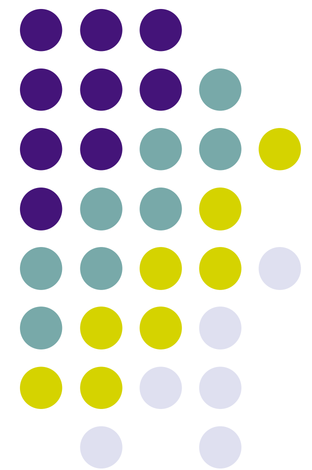
Object Oriented Design

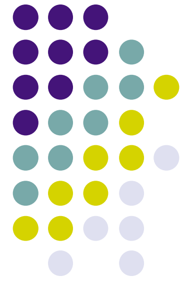
Kenneth M. Anderson

Lecture 20

CSCI 5828: Foundations of Software Engineering

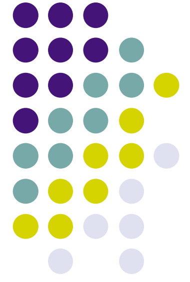


Object-Oriented Design



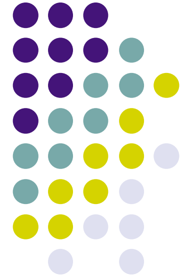
- Traditional procedural systems separate data and procedures, and model these separately
- Object orientation combines data and methods together into a cohesive whole
  - data abstraction
- The purpose of Object-Oriented (OO) design is to define the classes (and their relationships) that are needed to build a system that meets the requirements contained in the SRS

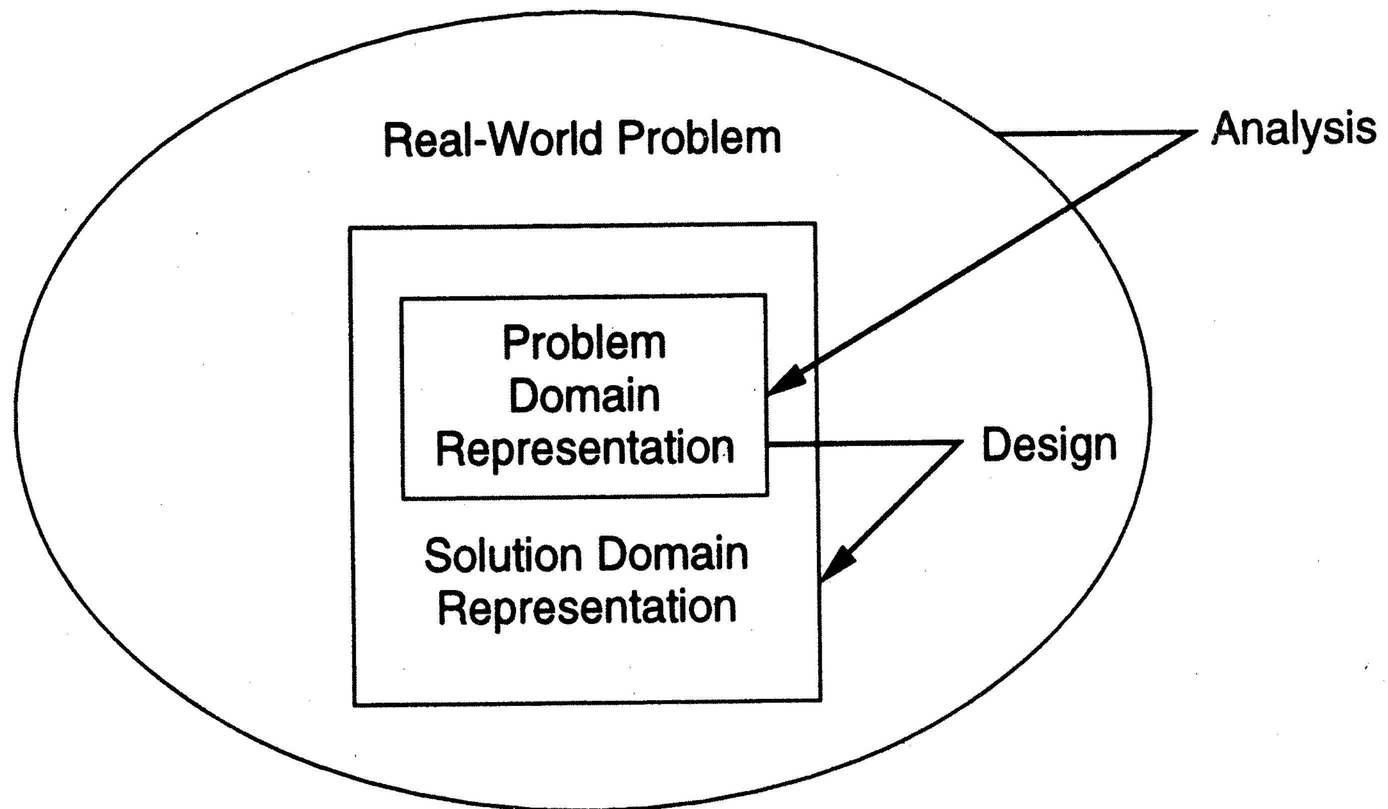
OO A&D

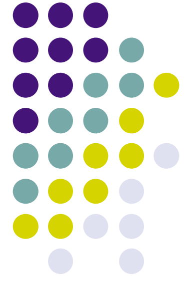


- OO techniques can be used in analysis (requirements) as well as design
  - The methods and notations are similar
- In OO analysis we model the problem domain, while in OO design we model the solution domain
- Often structures created during OO analysis are subsumed (reused, extended) in the structures produced by OO design
  - The line between OO analysis and OO design is blurry, as analysis structures will transition into model elements of the target system

