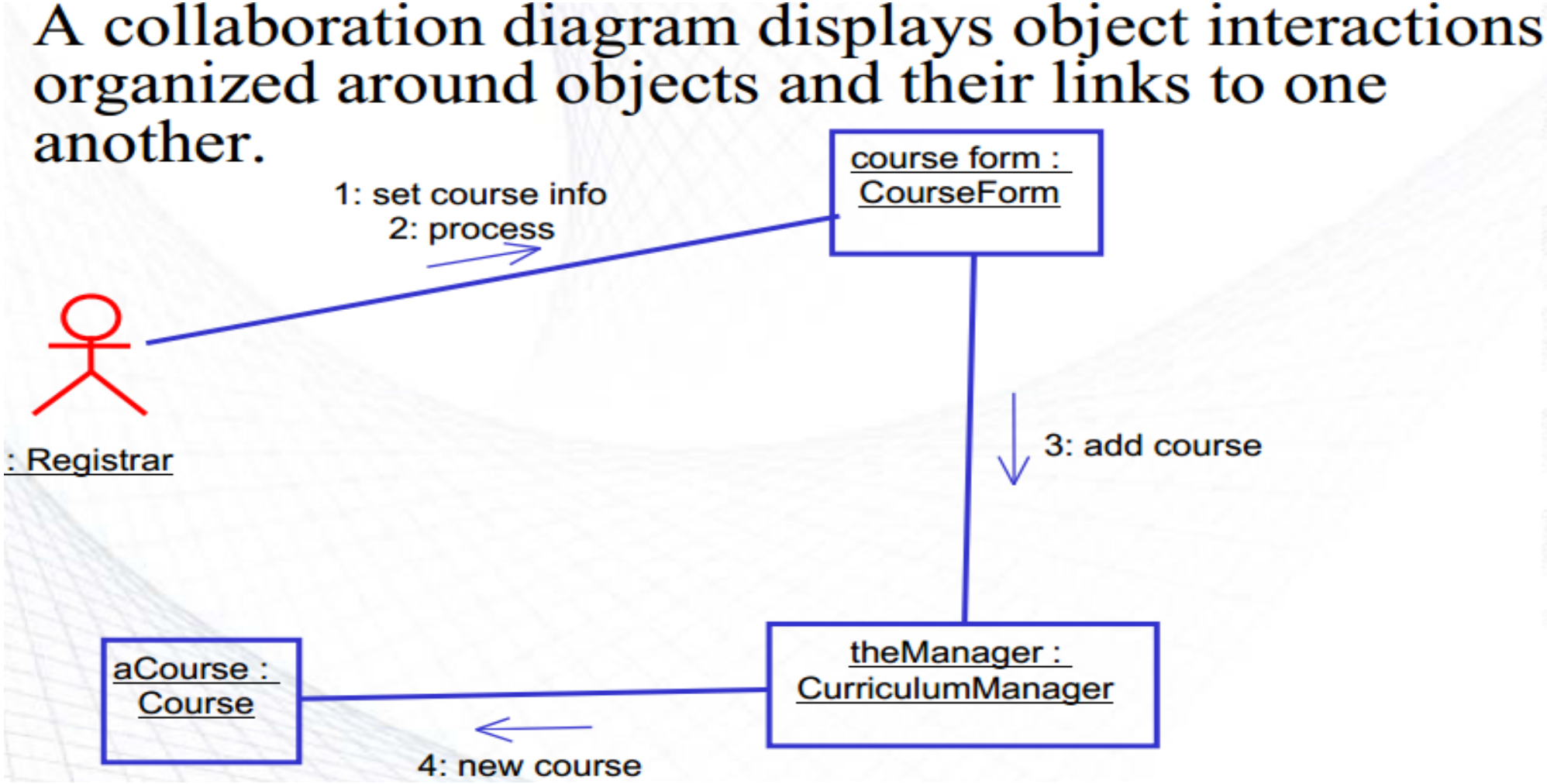


Example: UML Class Diagram

- A class diagram shows the structure of the software.

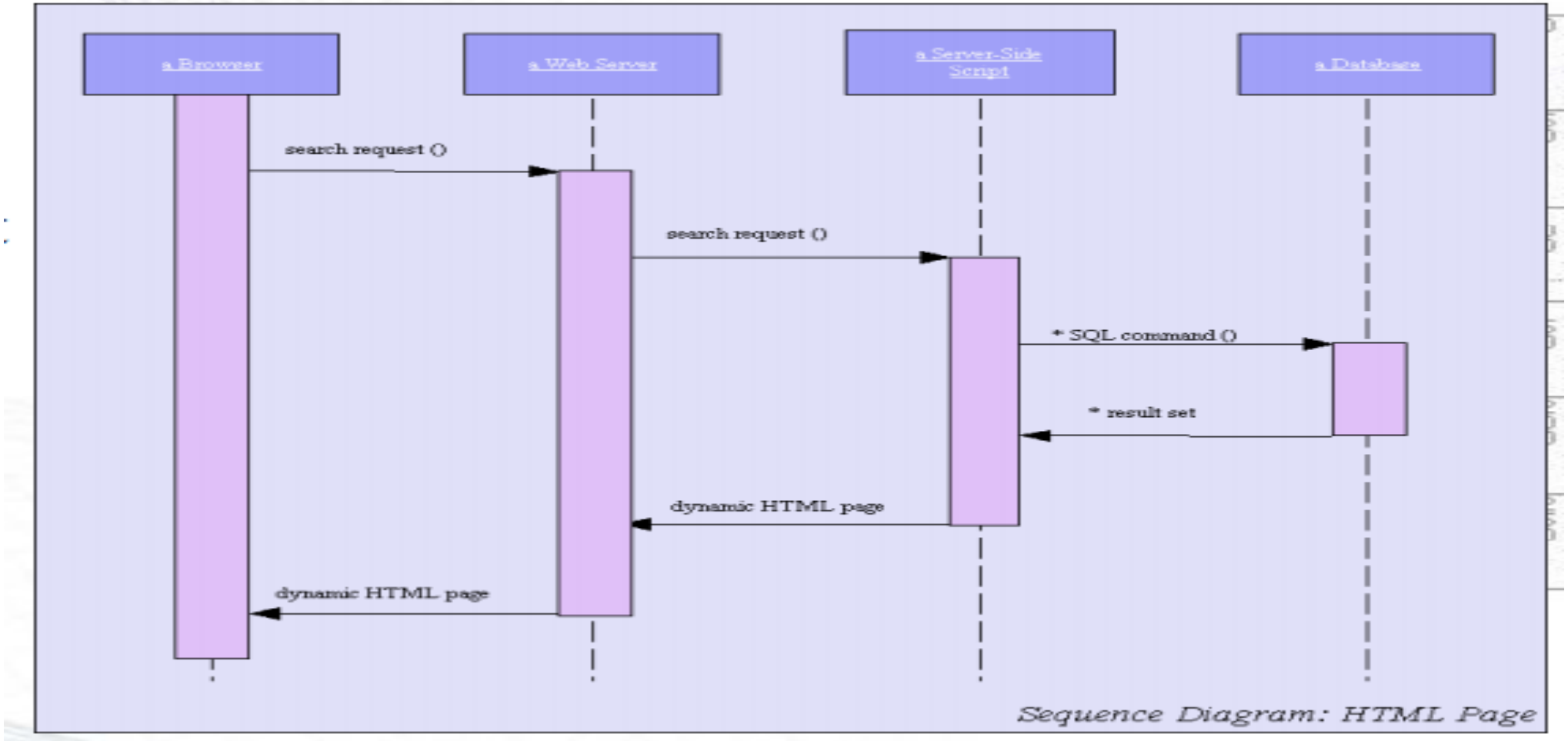


Example: UML Collaboration Diagram



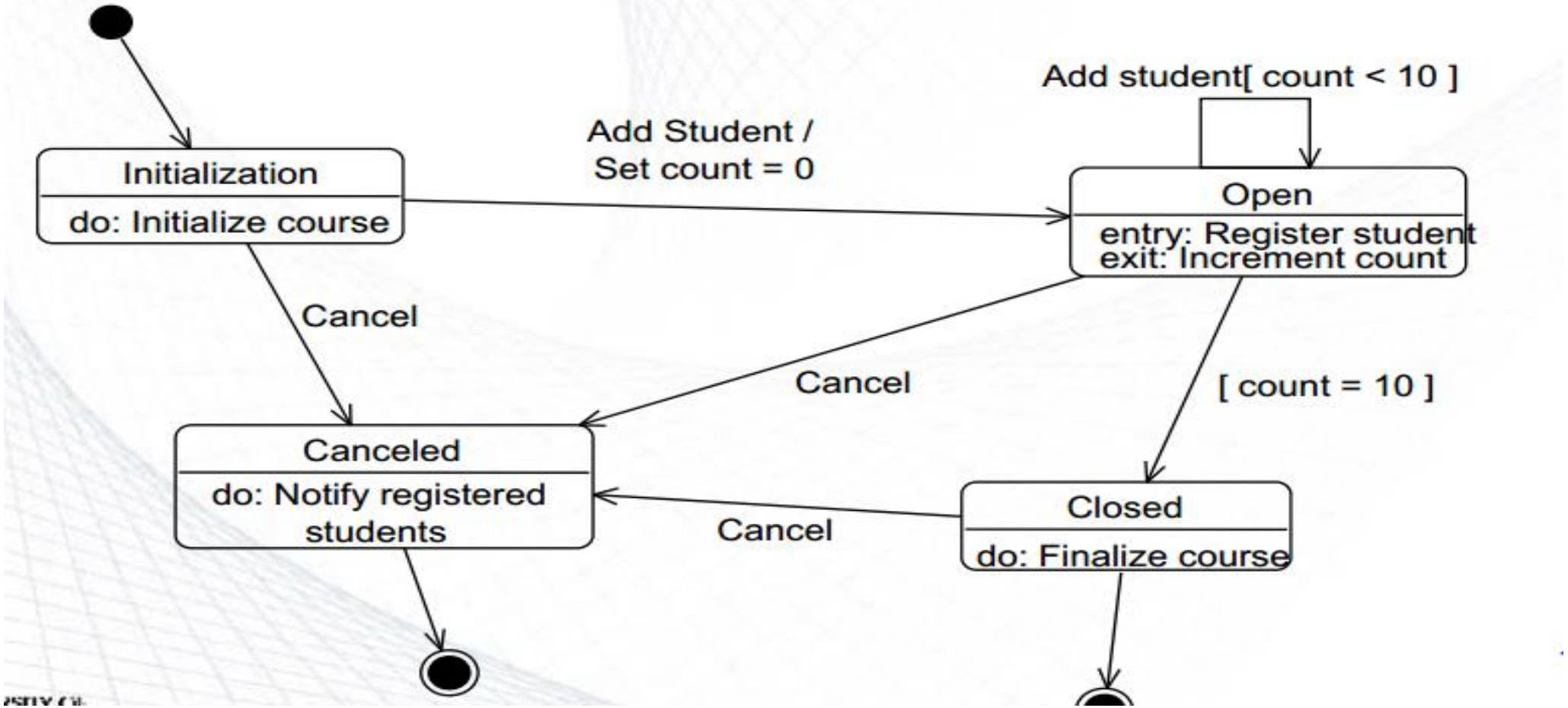
Example: UML Sequence Diagram

- A sequence diagram shows step by step what must happen to accomplish a piece of functionality provided by the system.



