CS 494
Object-Oriented Analysis & Design

On to Design

Reminder: Analysis models

- Earlier we modeled requirements using...
- Class Diagrams: Known as the *Conceptual Model*
  - Sometimes known as the logical model.
  - Classes represent domain-level entities. (E.g. things in the user's world.)
    - Thus no classes for implementation-level things.
  - Associations model domain-level relationships. (E.g. user-understood relationships between things in the user's world.)
    - Usually don't show *navigation* on associations

Reminder: Analysis models (2)

- Use Cases and Sequence Diagrams
  - Scenarios in a Use Case can be represented by UML sequence diagrams
  - Objects in the sequence diagram could be either:
    - The system and the actors, or...
    - Domain-level entities modeled in the conceptual model (a class diagram)
  - Messages between objects are:
    - Again, at a high-level of abstraction
    - Scenario descriptions become messages

Reminder: Goals for design

- Create detailed "plans" (like blueprints) for implementation
- Build these from requirements models so we are confident that all user needs will be met
- Create design models **before** coding so that we can:
  - Compare different possible design solutions
  - Evaluate efficiency, ease of modification, maintainability, etc

UML Notations for Design

- Several UML notations provide various **views** of a design
- **Class diagrams:** Possibly created at two different levels of abstraction for design:
  - **Specification level:** Classes model *types*, and we focus solely on *interfaces* between software modules
  - **Implementation level:** Think of this as a true "software blueprint". We can go directly to code from this model.
- Two types of Interaction Diagrams:
  - Sequence diagrams and Collaboration diagrams

UML Notations for Design (2)

- **Sequence diagrams**
  - Objects will be variables implemented in code
  - Messages are operations (e.g. C++ member functions) applied to objects
  - Sequence diagrams thus show how a sequence of operations called between a set of objects accomplishes a larger task
  - Sequence diagrams for a particular scenario help identify operations needed in classes
  - They also allow us to verify that a design can support requirements (e.g. a use-case scenario)

UML Notations for Design (3)

- **State diagrams**
  - Models how a particular object responds to messages according to its state
  - For a single object, show *states* and *transitions* between states
  - Transitions may be conditional based on a *guard* condition
  - May show an *action* an object takes on transition, or also *activity* carried out within a state
  - Occasionally used to model a system's or subsystem's behavior (not just one object's)

UML Notations for Design (4)

- Packages
  - A simple notation that groups classes together
  - Possible to use this to show contents of a subsystem
    - Show dependencies between packages
    - Show visibility of classes between packages
  - Not really a rich enough notation for diagramming software architectures
- Component Diagrams
  - Models physical modules of code (e.g. files, DLLs, physical databases)

Design Process

- There are many different approaches to design, but here is something typical.
- First, create a model of the high-level *system architecture*
  - UML does not really provide a notation this
- Next, use the conceptual class model to build a design-level class model or models
  - Here we'll assume we're just building an *implementation-level* class model
- Also, model dynamic behavior using interaction diagrams.

Design Process (cont'd)

- We'll use sequence diagrams with objects from the implementation-level class model
  - Sequence diagrams show how design-level objects will carry out actions to implement scenarios defined as part of use-case analysis
  - Messages between objects are member-function calls between objects
  - Important: Only member-function calls are shown, but other language statements (e.g. assignments) are executed between calls (of course).

Design Process (cont'd)

- **Important:** Development of class and sequence diagrams is iterative and concurrent
- When we create sequence diagrams for a new scenarios, we discover classes and operations that need to be added to the class model
- The two models grow together. Neither is a complete view of the system.
- Other documentation in text form is often used to provide details about class diagrams and sequence diagrams

Specification-Level Class Diagrams

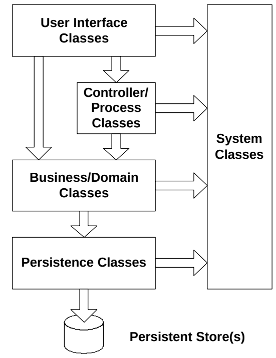
- How does a design-level class diagram differ from a conceptual-level diagram?
  - No longer just an external view!
  - We are now modeling "how" not just "what".
- This class diagram must document:
  - Additional classes
  - How you will implement associations
    - Multiplicity, Navigability or Direction; Association classes

Additional Classes in a Design

- Are additional classes needed? Of course!
  In general...
- Design-level "internal" classes
  - Data manager classes. E.g. collection objects that were simply associations before
  - Facilitator or helper classes that assist with complex tasks (e.g. ObservableComponent)
  - Factory classes that assist in creating new objects
  - Classes to implement other design patterns
- Is there any guidance or strategy for determining these?