Relationship of OO A&D



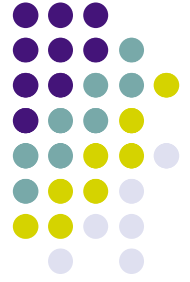




OO Concepts

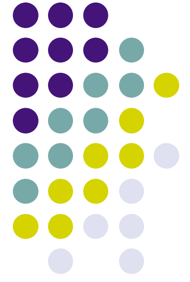
- Encapsulation
  - grouping of related ideas into one unit which we can refer to by a single name
  - For example, methods, classes, packages
- Provides information hiding by restricting the external visibility of a unit's information
- In OO A&D, the object is the unit of encapsulation
  - An object's data is hidden behind the public interface (methods) of the object

OO Concepts…



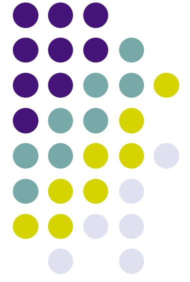
- State Retention
  - the functions of function-oriented design do not retain state; an object, on the other hand, is aware of its past and maintains state across method invocations
- Identity – each object can be identified and treated as a distinct entity
  - very important issue, see lecture 10
- Behavior – state and methods together define the behavior of an object, or how an object responds to the messages passed to it

OO Concepts..



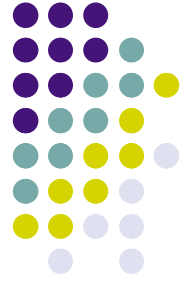
- Classes – a class is a stencil from which objects are created; defines the structure and services of a "class" of objects. A class has
  - An interface which defines which parts of an object can be accessed from outside
  - A body that implements the operations
  - Instance variables to hold object state
- Objects and classes are different; a class is a type, an object is an instance
  - State and identity is associated with objects

OO Concepts – access



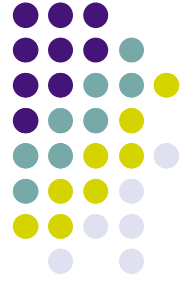
- Operations in a class can be
  - Public: accessible from outside
  - Private: accessible only from within the class
  - Protected: accessible from within the class and from within subclasses

Inheritance



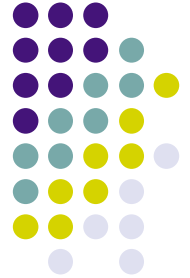
- Inheritance is unique to OO and not available in function-oriented languages/models
- If class B inherits information from class A, it implicitly acquires the attributes and methods of A
  - Attributes and methods of A are reused by B
- When B inherits from A, B is the subclass or derived class and A is the base class or superclass

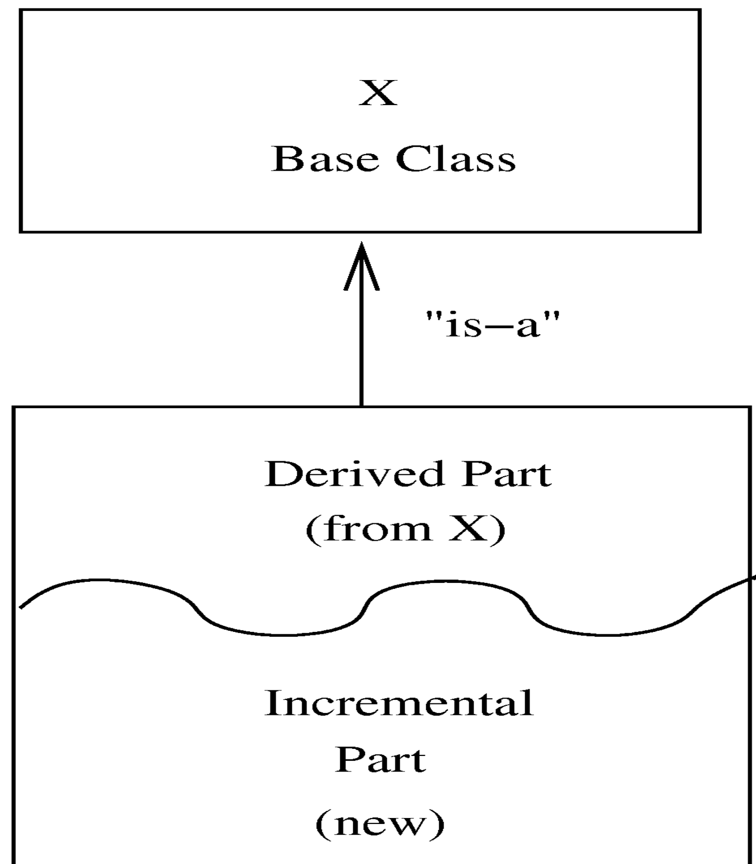
Inheritance..