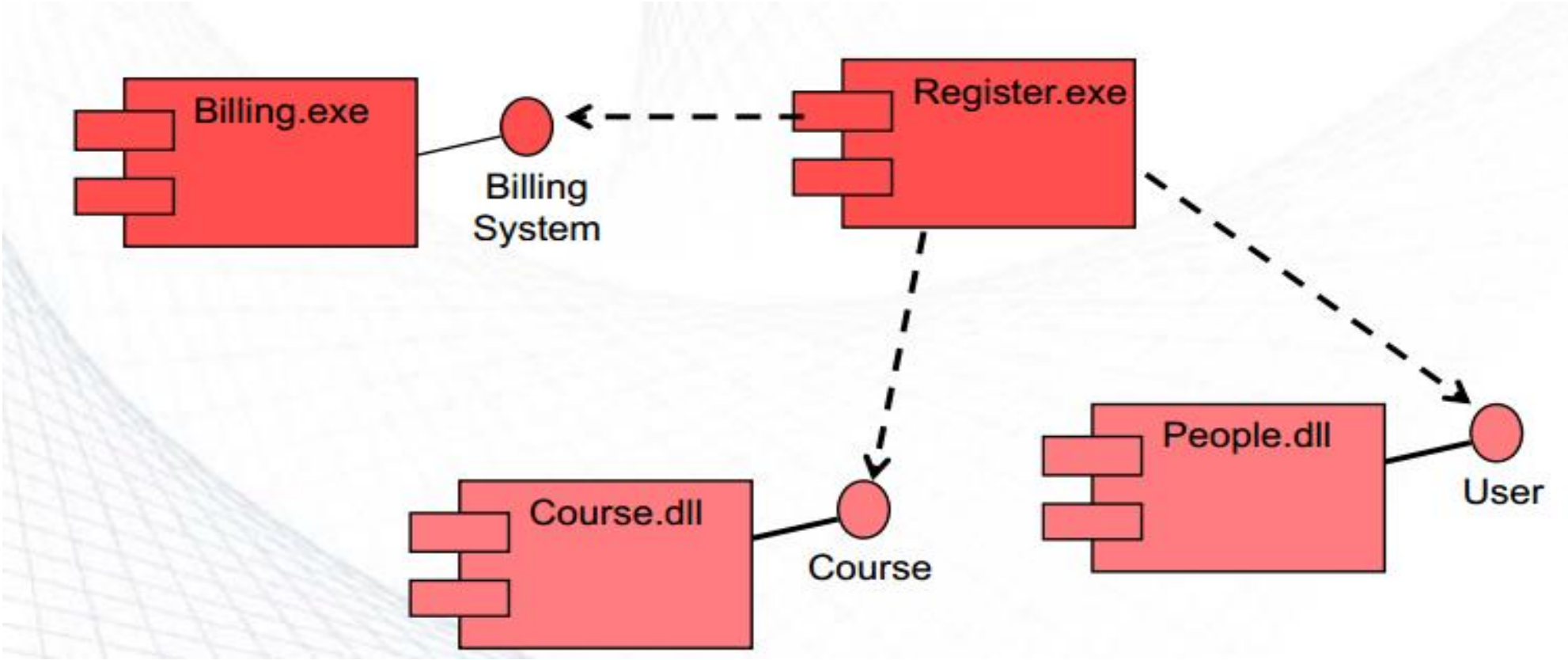
Example: UML State-chart Diagram

- A statechart diagram shows the lifecycle of a single class.

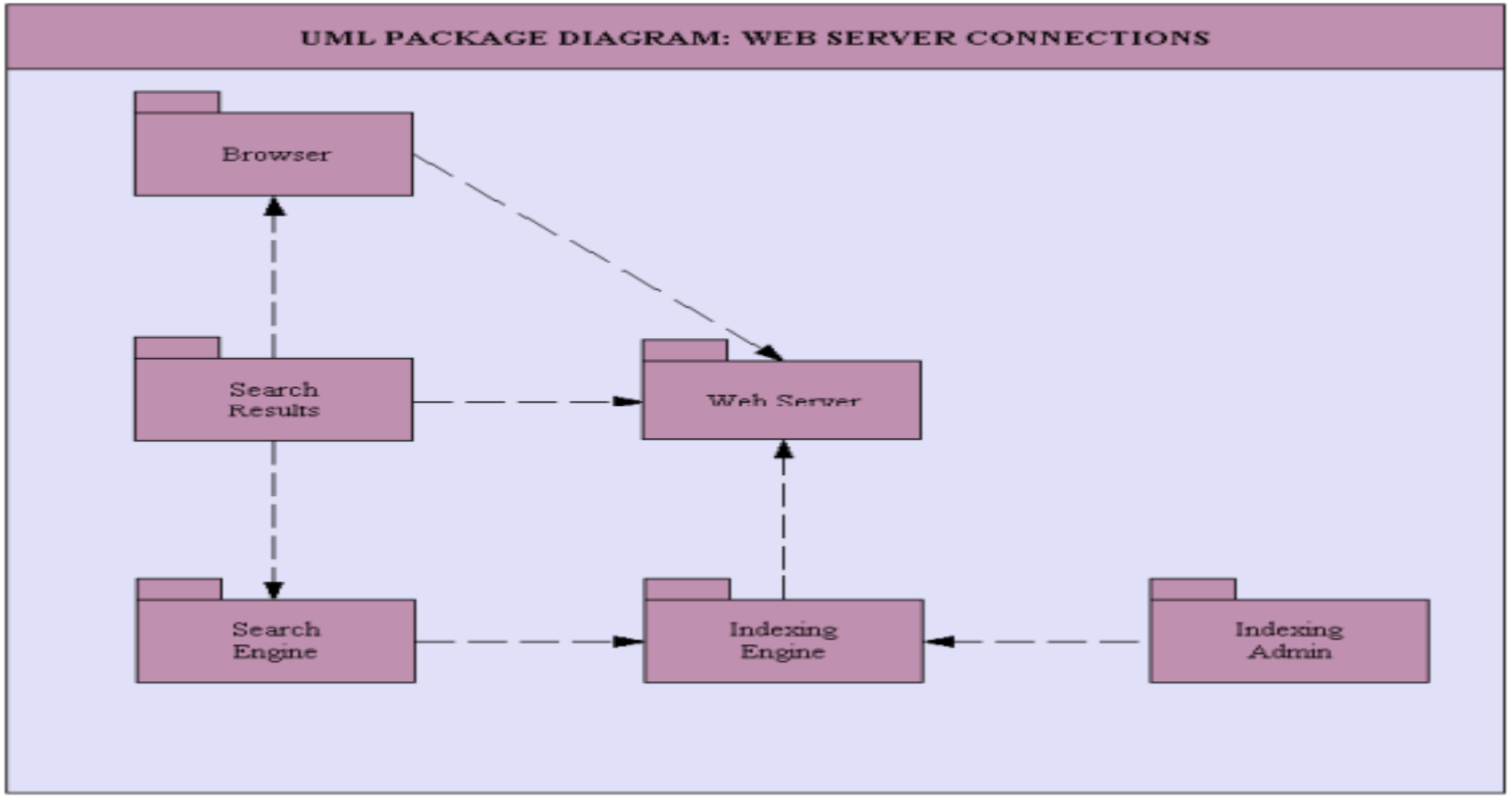


Example: UML Component Diagram

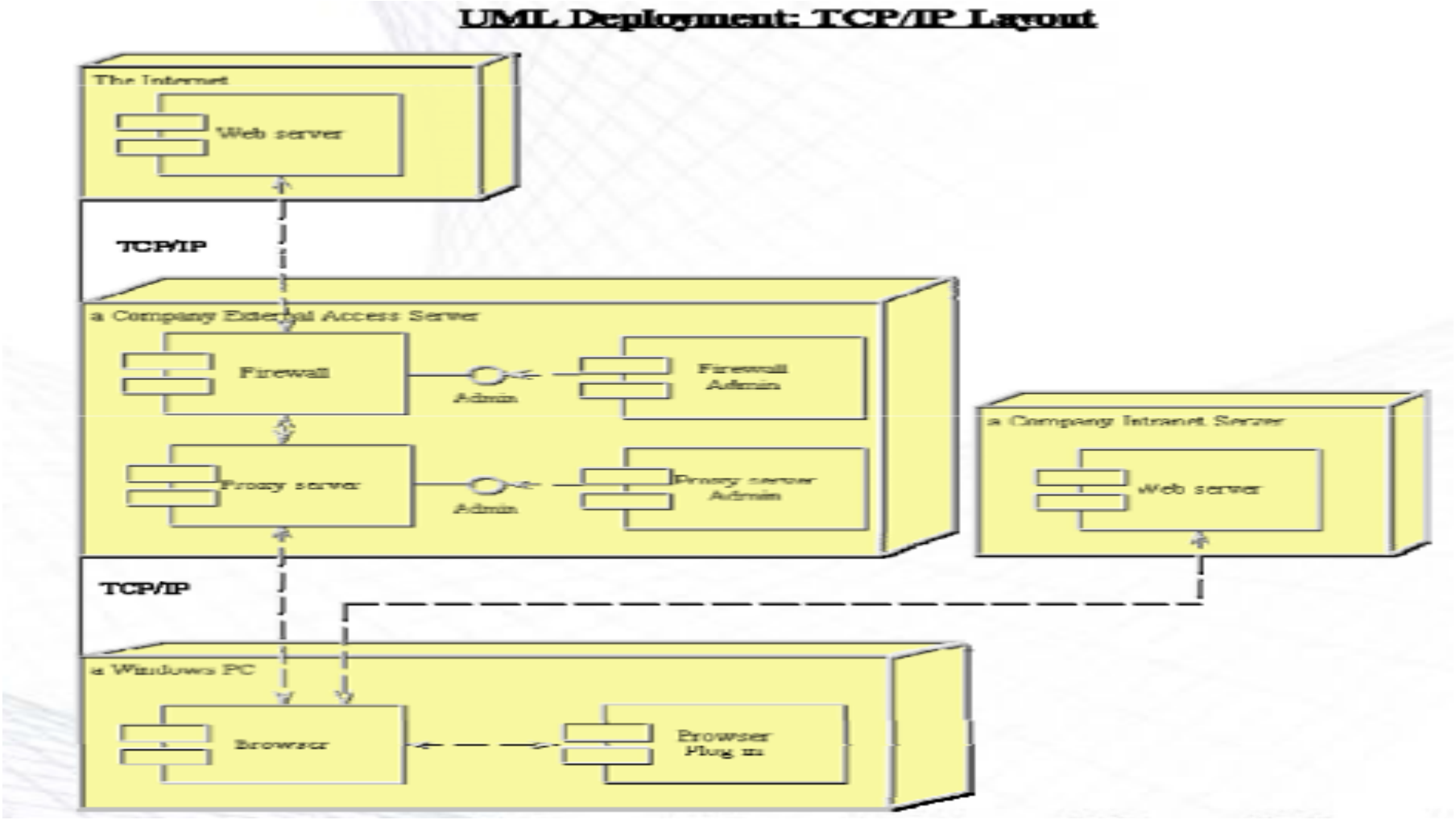
- Component diagrams illustrate the organization an dependencies among software components.



