CS211 Lecture: Detailed Design and Implementation

Last revised October 5, 2007

Objectives:

1. To introduce the use of a complete UML class box to document the name, attributes, and methods of a class
2. To show how information flows from an interaction diagram to a class design
3. To review javadoc class documentation
4. To introduce method preconditions, postconditions; class invariants.

Materials :

1. Online display of various ATM Example pages
2. Javadoc documentation for Registration system labs classes and projectable of source code for class RegistrationModel (class comment+selected methods only).
3. Projectable of source code for video store SimpleDate class
4. Javadoc documentation for java.awt.BorderLayout and projectable of source code for constants
5. Gries' coffee can problem - demo plus handout of code

I. Introduction

A. As we pointed out at the start of the course, there are many different processes that can be followed in software development (e.g. waterfall life cycle, RUP, etc).

B. Regardless of what process is followed, however, certain tasks will need to be done as part of the development process *per se* - whether all at once, iteratively, or incrementally. In fact, activities like these will be part of any situation in which one uses his/her professional skills to help solve someone else's problem - not just when creating software or even in a computer field.

1. Establishing Requirements: The goal of this is to spell out what constitutes a satisfactory solution to the problem.

2. Analysis. The goal of this is to *understand* the problem. The key question is "What?".

3. Design. The goal of this is to develop the *overall structure* of a solution to the problem in terms of individual, buildable components and their relationships to one another. The key question is "How?".

4. Implementation. The goal of this task is to actually *build* the system as designed.

5. Installation / Maintenance / Retirement

   All of these must be done in a context of commitment to Quality Assurance - *ensuring* that the individual components and the system as a whole do what they are supposed to do (which may involve identifying their shortcomings and fixing them.)

C. We have been focussing our attention on the second and third of these tasks: analysis and (overall) design. To do this, we have looked at several tools:

   1. Class diagrams - a tool to show the various classes needed for a system, and to identify relationships between these classes - a tool to help us document the static structure of a system.

   2. CRC cards - a tool to help us identify the responsibilities of each class.

   3. Interaction diagrams - a tool to help us document what we discovered by using CRC cards, by showing how each use case is realized by the interaction of cooperating objects - one of several tools to help us capture the dynamic behavior of a system.

   4. State Diagrams - a tool to help capture the dynamic behavior of individual objects (where appropriate).

D. In developing CRC cards and interaction diagrams, we often discover the need for additional classes beyond those we initially discovered when we were analyzing the domain.

   1. These include classes for boundary objects and controller objects. In fact, a use case will typically be started by some boundary object, and will have some control object responsible for carrying it out.

   2. One writer has estimated that the total number of classes in an application will typically be about 5 times the number initially discovered during analysis.

E. We now turn to implementation phase. Here, we will focus on implementing the individual classes, using the CRC Cards and class diagram to identify the classes that need to be built, and the interaction and statechart diagrams (and CRC cards) to help us build each class.

F. There is a design component to this phase as well - sometimes known as *detailed design*. We can contrast this sort of design with the overall design done earlier, as follows.

1. In overall design, we are concerned with *identifying* the classes and discovering their *relationships*. One of the end results of overall design is a class diagram, showing the various classes and how they relate to one another.

    a) In order to keep the drawing manageable, at this stage I usually represent each class by a rectangle containing only its name.

    b) In fact, if the number of classes is large, we may group classes into packages and focus on these larger groupings.

2. In detailed design, we focus on each individual class.

    a) We must develop:

        (1) Its interface - what "face" it presents to the rest of the system

        (2) Its implementation - how we will actually realize the behavior prescribed by the interface.

    b) In the process of doing this, we will identify the class's:

        (1) Attributes

        (2) Operations

    c) To document this, we may draw a more detailed UML representation for the class: a rectangle with three compartments:

        (1) Class name

        (2) Attributes

        (3) Methods

d) A note on notational conventions - UML uses the notations variable: type for attributes, parameter: type and method(...): type for method signatures, and the symbols + for public, # for protected, and - for private.