- A subclass B generally has a derived part (inherited from A) as well as new attributes (new instance variables or methods)
  - B’s specification only defines the new attributes
- This creates an “is-a” relationship
  - objects of type B are also objects of type A

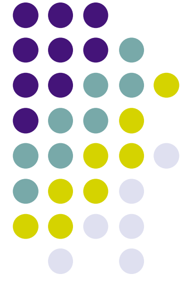
Inheritance…





Y – Derived class

Inheritance…



- The inheritance relationship between classes forms a class hierarchy
  - In models, hierarchy should represent the natural relationships present in the problem domain
  - In a hierarchy, all the common features of a set of objects can be accumulated in a superclass
- This relationship is also known as a generalization-specialization relationship
  - since subclasses specialize (or extend) the more generic information contained in the superclass

Graphical Object

color
draw–style

move()
roatate()
scale()
setColor()

ZeroAreaObject

NonZeroAreaObject

fillColor
fillStyle

Line

start
end

OpenCurve

Polygon

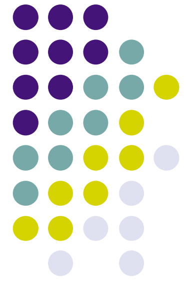
noOfsides
vertices []

area()

Circle

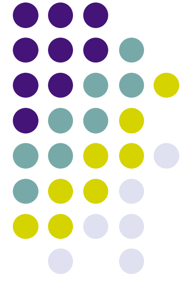
center
radius

Inheritance…



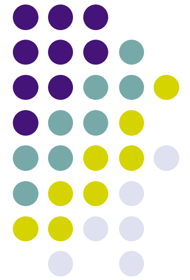
- There are several types of inheritance
  - Strict inheritance: a subclass uses all of the features of its parent class without modification
    - The subclass only adds new attributes or methods
  - Non-strict inheritance: a subclass may redefine features of the superclass or ignore features of the superclass
- Strict inheritance supports “is-a” cleanly and has fewer side effects
  - If a subclass redefines a method of the parent, it can potentially break the contract that the superclass offers its users

Inheritance…



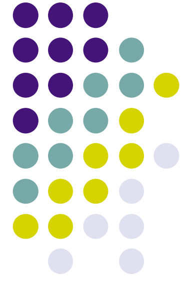
- Single inheritance – a subclass inherits from only one superclass
  - Class hierarchy is a tree
- Multiple inheritance – a class inherits from more than one class
  - Can cause runtime conflicts
  - Repeated inheritance - a class inherits from a class but from two separate paths

Inheritance and Polymorphism



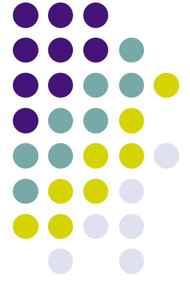
- Inheritance enables polymorphism, i.e. an object can be of different types
  - An object of type B is also an object of type A
- Hence an object has a static type and a dynamic type
  - Implications on type checking
  - Also brings dynamic binding of operations which allows writing of general code where operations do different things depending on the type

Module Level Concepts



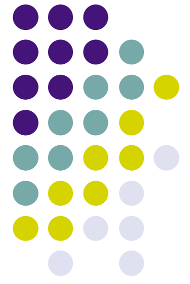
- Basic modules are classes
- During OO design, a key activity is to specify the classes in the system being built
- In creating our design, we want it to be "correct" (i.e. cover its requirements)
  - But a design should also be "good" – efficient, modifiable, stable, …
- We can evaluate an OO design using three concepts
  - coupling, cohesion, and open-closed principle

Coupling



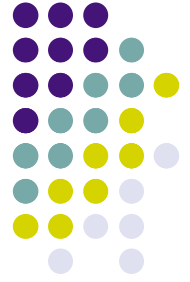
- In OO design, three types of coupling exists
  - interaction
  - component
  - inheritance

Coupling…



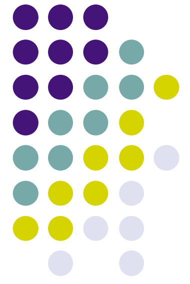
- Interaction coupling occurs when the methods of a class invoke methods of another class
  - this can't be avoided, obviously…
  - but we want to ensure that an object's public interface is used
    - a method of class A should NOT directly manipulate the attributes of another class B
    - Why?