Example: UML Package Diagram



Example: UML Deployment Diagram

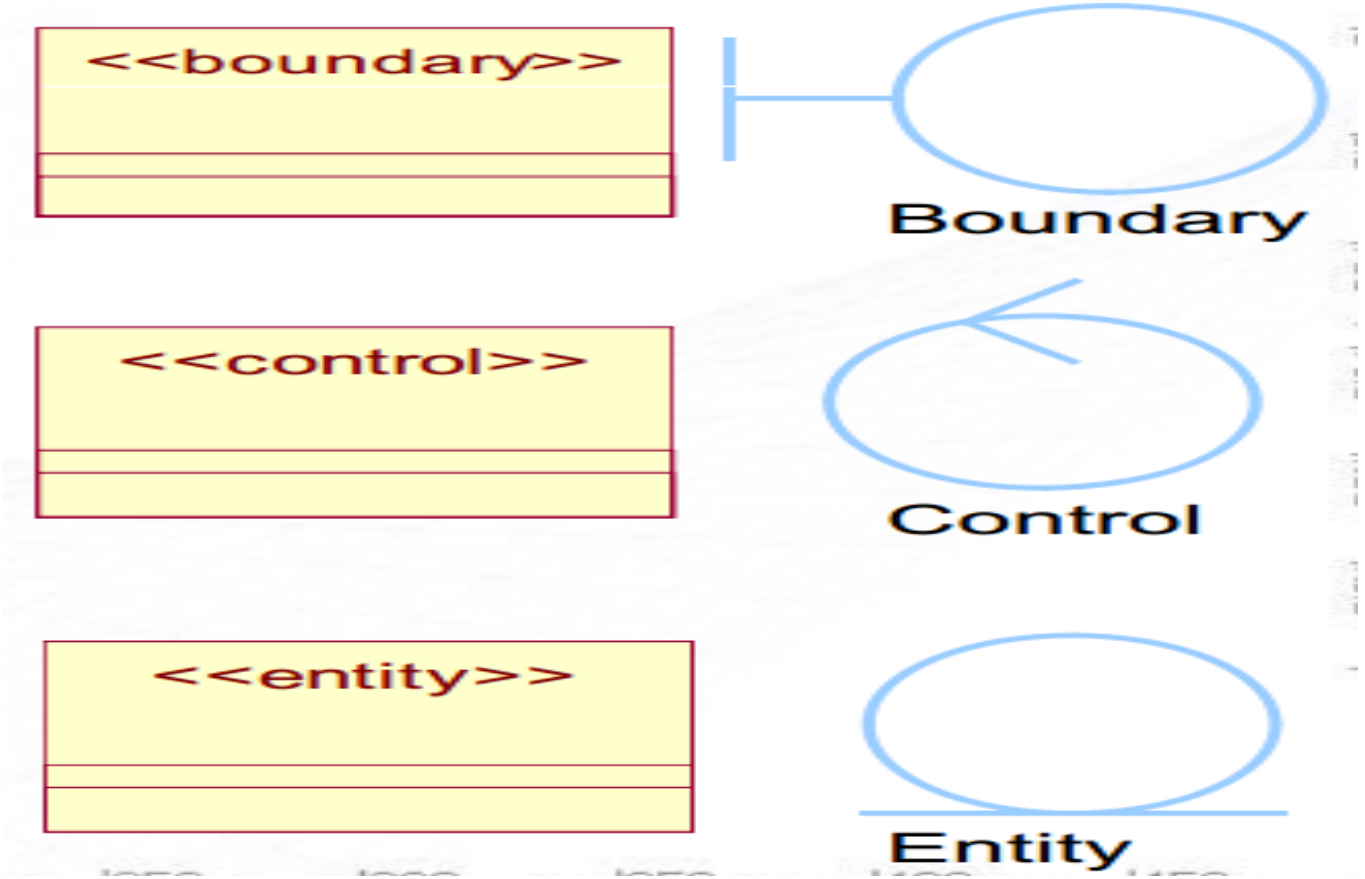


Number of Domain Classes (#DC)

- **Measurement:** #DC can be easily measured, even without tool support.
- **Usage:** #DC can be used for tracking the overall software process. It can only reflect major changes to the system (creation, deletion, or replacement of domain classes). This metric ignores the associations or relationships between the classes.

Domain Classes (#DC)

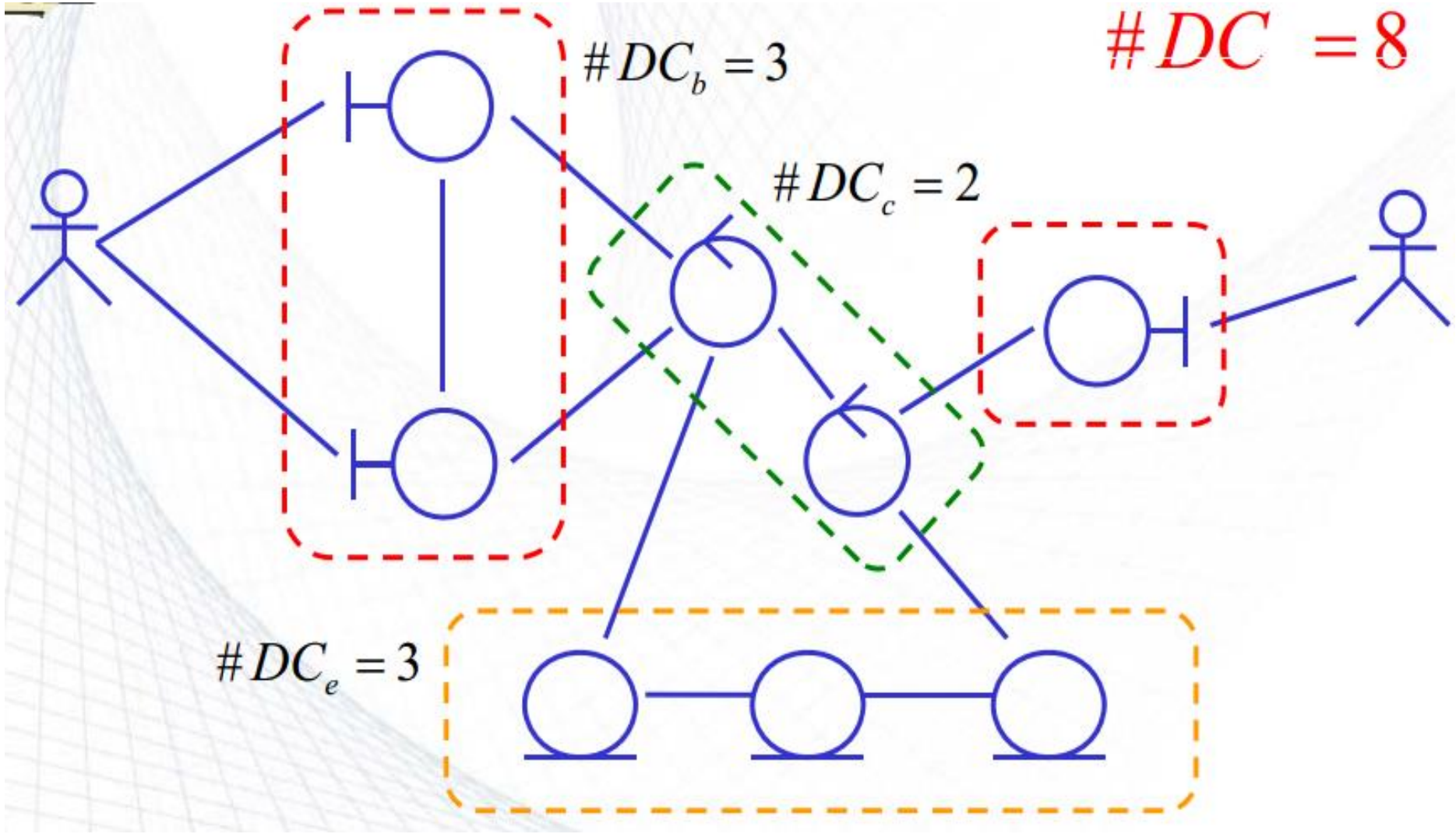
- The analysis classes can be further broken down to class stereotypes.
- Stereotyped class is still a class, but has additional information that is defined by the stereotype.



Domain Classes (#DC) (cont.)

- **Boundary class** models the interaction between the system's surroundings and its inner workings.
  - ➢ $\#DC_b$ is the number of boundary classes.
- **Control class** controls the behavior of a use case and delegates the work of the use case to other classes
  - ➢ $\#DC_c$ is the number of control classes.
- **Entity class** models the key concepts of the system (usually models persistent information)
  - ➢ #DCe is the number of entity classes

Example: #DC

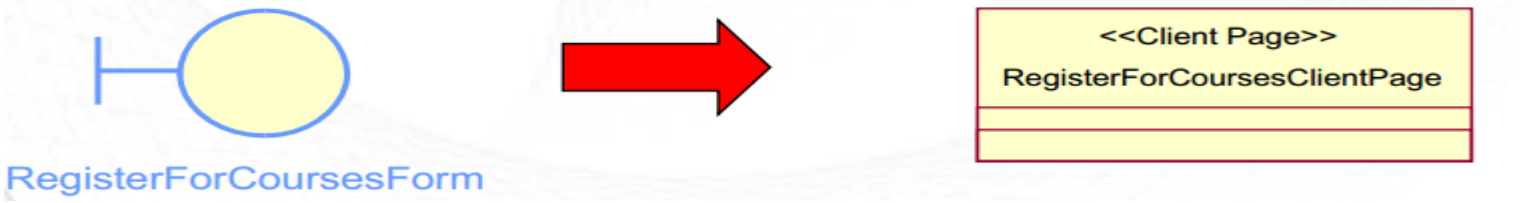


From Analysis to Design Classes (group 8)

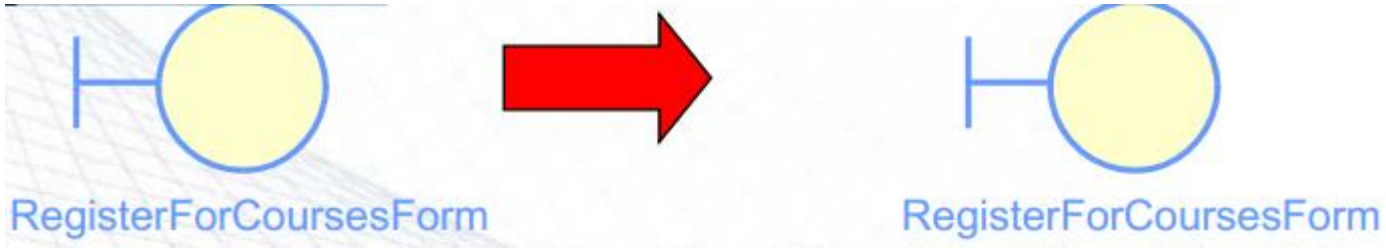
- Can we estimate the number of ***design classes*** from the ***analysis classes***?
- An analysis class maps directly to a design class or
- More complex analysis classes may
  - ➢Split into multiple classes
  - ➢Become a package
  - ➢Become a subsystem
  - ➢Any combination of the above

Expansion: Boundary Class

- In a Web application, each boundary class representing a form becomes a JSP, servlet or client page, or a combination of the three.
  - Example: RegisterForCoursesForm as a client page

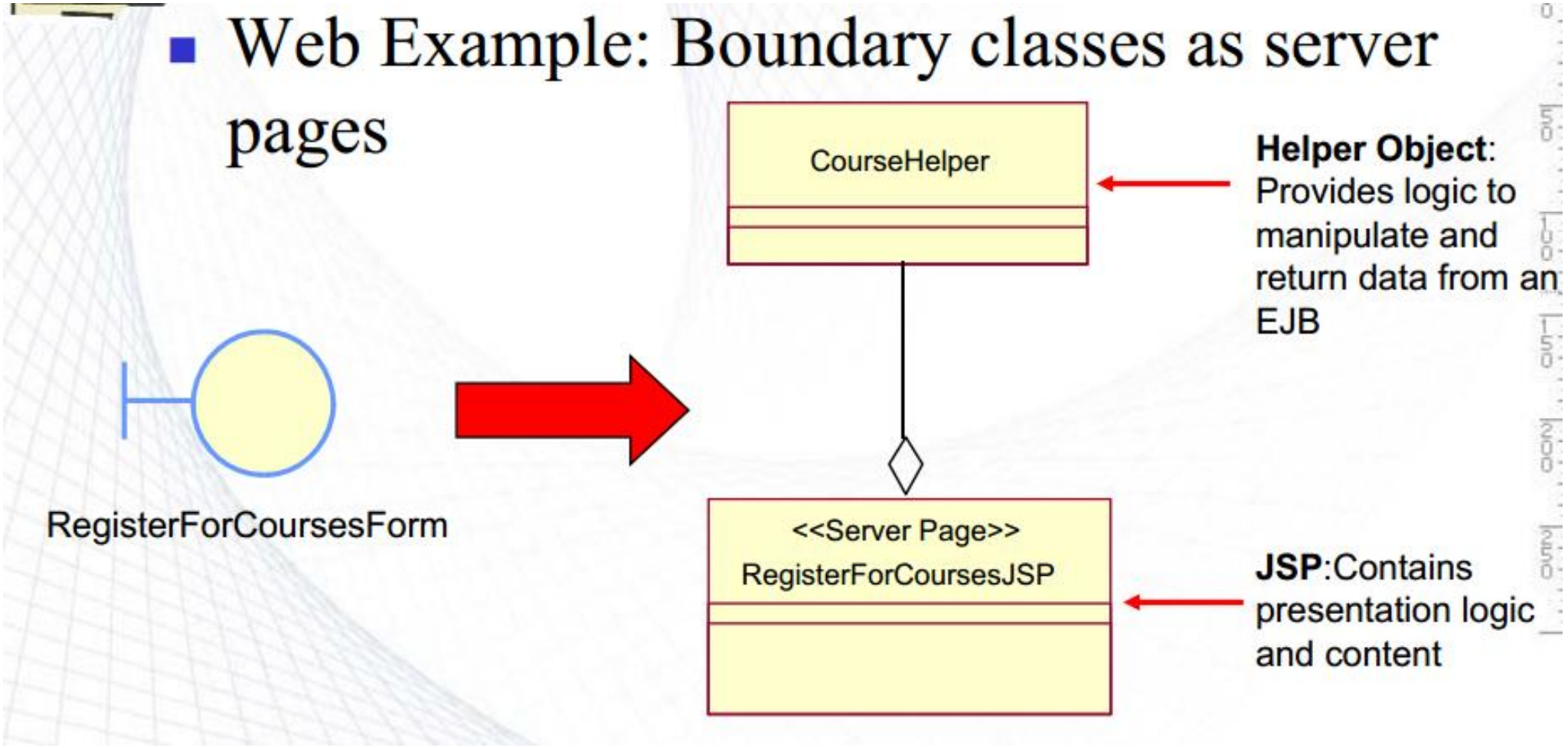


- In a GUI environment, each boundary class continues to represent a form.