Class Types in a Layered Architecture

- **From Ambler, Sect. 7.1**
- **5-layer model**
- **Classes only interact within layers, or as shown by arrows**
  - **Direction matters!**
- **Next slide describes these**



Possible Design Class Types

- **UI classes**
- **Business/Domain classes**
  - **Implement domain-objects from Analysis**
  - **Data objects plus their behaviors**
- **Controller/Process classes**
  - **implement business logic, collaborations between business objects and/or other controller**
- **Persistence classes**
  - **How to store, retrieve, delete objects**
  - **Hides underlying data stores from rest of system**
- **System classes**
  - **<u>Wrap</u> OS-specific functionality in case that changes**

Controller/Process Layer

- **Implements business logic**
  - **Encapsulate a business rule (Ambler, Sect. 3.6)**
  - **These often require interactions etc. between objects of different classes**
    - **Example from a student course enrollment system:**

      When can a Student enroll in a Seminar?
      - **Depends on schedule, pre-requisites, other constraints**

More on Controllers

- **Why not just put business logic into the Domain class?**
  - **Business rules change. We want domain classes to be reusable.**
  - **In UI class? Then must use that UI to carry out this process. (Too tightly coupled.)**
- **How to find Controller classes?**
  - **To start: <u>consider</u> one for each use-case**
  - **If trivial or belongs in domain class, don't.**

Ambler's Controller Class Example

- **Example in Ambler, page 259**
  - **Class: EnrollInSeminar (what's interesting about that name?)**
    - **Has link to a Student object**
    - **An instance given to SeminarSelector object (UI), which calls seminarSelected(seminar) on it**
    - **It tests if Student/Seminar combination is OK**
    - **An instance given to FeeDisplay object (UI), which makes sure user willing to pay**
    - **If so, it's verifyEnrollment() is called to finalize enrollment**

Controller Classes: Good OO?

- **Violates a principle of the OO approach!**
  - **Data and behavior kept together!**
- **Yes, but is this always the best solution?**
  - **DVDs and DVD players -- why not one unit?**
  - **Cameras and film vs. disposable cameras**
- **Consider coupling, change, flexibility…**
- **Controller classes are an example of the *Mediator* design pattern**
- **Mediator or control classes might grow to become *god classes***
  - **too much control, or too centralized**

Implementing Associations

- **How** associations are implemented is affected by **multiplicity**.
- **Where** they are implemented depends on **navigability**.
  - In one class or in both?
  - Until now we may not have worried about direction of associations. That's fine!
  - Often navigability cannot be determined until design phase.
  - Often it changes as we do more design.
  - In prototypes we often keep links bidirectional for flexibility.

Implementing Associations (2)

- Often we use class operations to hide implementation details of associations
  - getters, setters, traversal functions, update functions, etc.
  - Don't forget: in C++, in-line functions are efficient
  - Also, derived associations (or attributes) are implemented as member functions that calculate something that is not stored directly in the class.

One-Way Associations

- If an association should just be navigable in just one direction, use the "arrow form" of the UML association in your class diagram.
  - In UML no arrows means two-way or bi-directional.
- For implementation, the "target" object becomes an attribute in the class
  - In C++, it could be stored as an *embedded object* or as a pointer
  - In Java, objects are always references variables (so embedded objects really are pointers)
- Consider using association name or role name from the class diagram to name this attribute

Multiplicity and One-Way Associations

- If the multiplicity is "1" or "0..1" then the attribute would be a pointer to an object of the target class
  - E.g. attribute in class Phone: selectedLine: Line*
- If the multiplicity is "many" but has a fixed maximum, then use **array** of pointers (or objects)
  - E.g. "3", "0..3", "2..4"
- If no fixed maximum, e.g. "1..*" or "0..*", then use a collection object as an attribute that stores an arbitrarily large number of pointers or objects
- For *qualified associations* use a hash-table or *map* object to associate key with target object

Multiplicity and One-Way Assoc. (2)

- Examples using the C++ standard library...
- A *vector* class is like an array with no maximum capacity
  - Example attribute in class Phone:
    linkedLines: vector<Line*>
- Other C++ classes might be appropriate too: set, list
  - Arrays should only be used if you know the maximum
- Note: Your team might agree not to show the "*" to indicate pointers. Conventions vary.