Coupling…



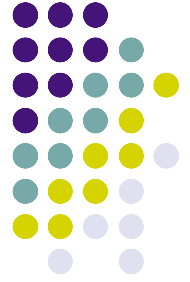
- Component coupling – when a class A has variables of another class C
  - A has instance variables of type C
  - A has a method with a parameter of type C
  - A has a method with a local variable of type C
- When A is coupled with C, it is coupled with all subclasses of C as well
  - Component coupling will generally imply the presence of interaction coupling also

Coupling…



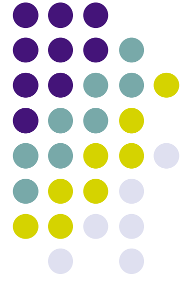
- Inheritance coupling – two classes are coupled if one is a subclass of the other
  - again, can't be avoided, inheritance is a useful and desirable feature of OO approaches
  - however, a subclass should strive to only add features (attributes, methods) to its superclass
    - as opposed to modifying the features it inherits from its superclass

Cohesion



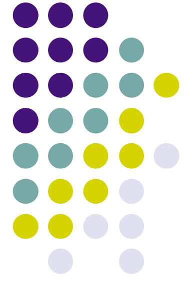
- Cohesion is an intramodule concept
- Focuses on why elements are together
  - Only elements tightly related should exist together in a module (class)
  - This gives a module a clear abstraction and makes it easier to understand
- Higher cohesion leads to lower coupling as many otherwise interacting elements are already contained in the module
- Goal is to have high cohesion in modules
- Three types of cohesion in OO design
  - method, class, and inheritance

Cohesion…



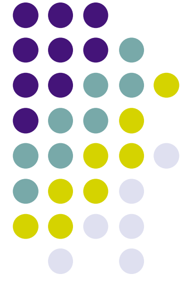
- Method cohesion
  - A class should attempt to have highly cohesive methods, in which all of the elements within a method body help to implement a clearly specified function
- Class cohesion
  - A class itself should be cohesive with each of its methods (and attributes) contributing to implement the class's clearly specified role

Cohesion…



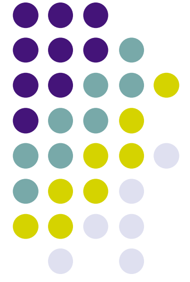
- Inheritance cohesion – focuses on why classes are together in a hierarchy
  - Two reasons for subclassing
    - generalization-specialization and reuse
    - The former occurs when the classes in the hierarchy are modeling true semantic (“is-a”) relationships found in the problem domain
    - The latter sometimes occurs when a pre-existing class does most of what you need but for a different part of the semantic space; the subclass may not participate in an “is-a” relationship; this should be avoided!

Open-closed Principle



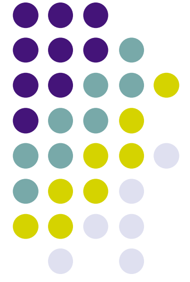
- Principle: Classes should be open for extension but closed for modification
  - Behavior can be extended to accommodate new requirements, but existing code is not modified
    - allows addition of code, but not modification of existing code
  - Minimizes risk of having existing functionality stop working due to changes – a very important consideration while changing code

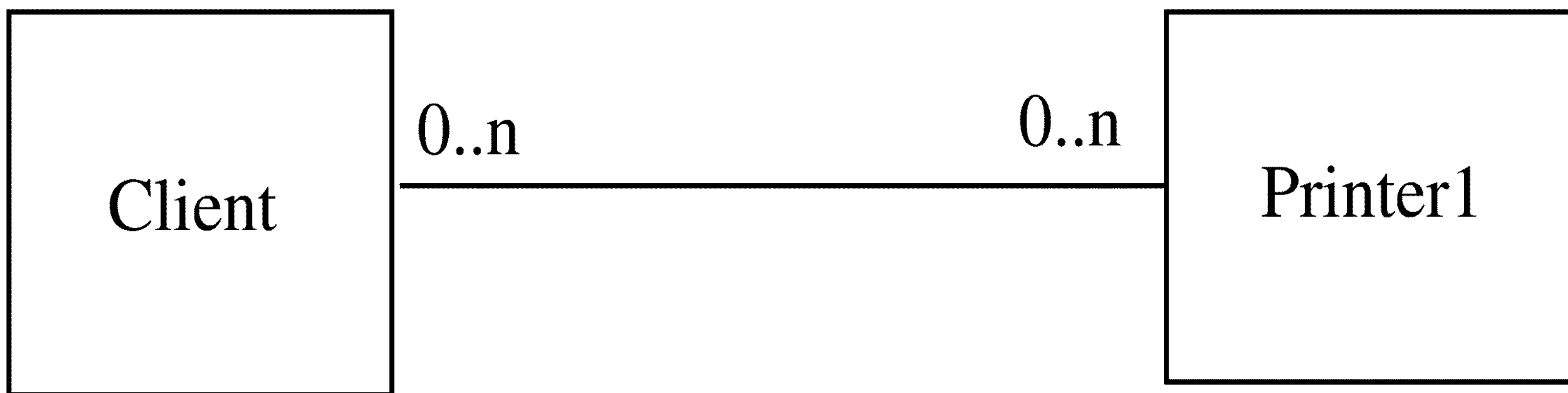
Open-closed Principle…



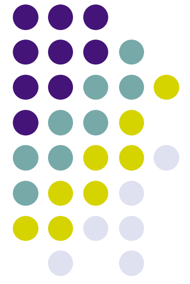
- In OO design, this principle is satisfied by using inheritance and polymorphism
  - Inheritance allows creating a new class to extend behavior without changing the original class
  - This can be used to support the open-closed principle
  - Consider example of a client object which interacts with a printer object for printing

Example



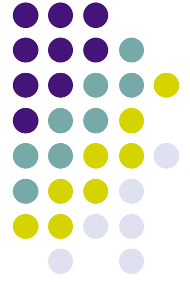


Example..