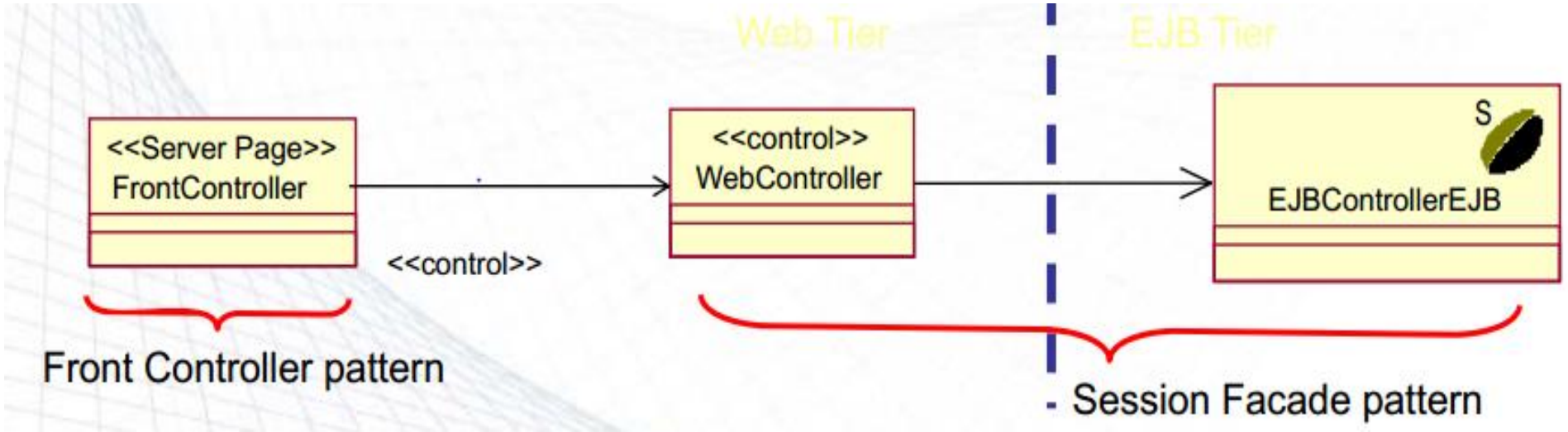
Expansion: Boundary Class (cont.)

- Web Example: Boundary classes as server pages



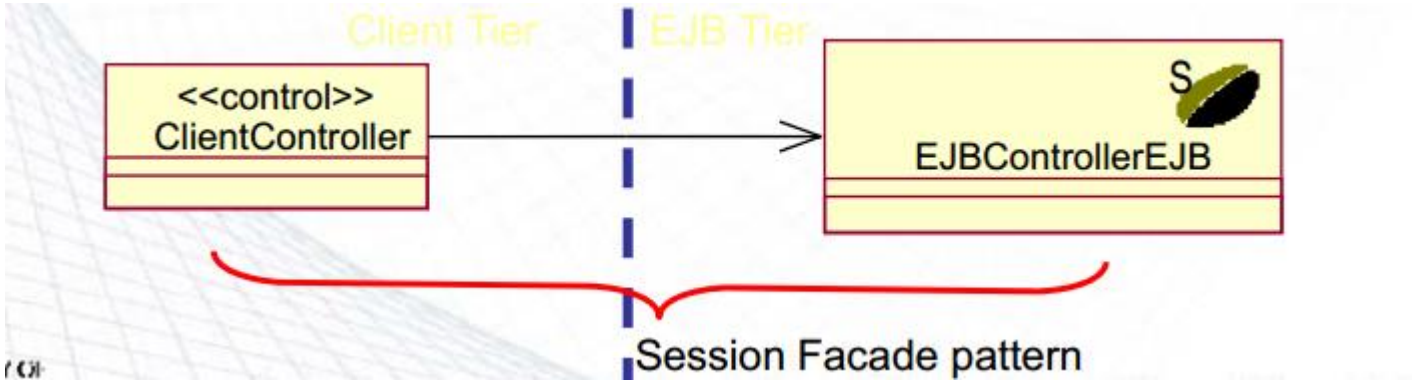
Expansion: Control Classes

- In a Web application, control classes become use-case dispatchers, which are composed of three elements: a front controller (Servlet or JSP), Web controller, and EJB controller (Session bean).



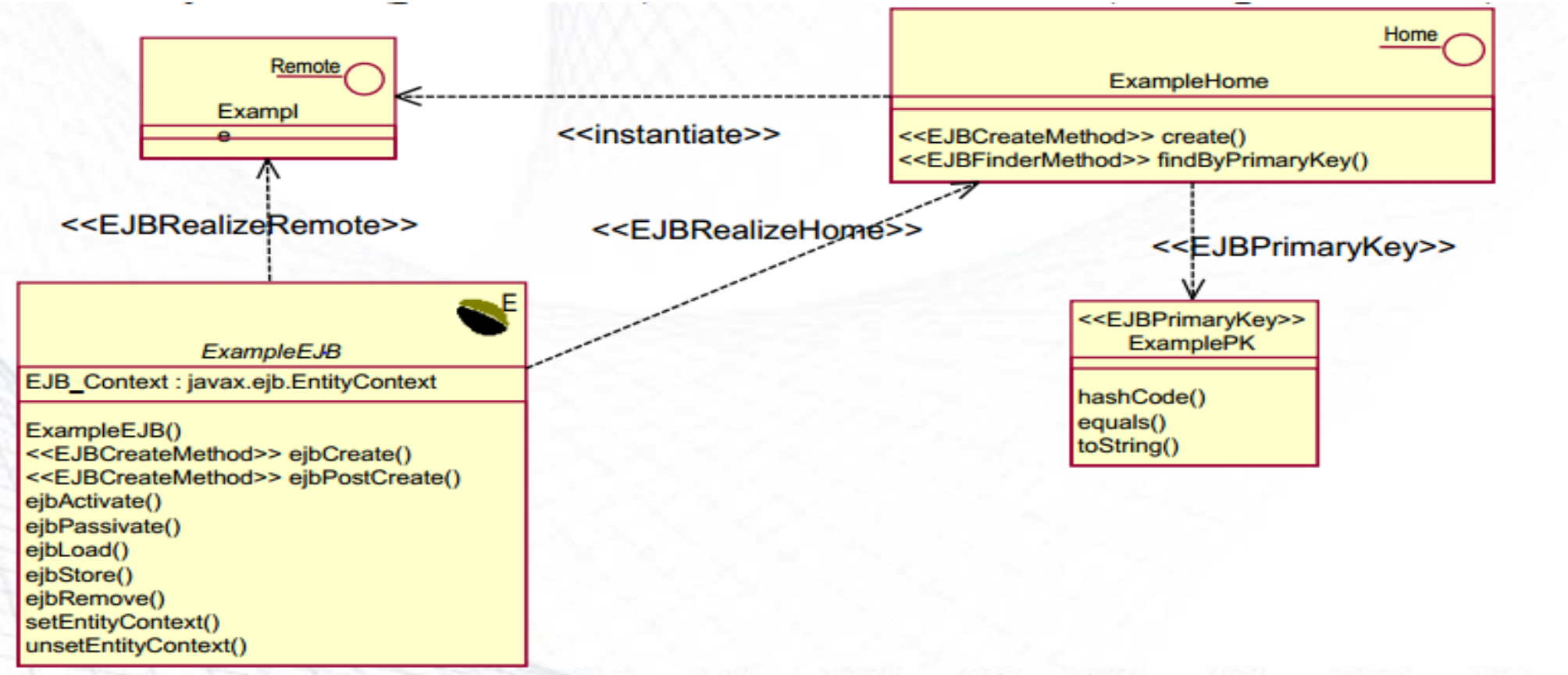
Expansion: Control Classes (cont.)

- In a GUI environment, control classes become use-case dispatchers which are composed of two elements: a client controller and EJB controller (Session bean).
- The client controller acts as a proxy for the EJB controller and is responsible for forwarding events from the boundary class to the EJB controller.
- An EJB controller accepts the events and makes calls on the enterprise beans affected by the event.



Expansion: Entity Classes

- Each entity p class becomes an enterprise bean:
  - ➢Entity bean (persistent) or session bean (non-persistent)



Expansion Rate

- Typical expansion rate for converting analysis classes to design classes, using Java technology:
  - Boundary Class × 1 or 2
  - Control Class × 2 or 3
  - Entity Class × 4

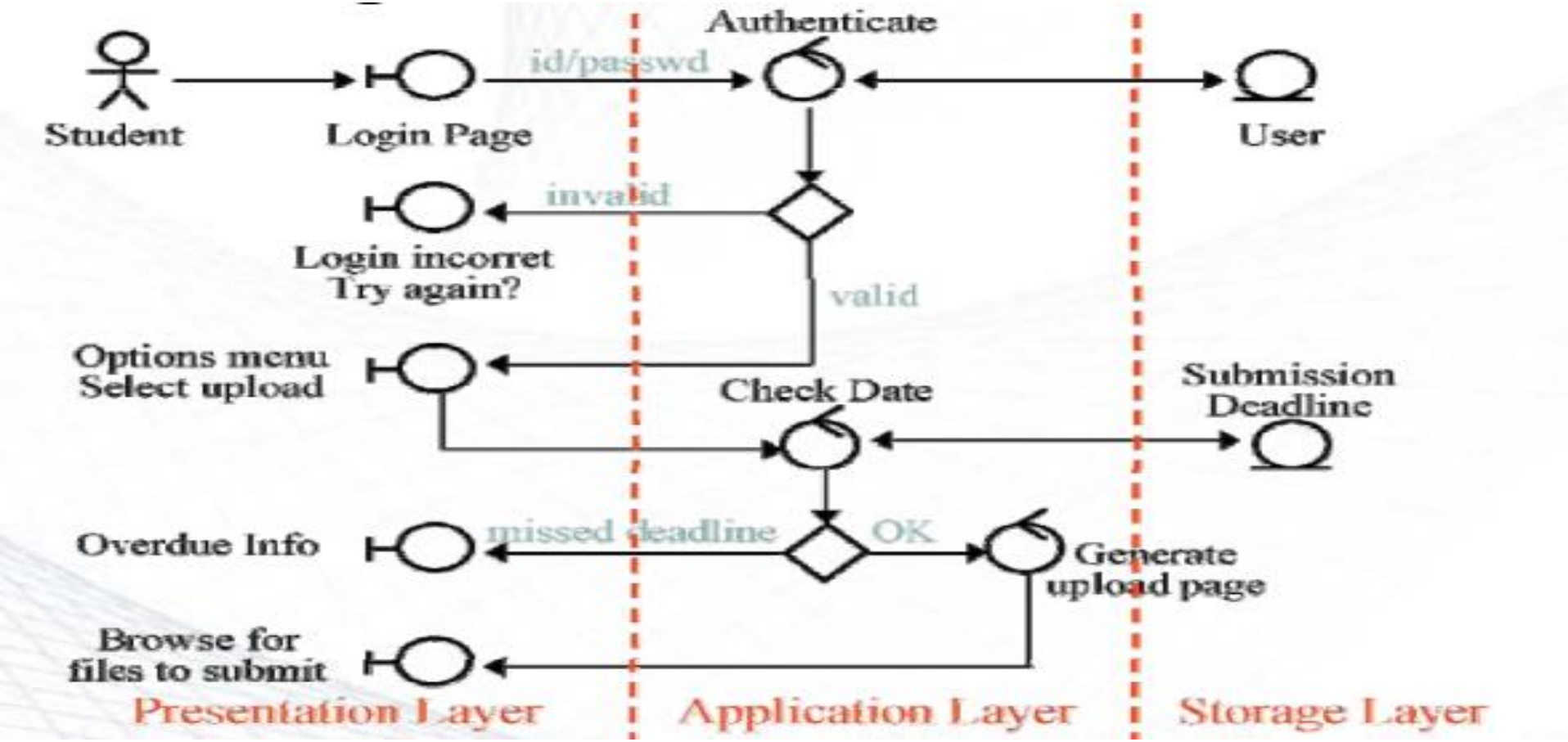
Example: #Design Classes

- The total estimated number of design classes are:

$$\#DC_b = 3 \times 2$$
$$\#DC_c = 2 \times 3$$
$$\#DC_e = 3 \times 4$$
$$Total = 24$$

Example

- The following figure depicts analysis class model for a search engine.