3. In implementation, we actually build and test the code for each class, which means translating the UML design into code in Java or whatever programming language we are using.

   a) The translation of the attributes into Java code is trivial.

   b) In the case of the methods, the signatures given in the UML design become the method interfaces. Of course, we still need to write the method bodies. Here, our interaction diagrams come into play.

4. Since implementation of a good design is relatively straight-forward, we will spend most of our time on design.

II. Designing the Interface of a class

A. The interface of a class is the "face" that it presents to other classes - i.e. its public features.

   1. In a UML class diagram, public features are denoted by a "+" symbol. In Java, of course, these features will actually be declared as public in the code.

   2. The interface of a class needs to be designed carefully. Other classes will depend *only* on the public interface of a given class. We are free to change the implementation without forcing other classes to change; but if we change the interface, then any class that depends on it may also have to change. Thus, we want our interface design to be stable and complete.

B. An important starting point for designing a class is to write out a brief statement of what its basic role is - what does it represent and/or do in the overall context of the system.

   1. If the class is properly cohesive, this will be a single statement.

   2. If we cannot come up with such a statement, it may be that we don't have a properly cohesive class!

   3. As we did in CS112. we will document our classes using javadoc. One component of the javadoc documentation for the class is a *class*

comment - which spells out the purpose of the class. (We will discuss other javadoc features at the appropriate point later on.)

EXAMPLE:

a) Show online documentation for Registration Labs classes

b) PROJECT: javadoc class comment in the source code for class `RegistrationModel`.

C. Languages like Java allow the interface of a class to include both attributes (fields) and behaviors (methods). It is almost always the case that fields should be private (some writers would argue always, not just almost always), so that the interface consists only of:

1. Methods

2. Constants (public static final ...)

3. Note that, while good design dictates that methods and constants *may* be part of the public interface of a given class, good design does not *require* that *all* methods and constants be part of the public interface. If we have some methods and/or constants that are needed for the implementation of the class, but are not used by the "outside world", they belong to the private implementation .

4. In general, we will use javadoc to document each feature that is part of the public interface of a class - including any protected features that, while not publicly accessible, are yet needed by subclasses.

D. A key question in designing an interface, then, is "what methods does this class need"? Here, our interaction diagrams are our primary resource. Every message that an object of our class is shown as receiving in an interaction diagram must be realized by a corresponding method in our class's interface.

1. As an example of this, consider the class `CashDispenser` from the ATM example. Each interaction diagram in which a `CashDispenser` object appears potentially contributes one or more methods to the interface of a `CashDispenser` object.

   PROJECT: Detailed design for `CashDispenser`.

   Referring to the Operations, observe that each of the methods in the design actually shows up a message sent *to* a CashDispenser object in some interaction. (Must look at every interaction where CashDispenser appears to find them all)

a) `setInitialCash()` appears as a message sent to the `CashDispenser` from the `ATM` in the System Startup interaction.

   SHOW

b) `checkCashOnHand()` and `dispenseCash()` appear as messages send to the `CashDispenser` from a `WithdrawalTransaction` in the Cash Withdrawal interaction.

   SHOW

c) No other messages are sent to a `CashDispenser` object in any interaction, and no other ordinary operations (i.e. other than the constructor) show up in the detailed design as a result.

2. Notice that we are only interested here in the messages a given class of object *receives*; not in the messages it *sends* (which are part of its implementation).

3. Sometimes, another issue to consider in determining the methods of an object is the "common object interface" - methods declared in class `Object` (which is the ultimate base class of all classes) that can be overridden where appropriate. Most of the time, you will not need to worry about any of these. The ones you are most likely to need to override are:

   a) The `boolean equals(Object)` method used for comparisons for equality of value.

   b) The `String toString()` method used to create a printable representation of the object - sometimes useful when debugging.

      EXAMPLE: Show overrides in class used `SimpleDate` for project.

E. An important principle of good design is that our methods should be cohesive - i.e. each method should perform a single, well-defined task.

1. A way to check for cohesion is to see if it is possible to write a simple statement that describes what the method does.

2. In fact, this statement will later become part of the documentation for the method - so writing it now will save time later.

   EXAMPLE: Look at documentation for class `java.io.File`. Note descriptions of each method.