- Client directly calls methods on Printer1
- If another printer is required
  - A new class Printer2 will be created
  - But the client will have to be modified if it wants to use this new class
- Alternative approach
  - Have Printer1 be a subclass of an abstract base class called Printer
  - Client is coded to access a variable of type Printer, which is instantiated to be an instance of the Printer1 class
  - When Printer2 comes along, it is made a subclass of Printer as well, and the client can use it without modification

Example…

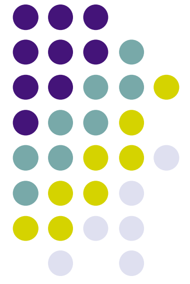


Client — 0..n — 0..n — Printer

Printer 1

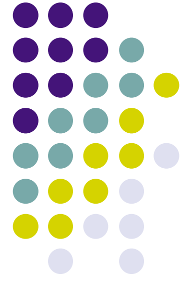
Printer 2

Liskov's Substitution Principle



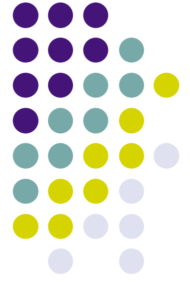
- Principle: A program using an object o1 of base class C should remain unchanged if o1 is replaced by an object of a subclass of C
  - The open-closed principle allows the creation of hierarchies that intrinsically support this principle

Unified Modeling Language (UML) and Modeling



- UML is a graphical design notation useful for OO analysis and design
  - Provides nine types of diagrams to model both static and dynamic aspects of a software system
- UML is used by various OO design methodologies to capture decisions about the structure of a system under design

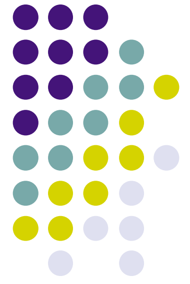
Modeling



- Modeling is used in many disciplines
- A model is a simplification of reality
  - “All models are wrong, some are useful”
- A good model includes those elements that have broad effect and omits minor elements
  - A model of a system is not the system!

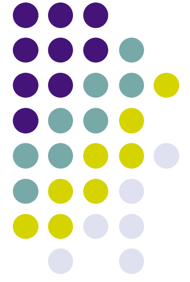
- We’ve covered models at the beginning of the semester in the concurrency textbook

Modeling



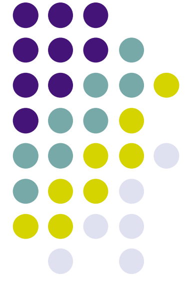
- UML is used to create models of OO systems
- It contains notations to model both structural and behavioral aspects of these systems
  - Structure-related notations
    - class, object, package, use case, component, and deployment diagrams
  - Behavior-related notations
    - structure, collaboration, state, and activity diagrams

Class Diagrams



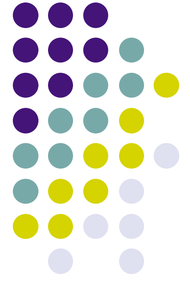
- The class diagram is a central piece of the design specification of an OO design. It specifies the
  - classes in a system
  - the associations between classes
    - including aggregation and composition relationships
  - the inheritance hierarchy
- We covered class diagrams back in lecture 10

Interaction Diagrams



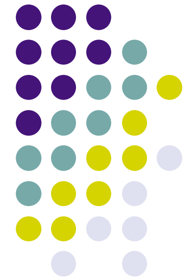
- Class diagrams represent static structures
  - They do not model the behavior of a system
- Interaction diagrams are used to provide insight into a system's dynamic behavior
  - Useful for showing, e.g., how the objects of a use case interact to achieve its functionality
  - Interaction is between objects, not classes
    - An object look likes a class, except its name is underlined
- Interaction diagrams come in two (mostly equivalent) styles
  - Collaboration diagram
  - Sequence diagram

Sequence Diagram



- Objects participating in an interaction are shown at the top
  - For each object a vertical bar represents its lifeline
  - A message from one object to another is represented as a labeled arrow
  - Messages can be guarded (similar to boolean guards in FSP)
- The ordering of messages is captured along a sequence diagram’s vertical axis

Example – sequence diag.