Example (cont.)

- The system will be implemented as a Web application using EJB technology. In the design phase, boundary classes are expanded by the ratio of 1 to 2; control classes are expanded by the ratio of 2 to 3, and each entity class is expanded to a subsystem having 4 to 8 design classes. A design class in Java on average has 20 methods, each method has 10 to 20 lines of code, and the productivity of an average Java programmer is 200 LOC per week for a salary of 5,000$ per month (4 weeks).
- Estimate the minimum and maximum for the
  - number of design classes; number of methods; total software size in LOC (assuming total size is 1.5 times methods LOC) and
  - total development cost.

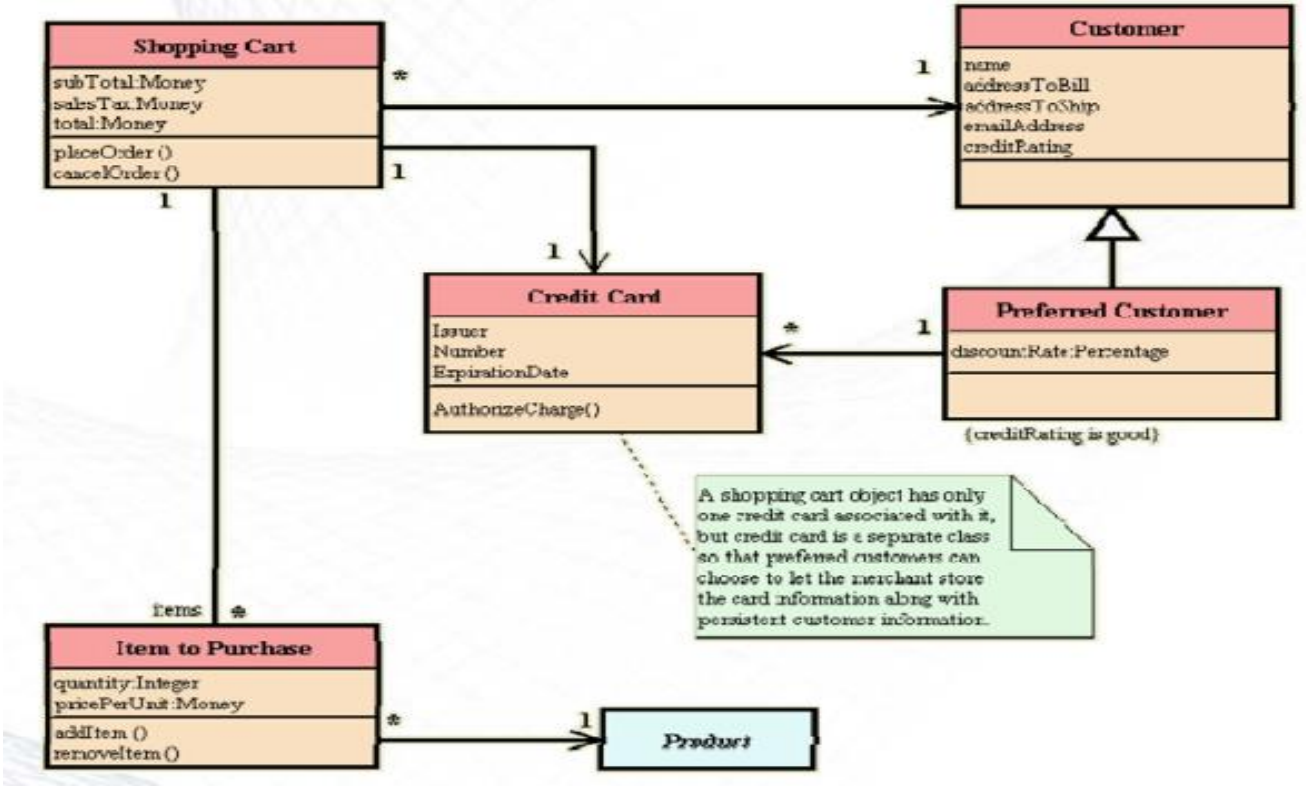
Example (cont.)

Analysis Classes	*No.*	*Total classes*	*Total methods*	*Total LOC*	*Development cost*
Boundary Class	**5**	**Min 19**	**Min 380**	**1.5 × 380 × 10 = 5,700 (minimum)**	**(5,700/200) × ($5,000/4)= 35,625$ (minimum)**
min (× 1)	**5**	**Max 35**	**Max 700**		
max (× 2)	**10**				
Control class	**3**			**1.5 × 380 × 20 = 11,400**	**(21,100/200) × ($5,000/4) = 131,875$ (maximum)**
min (× 2)	**6**				
max (× 3)	**9**				
Entity class	**2**			**1.5 × 700 × 10 = 10,500**	
min (× 4)	**8**				
max (× 8)	**16**			**1.5 × 700 × 20 = 21,100 (maximum)**	

Number of Classes (#c)

- **Measurement:** #c is the number of classes that make up a system.
- **Usage:** The number of design classes can be used to track the process of design. It ignores the association and aggregation among classes. Does not bear any structural meaning.

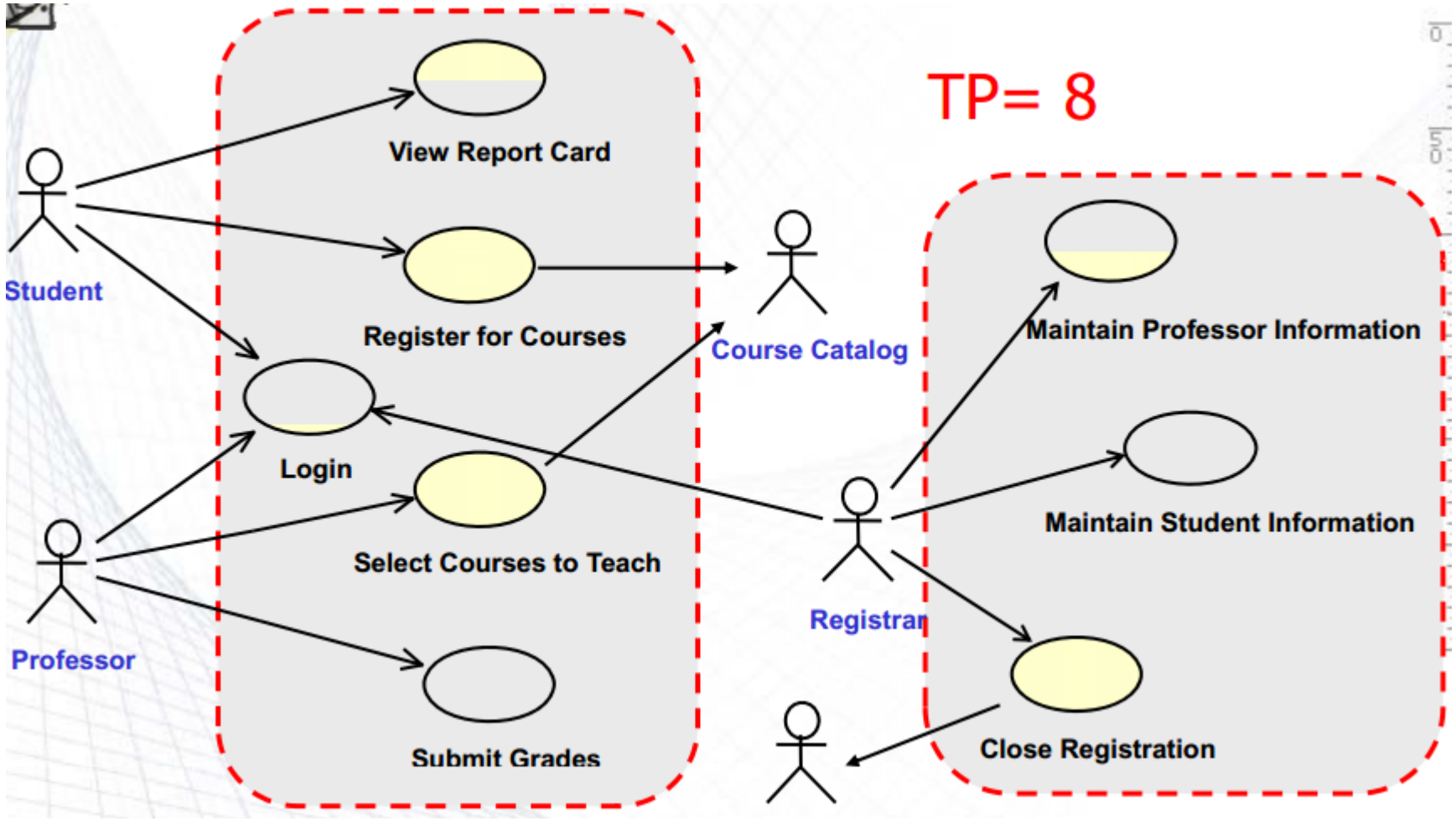
#C=5



Number of Atomic Scenarios (#TP)

- **Measurement:** Task Points are the simple count of the so called “atomic” task scripts (a more formal form of use cases) in an object-oriented analysis model.
- **Usage:** Task Points are suggested for tracking and estimating the overall software process. No empirical data has been reported on the practical use of it. Similar to #DC, it does not include any structural information about the system.