Implementing Two-Way Associations

- Three options, depending on your needs
  - Note: Sometimes it's OK if traversal in one direction is slower than the other
- Option One: Just like one-way but in **both** classes
  - Advantages: Equally efficient in both directions
  - But, requires more space
  - Also, updating links between objects is more complex
    - Often a good idea to use member functions to handle updates to links.

Implementing Two-Way Assoc. (2)

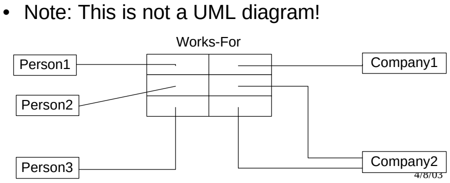
- Option Two:
  - In one class, Class A, implement just like one-way (see above) to access Class B objects.
  - In second class, Class B, write an operation that uses some kind of search of all objects of Class A to find the one that points back to the current B object.
    - Why? Saves space if access from B to A is very rare
    - But, requires there to be some place where all objects of Class A are stored

Implementing Two-Way Assoc. (3)

- Option Three: Implement an Association Class
  - This class will have only one instance, which stores all the links between objects of the two classes
  - Implemented as two dictionary or map objects
    - One points to Class A objects, the other to Class B objects
  - Search of this object is used to find links for one object

Example of Assoc. Object

- A person works for one company. A company has many employees.
- If pointers are not "bi-directional", then Works-For object must support efficient look-up of a Person object in order to find that object's company.
- Note: This is not a UML diagram!



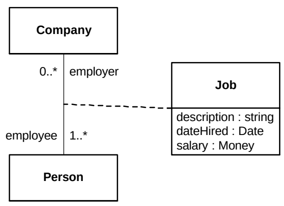
Flashback to previous slides…

- **Slides on class diagrams had "unused slides" at the end.**
- **Let's look at some of those now.**

Association Classes

- **Recall that qualified associations really mean that the link between two objects has an attribute**
- **Often associations are "first-class" things**
  - **They have a life-time, state, and maybe operations**
  - **Just like objects!**
- **Association classes**
  - **Same name as the association because...**
  - **They represent the same thing!**

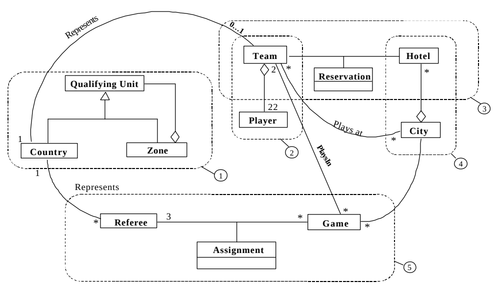
Association Class Example



World Cup Example

- **We need a system to handle the World Cup. Teams represent countries and are made up of 22 players.**
- **Countries qualify from zones, where each zone is either a country or a group of countries.**
- **Each team plays a given number of games in a specific city. Referees are assigned to games. Hotel reservations are made in the city where the teams play.**

World Cup Problem: Class Model



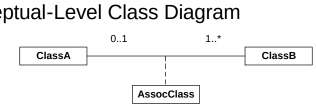
Return from flashback…

Implementing Association Classes

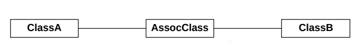
- Implementation depends on multiplicity
- If one-to-one, then it would be possible to...
  - Put attributes and operations inside either object
  - Or, put them in a separate class that's linked to either object
- If one-to-many, then same choices as one-to-one, but do this for the object on the "many" end
  - Again, could be a separate object (see next case)
- If many-to-many, you need a separate class with an object instantiated for each link

Example of Association Class Implementation

- Conceptual-Level Class Diagram



- Corresponding Design-Level Class Diagram



Notes on Example Implementation

- No direct link (pointer) in design or implementation between ClassA and ClassB instances! But...
- Each instance of an AssocClass object is linked to exactly one ClassA object and also to one ClassB object
  - This forms a 3-tuple for each conceptual-level link between a pair of ClassA and ClassB objects
- Note multiplicities reflect concept level:
  - One ClassA object is linked to 1-to-many AssocClass/ClassB pairs. Great!
  - One ClassB object links to 0-or-one AssocClass/ClassA pairs. Yes!