GradReport : GraduationReport

Student_obj : Student

Course_taken_obj : CourseTaken

Course_obj : Course

getStudentDetails()

getGrades()

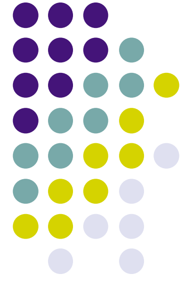
getCourseDetails()

ReturnDetails()

ReturnCourseDetails()

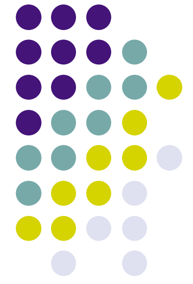
PrintReport()

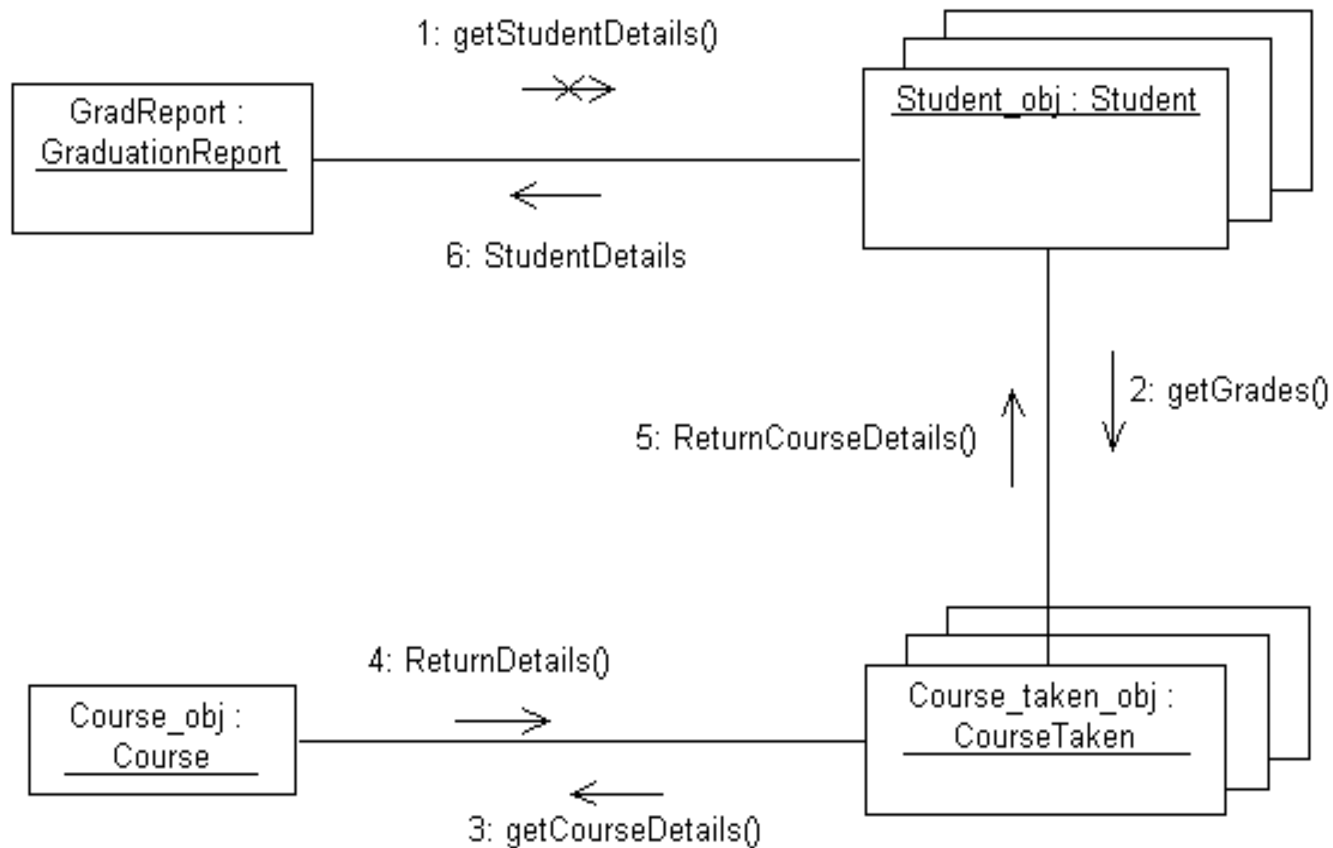
Collaboration diagram



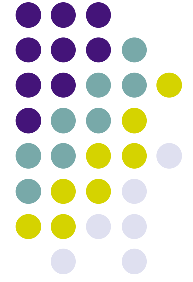
- Also shows how objects interact
- Instead of a timeline, the diagram shows the instantiation of associations between classes at run-time
  - The ordering of a set of messages is captured by numbering them