Example: #TP



Billing system

Number of Instance Methods (#im)

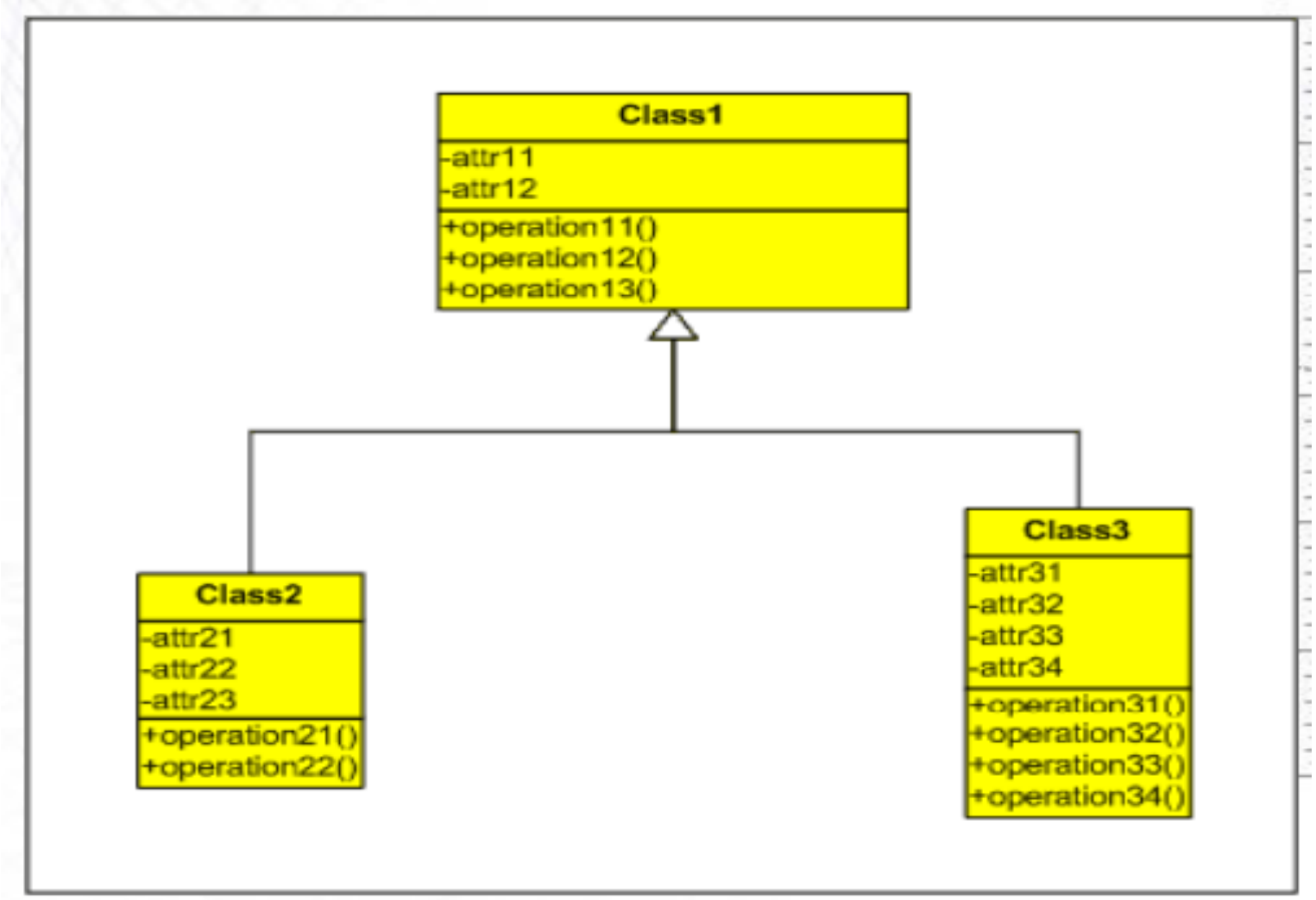
- **Measurement:** #im is the number of methods that siblings of a class can understand (regardless of eventual method access restrictions such as “private” or “protected”).
- **Usage:** Upper threshold value of 20 for #im may be used to indicate alarm for individual classes. Use the thresholds only for non-interface and non-generated classes. Interface classes, usually require higher thresholds (e.g., upper threshold of 40 for individual GUI-classes). A system-wide summation of all #im values can be used as a measure of design size (and be used for tracking the technical design process).

Number of Class Methods (#cm)

- **Measurement:** #cm the number of methods that a class can understand (regardless of eventual method access restrictions such as “private” or “protected”).
- **Usage:** Upper threshold value of 3 for #cm may be used to indicate alarm for individual classes. A system-wide summation of all #cm values can be used as a measure of design size (and be used for tracking the technical design process).

Example: #im and #cm

- For Class1
  #cm= 3
- For Class3
  #im= 7

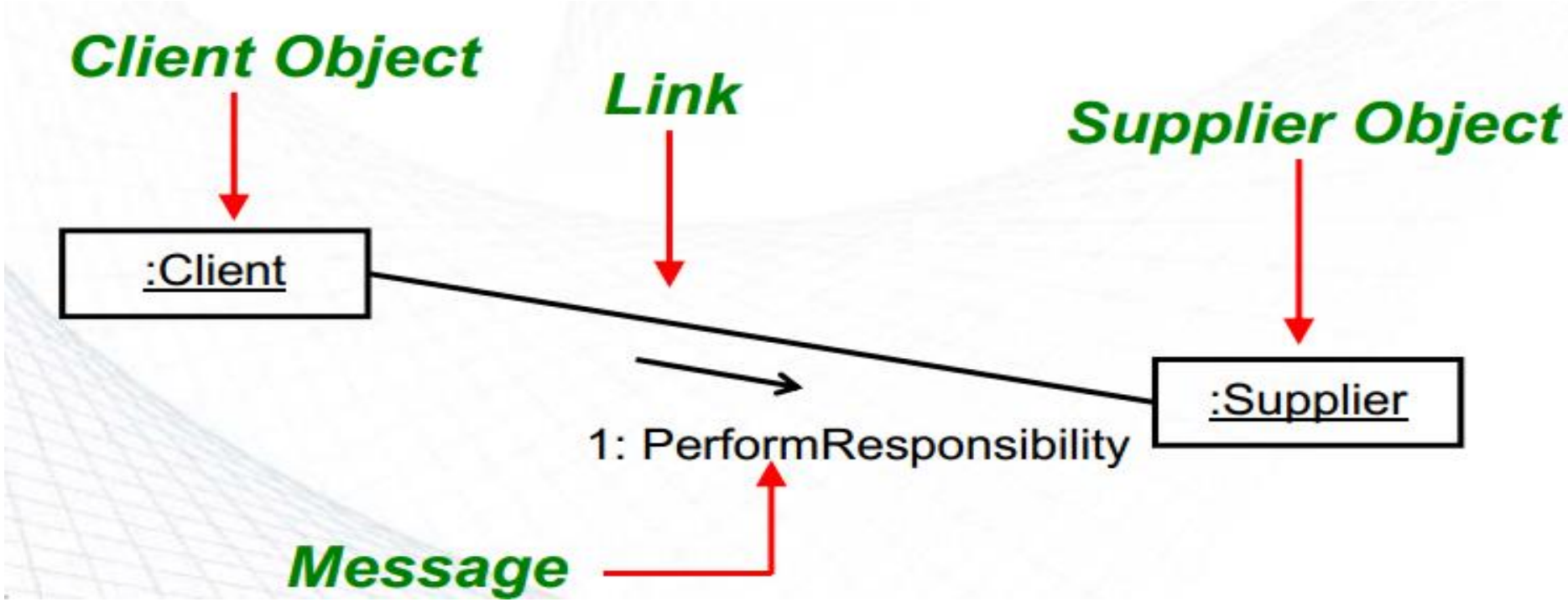


Coupling

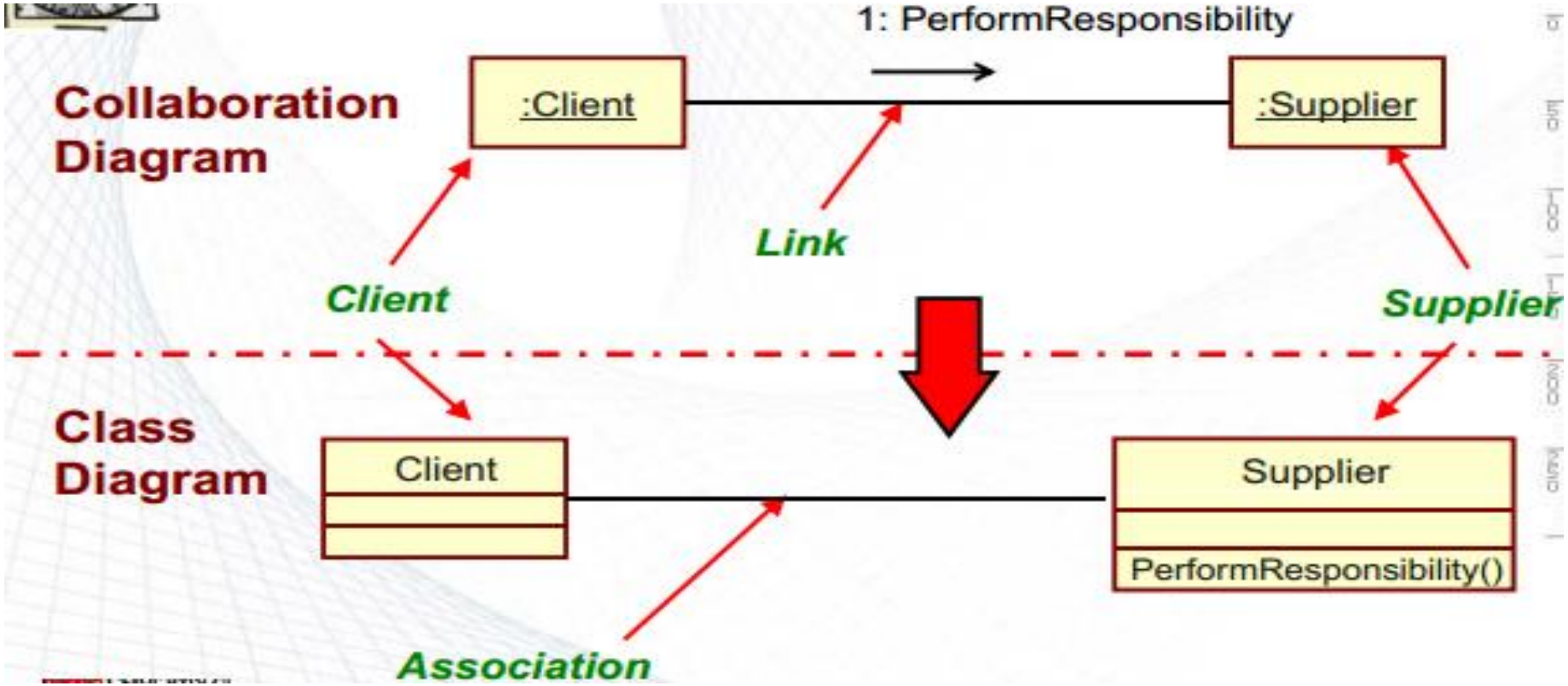
- Coupling describes how strongly one element (class / package) relates to another element
- The goal is to achieve “loose coupling”
- **Coupling between objects** is a count of the number of “links” between them.
- **Coupling between classes** (CBO) is a count of the number of other classes to which a class is related. It is measured by counting the number of distinct “associations” with the other classes.
- **Coupling between Packages** is a count of the number of distinct “associations” between packages.

What are Links and Associations?

- An object is an instance of a class
- In the same way, a “link” is an instance of an “association”

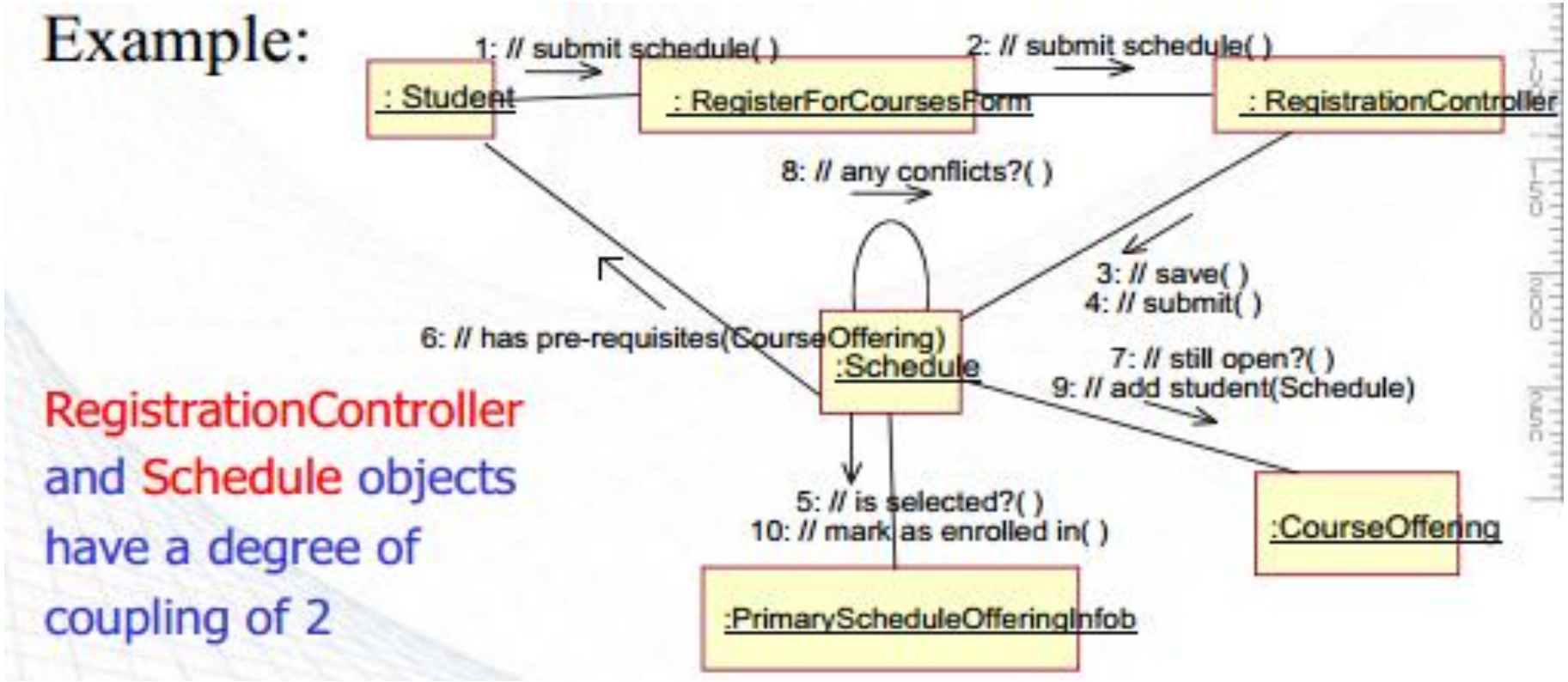


What are Links and Associations (cont.)



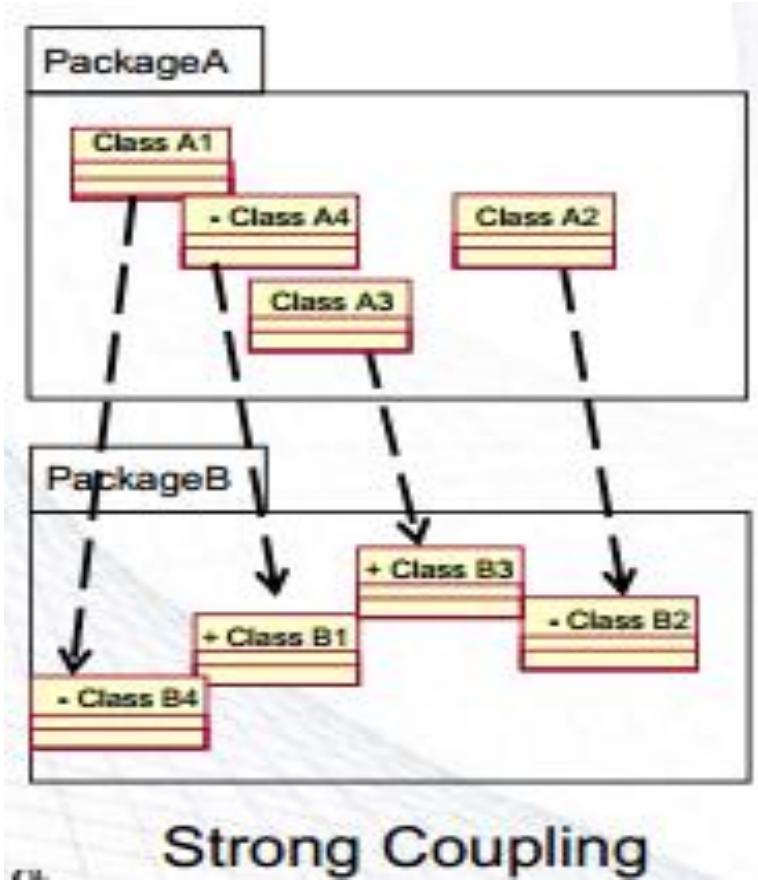
Coupling: How to Measure?

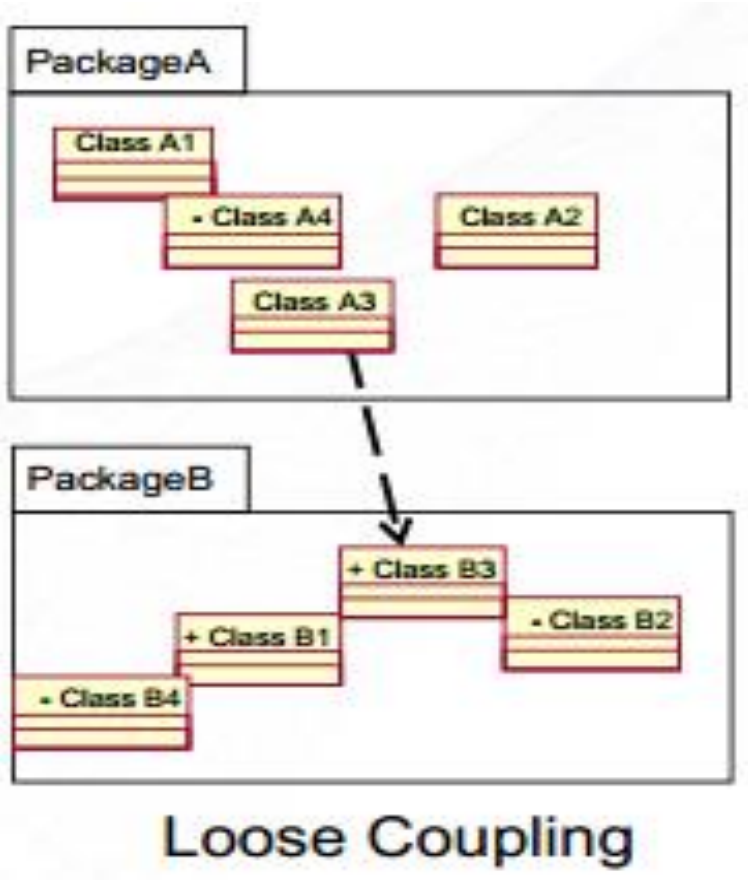
- Both collaboration and class diagrams can be used to measure coupling



Package Coupling: Class Relationships

- Strive for the loosest coupling possible

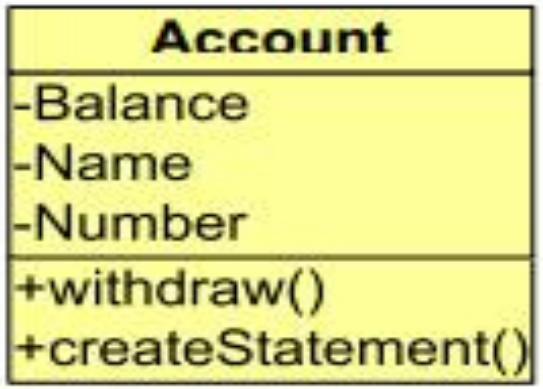




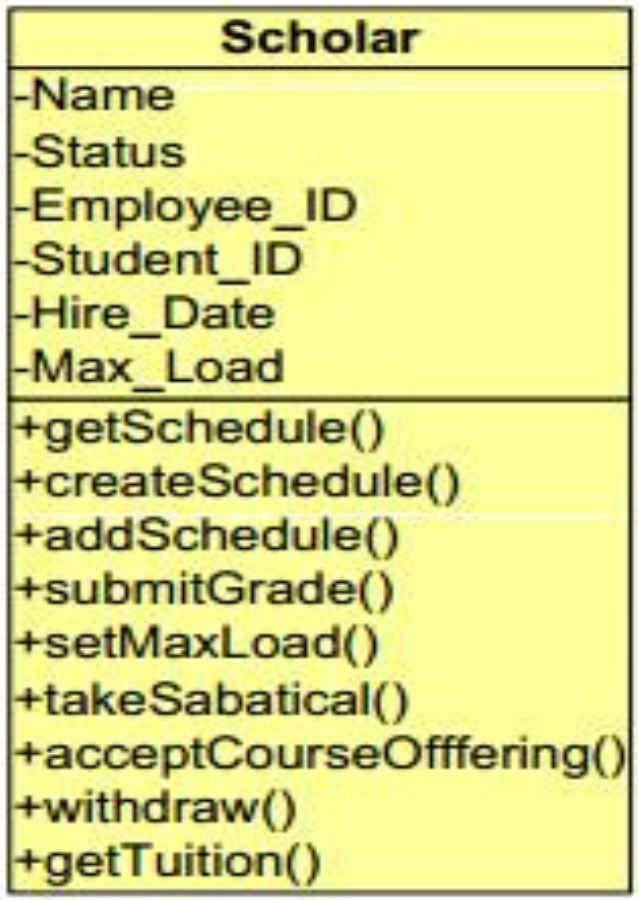
Cohesion

- Cohesion describes how strongly related the responsibilities between design elements can be described
  - ➢The goal is to achieve “high cohesion”
    - ✓High cohesion between classes is when class responsibilities are highly related
- **How to Measure?**
  - ➢Find “similarities” and “dissimilarities” between operations (methods) in a class.
  - ➢Remember a “link” will eventually be translated into an “operation.”
  - ➢What diagrams can be used?
    - ✓Class diagrams

Example: Cohesion



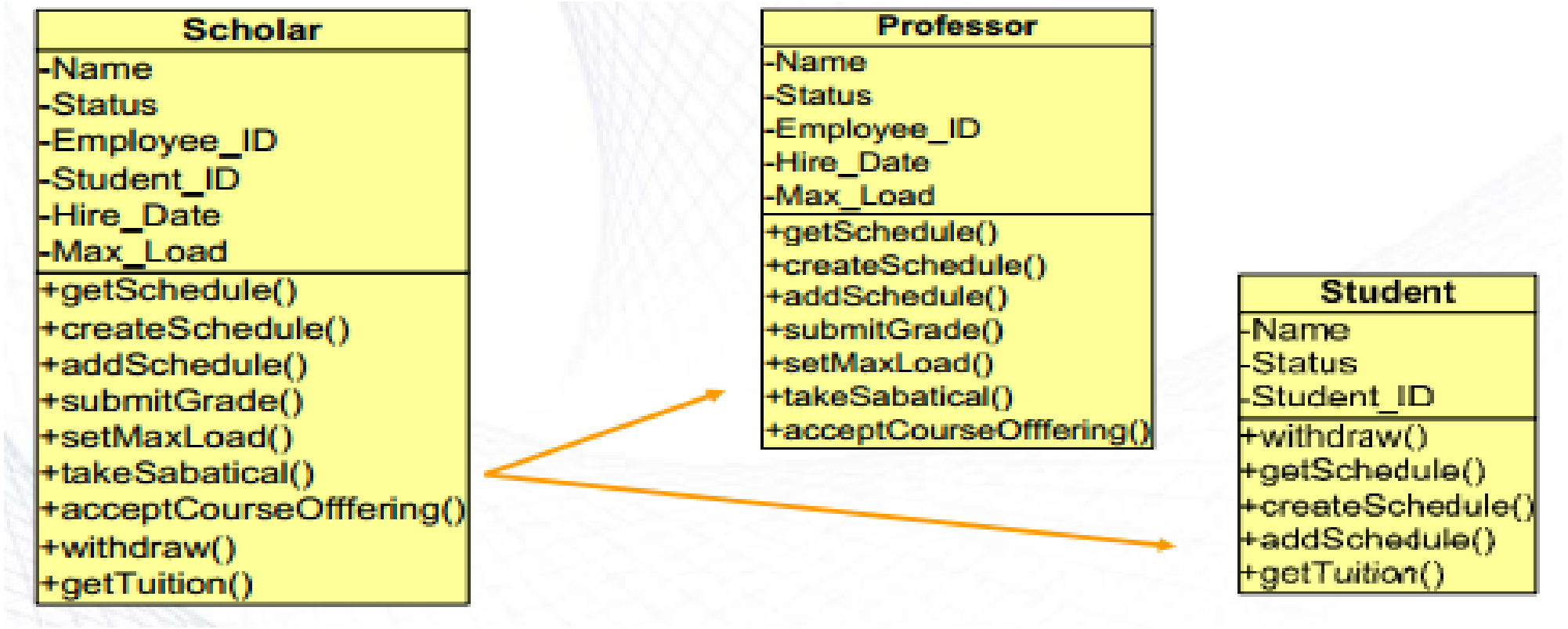
Good class cohesion



Bad class cohesion

Example: Cohesion (cont.)