Example – collaboration diag

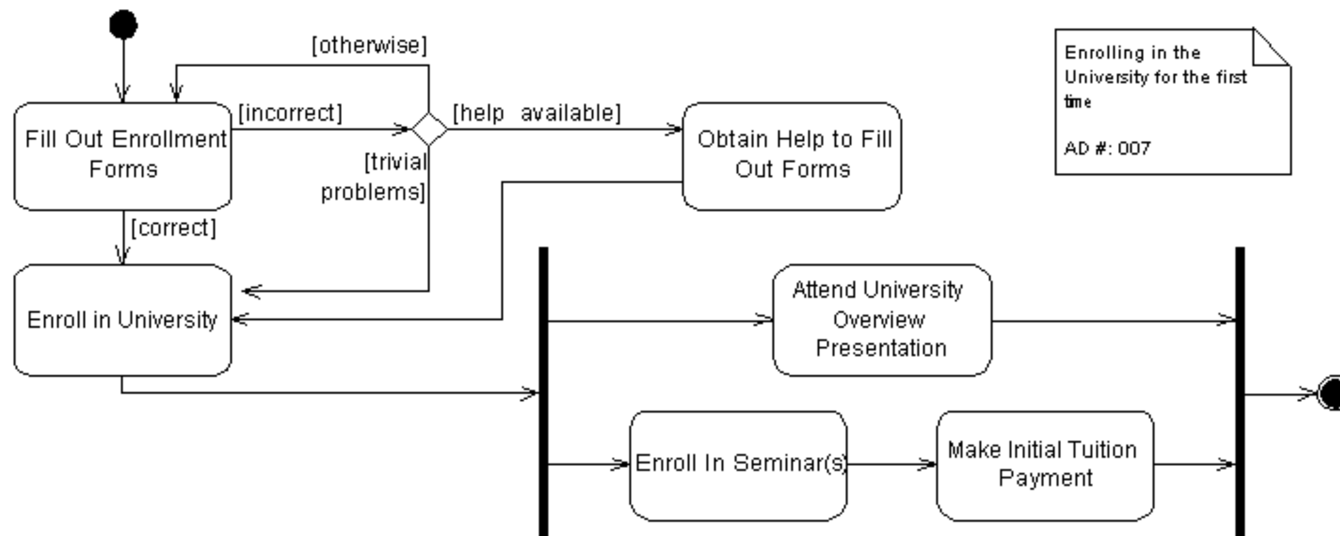




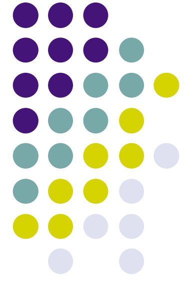
Other Diagrams



- State diagrams (Labeled Transition Systems)
- Activity diagrams (from Scott Ambler's website)

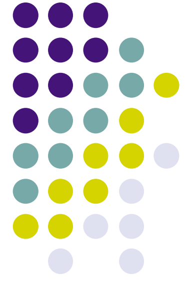


OO Design Methodologies

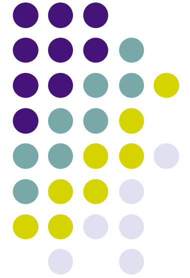


- Many OO A&D methodologies have been proposed
- Basic goal is to identify classes, understand their behavior, and relationships
  - Different UML models are used for this

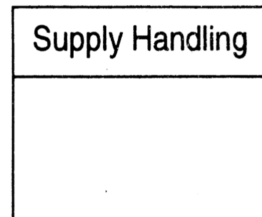
OO Design

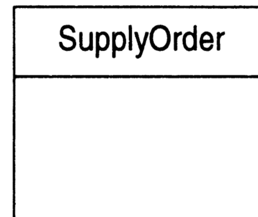


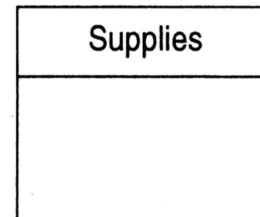
- Basic steps (note: different from text book)
  - Step 1: Analyze use cases
  - Step 2: Create activity diagrams for each use case
  - Step 3: Create class diagram based on 1 and 2
  - Step 4: Create interaction diagrams for activities contained in diagrams created in step 2
  - Step 5: Create state diagrams for classes created in step 3
  - Step 6: Iterate; each step above will reveal information about the other models that will need to be updated
    - for instance, services specified on objects in a sequence diagram, have to be added to those objects' classes in the class diagram

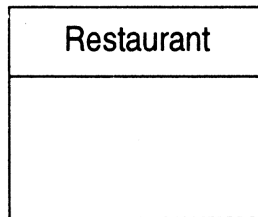


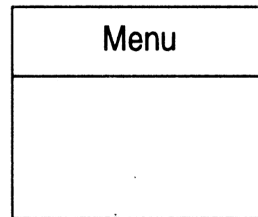
Restaurant example: Initial classes

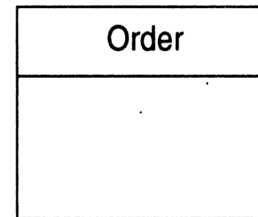


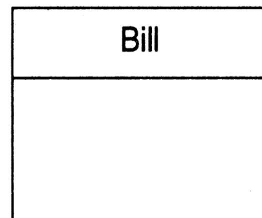


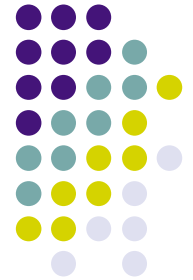












Supply Handling

CreditSupply ( )
DebitSupply ( )
PlaceOrder ( )
ProduceCheck ( )

SupplyOrder

ProduceCheck ( )

SupplyItem

Item Name
Unit Price

Quantity

Restaurant

SaleStat ( )
Descrepancy ( )