Cohesion can help split and merge the classes



Other OO Metrics

- **Size: Lines of Code (LOC)**
  - Project LOC= Import 's + Classes LOC
  - Class LOC= Class Declaration + Variable Declarations + Methods LOC + Inner (sub) Classes LOC
  - Method LOC= Method Declaration + Local Variable Declarations + Statements
- **Average Methods Per Class**
  - The number of methods and the complexity of methods involved is an indicator of how much time and effort is required to develop and maintain a class.
  - The larger the number of methods in a class the greater the potential impact on children, since children will inherit all the methods defined in the class.
  - Classes with large numbers of methods are likely to be more application specific, limiting the possibility of reuse.

$$\text{Average no. of Methods per Class} = \frac{\text{Total no. of methods}}{\text{Total no. of classes}}$$

Other OO Metrics (cont.)

- **Depth of Inheritance Tree**

➢ The deeper a class in the hierarchy, the greater the number of methods it is likely to inherit, hence, more complex behavior.

➢ Deeper trees constitute greater design complexity, since more methods and classes are involved.

➢ The deeper a particular class is in the hierarchy, the greater the potential reuse of inherited methods.

$$\text{Inheritance Tree Depth} = Max\{\text{Inheritance Tree Path Length}\}$$

- **Number of Used Methods**

➢ If a large number of methods can be invoked in response to a message, the testing and debugging of the class becomes more complicated since it requires a greater level of understanding required on the part of the tester.

➢ The larger the number of methods that can be invoked from a class the greater the complexity of , the greater the complexity of the class.

Other OO Metrics (cont.)

- **Object Library Effectiveness**

- If objects are actually being designed to be reusable beyond a single application, then the effects should appear in object library usage statistics.

$$\text{Average Number of Times a Library Object is Reused} = \frac{\text{Total Number of Object Reused}}{\text{Total Number of Library Objects}}$$

- **Degree of Reuse of Inheritance Methods**

➢ Simply defining methods in such a way that they can be reused via inheritance does not guarantee that those methods are actually reused.

➢ Percent of Potential Method Uses Actually Reused (PP):

$$PP = \frac{\text{Total no. of Actual Method Uses}}{\text{Total no. of Potential Method Uses}}$$

➢ Percent of Potential Method Uses Overridden (PM):

$$PM = \frac{\text{Total Number of Methods Overridden}}{\text{Total no. of Potential Method Uses}}$$

Other OO Metrics (cont.)

- **Average Method Complexity**
  - More complex methods are likely to be more difficult to maintain.
  - Greater method complexity is likely to lead to a lower degree of overall application comprehensibility.
  - Greater method complexity is likely to adversely affect application reliability.
  - More complex methods are likely to be more difficult to test.

$$\text{Average Method Complexity} = \frac{\sum V(G)}{\text{Total no. of application Methods}}$$

$$V(G) = e - n + 2$$

Other OO Metrics (cont.)

- **Application Granularity**

➢ An application constructed with more finely granular objects (i.e. a lower number of functions per object) is likely to be more easily maintained because objects should be smaller and less complex.

➢ More finely granular objects should also be more reusable.

$$\text{Application Granularity} = \frac{\text{Total Number of Objects}}{\text{Total Function Points}}$$

Other OO Metrics (cont.)

- **MOOD: Metrics for Object Oriented Design Toolkit**

➢ The MOOD metrics set refers to a basic structural mechanism for the OO measurement.

➢ The set includes:

- ✓ *Encapsulation* (MHF d AHF) and AHF)
- ✓ *Inheritance* (MIF and AIF)
- ✓ *Polymorphism* (PF)
- ✓ *Message-passing* (CF)

- Method Hiding Factor (MHF)

- MHF is defined as the ratio of the sum of the invisibilities of all methods defined in all classes to the total number of methods defined in the system under consideration.

- The invisibility of a od is not visible.

$$MHF = \frac{\sum_{i=1}^{TC}\sum_{m=1}^{M_d(C_i)}\left(1 - V(M_{mi})\right)}{\sum_{i=1}^{TC} M_d(C_i)} \qquad V(M_{mi}) = \frac{\sum_{j=1}^{TC} is\_visible(M_{mi}, C_j)}{TC - 1}$$

$$is\_visible(M_{mi}, C_j) = \begin{cases} 1 & iff \quad j \neq i \wedge C_j \text{ may call } M_{mi} \\ 0 & otherwise \end{cases}$$

- $M_d(C_i)$ is the number of methods declared in a class.

- TC is the total number of classes.

- Attribute Hiding Factor (AHF)

- AHF is defined as the ratio of the sum of the invisibilities of all attributes defined in all classes to the total number of attributes defined in the system.
- $A_d(C_i)$ is the number of attributes declared in a class.
- TC is the total number of classes.

$$AHF = \frac{\sum_{i=1}^{TC}\sum_{a=1}^{A_d(C_i)}\left(1 - V(A_{ai})\right)}{\sum_{i=1}^{TC} A_d(C_i)} \qquad V(A_{ai}) = \frac{\sum_{j=1}^{TC} is\_visible(A_{ai}, C_j)}{TC - 1}$$

$$is\_visible(A_{ai}, C_j) = \begin{cases} 1 & iff \quad j \neq i \wedge C_j \ may \ access \ A_{ai} \\ 0 & otherwise \end{cases}$$

- Method Inheritance Factor (MIF)

➢ MIF is defined as the ratio of the sum of the inherited methods in all classes of the system under consideration to the total number of available methods (locally defined plus inherited) for all classes.

$$MIF = \frac{\sum_{i=1}^{TC} M_i(C_i)}{\sum_{i=1}^{TC} M_a(C_i)} \qquad M_a(C_i) = M_d(C_i) + M_i(C_i)$$

$M_d(C_i)$: number of methods declared in a class

$M_a(C_i)$: number of methods invoked in association with C_i

$M_i(C_i)$: number of methods inherited (not overridden) in C_i

- # Attribute Inheritance Factor (AIF)

➢ AIF is defined as the ratio of the sum of inherited attributes in all classes of the system under consideration to the total number of available attributes (locally defined plus inherited) for all classes.

$$AIF = \frac{\sum_{i=1}^{TC} A_i(C_i)}{\sum_{i=1}^{TC} A_a(C_i)} \qquad A_a(C_i) = A_d(C_i) + A_i(C_i)$$

$A_d(C_i)$: number of attributes declared in a class

$A_a(C_i)$: number of attributes accessed in association with C_i

$A_i(C_i)$: number of attributes inherited in C_i

- # Polymorphism Factor (PF)

➢ PF is defined as the ratio of the actual number of possible different polymorphic situation for class C_i to the maximum number of possible distinct polymorphic situations for class C_i.

$$PF = \frac{\sum_{i=1}^{TC} M_o(C_i)}{\sum_{i=1}^{TC} [M_n(C_i) \times DC(C_i)]} \qquad M_d(C_i) = M_n(C_i) + M_o(C_i)$$

$M_n(C_i)$: number of new methods declared in a class

$M_o(C_i)$: number of overriding methods

$DC(C_i)$: number of classes descending from C_i

- # Coupling Factor (CF)

➢ CF is defined as the ratio of the maximum possible number of couplings in the system to the actual number of couplings not imputable to inheritance.

$$CF = \frac{\sum_{i=1}^{TC}\left[\sum_{j=1}^{TC} is\_client\left(C_i, C_j\right)\right]}{TC^2 - TC}$$

$$is\_client\left(C_i, C_j\right) = \begin{cases} 1 & iff \;\; C_c \Rightarrow C_s \;\wedge\; C_c \neq C_s \\ 0 & otherwise \end{cases}$$

$C_c \Rightarrow C_s$ is relationship between client class (C) and supplier class (S).

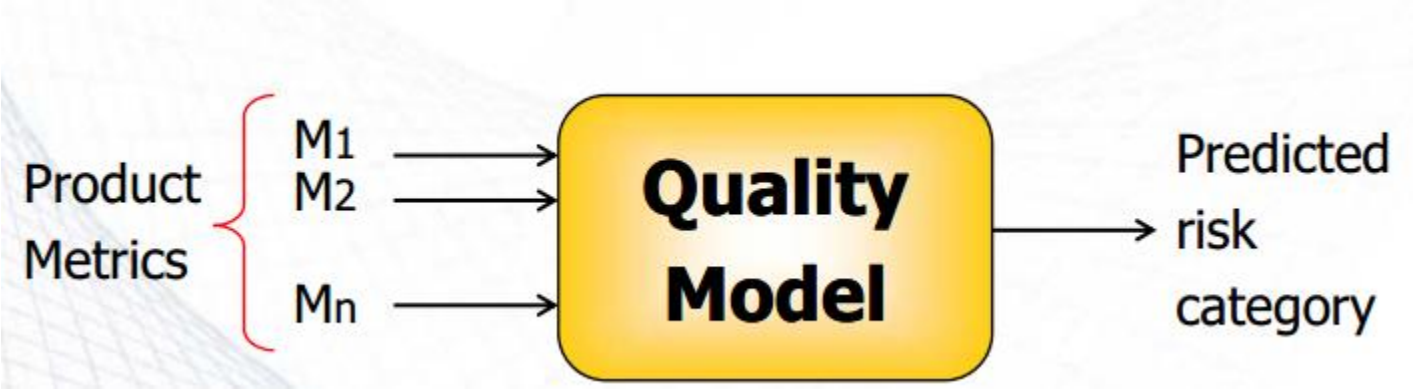
OO Metrics: Quality and Risk Metrics for OO Software

High Risk Components Identification

- Empirical studies show that most faults are found in only a few of a system's components. If these few components can be identified early, then actions such as focusing defect detection activities on high-risk component b s can be taken.
- How to identify high-risk components?
  1. Devise quality models
  2. Define practical thresholds

Object-Oriented Quality Models

- A quality model is usually developed using a statistical modeling or machine learning technique, or a combination of the two techniques, using historical data.



OO Quality Models: Example

Probability of a Class Having a Fault

$$p = \frac{1}{1 + e^{-(-3.97 + 0.464\,NAI + 1.47\,OCMEC + 1.06\,DIT)}}$$

- P is a probability of class having a fault
- NAI is the total number of attributes defined in the class
- OCMEC is the number of other classes that have methods with parameter types of this class (i.e., a form of export coupling)
- DIT is the depth of the inheritance tree which measures how far down an inheritance hierarchy a class is.
- If the predicted probability of a fault is greater than 0.33, then the class should be considered as high risk)!

2. Object-Oriented Thresholds

- What is threshold?
- The range of values on the software product metrics that delineate between acceptable and unacceptable values.
- The practical utility of object-oriented metrics would be enhanced if meaningful thresholds could be identified.
- Example: The average number of attributes (public or private variables) per class should be less than 6. More attributes indicate that the classes are doing more than they should.

Experience-Based Size Threshold

- The average method size should be less than 8 LOC for Smalltalk and 24 LOC for C++. Bigger averages indicate OO design problems (i.e., function-oriented coding).
- The average number of methods per class should be less than 20. Bigger averages indicate too much responsibility in too few classes.
- The average number of attributes (public or private variables) per class should be less than 6. More attributes indicate that one class is doing more than it should.

Experience-Based Inheritance Threshold

- The class hierarchy nesting level should be less than 6. Start counting at the level of any framework classes that you use or the root class if you don’t.

Experience-Based Coupling Threshold

- The number of package-to-package relationships should be less than the average number of class-to-class relationships within a package.
- The number of class-to-class relationships within a package should be relatively high.
- Coupling between objects (CBO) is a useful indicator of fault-prone classes.

Experience-Based Effort Threshold

1. A prototype class has 10 to 15 methods, each with 5 to 10 lines of code (in Java), and takes 1 person week to develop.

2. A production class has 20 to absolute maximum of 30 methods, each with 10 to 20 lines of code, and takes 8 person-weeks to develop. In both these cases, development includes documentation and testing.

3. The number of classes and methods thrown away should occur at a steady rate throughout most of the development process