Menu

MenuItem

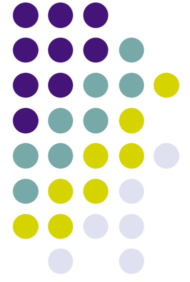
Item Name
Item Number
Price
Supplies Used

Order

ProduceBill ( )

Quantity

Note: this is not pure UML notation; see Lecture 10 for Additional details

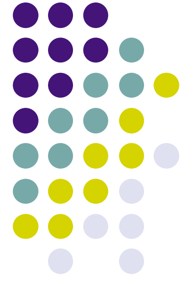


Restaurant example: sequence diagram

menu : Menu
customer : Customer
order : Order
bill : Bill
kitchen : Kitchen

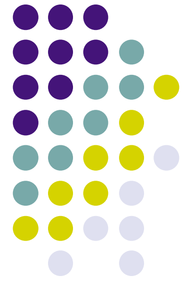
read
place order
prepare
dishes
serve
getBill
prepare
bill
bill
pay bill

Metrics



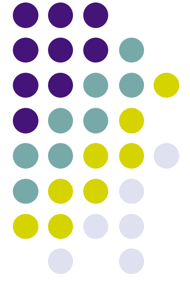
- OO metrics focus on identifying the complexity of classes in an OO design
  - Weighted Methods per Class
  - Depth of Inheritance Tree
  - Number of Children
  - Coupling Between Classes
  - Response for a Class
  - Lack of Cohesion in Methods

Weighted Methods Per Class



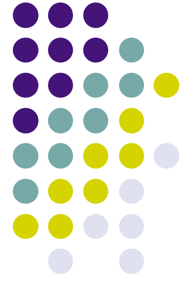
- The complexity of a class depends on the number of methods it has and the complexity of those methods
  - For a class with methods M_1, M_2, …, M_n, determine a complexity value for each method, c_1, c_2, …, c_n
    - using any metric that estimates complexity for functions (estimated size, interface complexity, data flow complexity, etc.)
  - WMC = Σc_i ; this metric has been shown to have a reasonable correlation with fault proneness

Metrics…



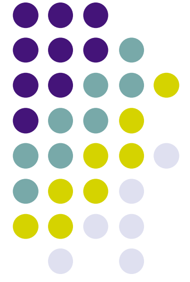
- Depth of Inheritance Tree
  - DIT of class C is depth from the root class
  - DIT is significant in predicting fault proneness
    - basic idea: the deeper in the tree, the more methods a particular class has, making it harder to change
- Number of Children
  - Immediate number of subclasses of C
  - Gives a sense of reuse of C's features
  - Most classes have a NOC of 0; one study showed, however, that classes with a high NOC had a tendency to be less fault prone than others

Metrics…



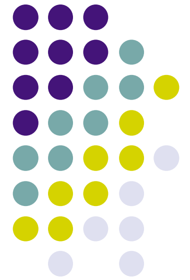
- Coupling between classes
  - Number of classes to which this class is coupled
  - Two classes are coupled if methods of one use methods or attributes of another
  - A study has shown that the CBC metric is significant in predicting the fault proneness of classes

Metrics…



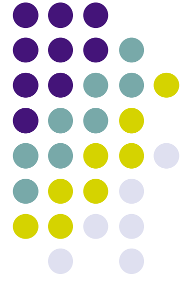
- Response for a Class
  - CBC metric does not quantify the strength of the connections its class has with other classes (it only counts them)
  - The response for a class metric attempts to quantify this by capturing the total number of methods that can be invoked from an object of this class
  - Thus even if a class has a CBC of “1”, its RFC value may be much higher
  - A study has shown that the higher a class’s RFC value is, the larger the probability that class will contain defects

Metrics…



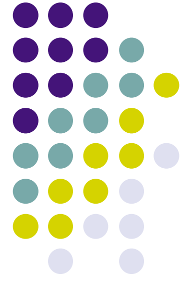
- Lack of cohesion in methods
  - Two methods form a cohesive pair if they access common variables (they form a non-cohesive pair if they have no common variables)
  - LCOM is the number of method pairs that are non-cohesive minus the number of cohesive pairs
- Highly cohesive classes have small LCOM values
  - A high LCOM value indicates that the class is trying to do too many things and its features should be partitioned into different classes
- However, a study found that this metric is NOT useful in predicting the fault proneness of a class

Metrics



- Note: the study referenced in the previous slides was published in the following paper
  - V. R. Basili, L. Briand, and W. L. Melo. A validation of object-oriented design metrics as quality indicators. IEEE Transactions on Software Engineering, 22(10):751-761, Oct 1996.

Summary



- OO design is a newer paradigm that is replacing function-oriented design techniques
- OO A&D combines both data and methods into cohesive units (classes)
- UML is a notation that is often used to model OO systems
  - It provides various diagrams for modeling a system’s structure, dynamic behavior, states, architecture, etc.
- Creating an OO design is an iterative process based on applying the knowledge stored in a system’s use cases
- Several OO metrics exist that are useful in prediciting the fault proneness of a class