3. The method name should clearly reflect the description of what the method does. Often, the name will be a single verb, or a verb and an object. The name may be an imperative verb - if the basic task of the method is to *do* something; or it may be an interrogative verb - if the basic task of the method is to *answer a question*.

   EXAMPLE: Note examples of each in methods of `File`.

4. Something to watch out for - both in method descriptions and in method names - is the need to use conjunctions like "and". This is often a symptom of a method that is not cohesive.

F. One important consideration in designing a method is the *parameters* needed by the method.

1. Parameters are typically used to pass information *into* the method. Thus, in designing a parameter list, a key question to ask is "what does the sender of the message know that this method needs to know?" Each such piece of information will need to be a parameter.

2. There is a principle of narrow interfaces which suggests that we should try to find the *minimal* set of parameters necessary to allow the method to do its job.

   EXAMPLE: Discuss parameter lists for each message in the Session Interaction

G. Another important consideration is the *return value* of the method.

1. A question to ask: does the sender of this message need to learn anything new as a result of sending this message?

2. Typically, information is returned by a message through a return value.

   EXAMPLE: Show examples in Session interaction

3. Sometimes, a parameter must be used - an object which the method is allowed to alter, and the caller of the method sees the changes.

   EXAMPLE:

   The balances parameter to the `sendToBank()` method of the various types of transaction - *SHOW* in Withdrawal interaction. Note that this method has to return *two* pieces of information to its caller:

   a) A status

b) If successful, current balances of the account

SHOW Code for class banking.`Balances`

H. Just as we use a javadoc class comment to document each class, we use a javadoc method comment to document each method. The documentation for a method includes:

1. A statement of the purpose of the method. (Which should, again, be a single statement if the method is cohesive).

2. A description of the parameters of the method.

3. A description of the return value - if any.

   SHOW: Documentation for course-related methods of class `RegistrationModel` for Registration labs.

   PROJECT: java source code for these methods, showing javadoc comment.

I. While the bulk of a class's interface will typically be methods, it is also sometimes useful to define symbolic constants that can serve as parameters to these methods

1. EXAMPLE: `java.awt.BorderLayout`

2. In Java, constants are declared as final static. A convention in Java is to give constants names consisting of all upper-case letters, separated by underscores if need be.

3. Public constants should also be documented via javadoc

   SHOW Documentation for constants of class `java.awt.BorderLayout`

   PROJECT: source code showing javadoc comments.

III. Preconditions, Postconditions, and Invariants,

A. As part of designing the interface for a class, it is useful to think about the preconditions and postconditions for the various methods, and about class invariants.

1. A precondition for a method is a statement of what must be true in order for the method to be validly called.

   EXAMPLE:

   As you may have discovered in lab, the remove(int) method of a List collection can be used to remove a specific element of a List. However, the method has a precondition that the specified element must exist - e.g. you can't remove the element at position 5 from a list that contains 3 elements, nor can you remove the element at position 0 (the first position) from an empty list.

   What happens if you fail to observe this precondition?

   ASK

2. A postcondition for a method is a statement of what the method will guarantee to be true - provided it is called with its precondition satisfied.

   EXAMPLE: The postcondition for the `remove(int)` method of a `List` collection is that the specified element is removed and all higher numbered elements (if any) are shifted down - e.g. if you remove element 2 from a `List`, then element 3 (if there is one) becomes the new element 2, element 4 (if there is one) becomes the new element 3, etc.

   Note that a method is <u>not</u> required to guarantee its postcondition if it is called with its precondition not satisfied. (In fact, it's not required to guarantee anything!)

3. A class invariant is a statement that is true of any object at any time it is visible to other classes. An invariant satisfies two properties:

   a) It is satisfied by any newly-constructed instance of the class.

      Therefore, a primary responsibility of each constructor is to make sure that any newly-constructed object satisfies the class invariant.

   b) Calling a public method of the class with the invariant true and the preconditions of the method satisfied results in the invariant

remaining true (though it may temporarily become false during the execution of the method)

(1) Therefore, a primary responsibility of any public method is to preserve the invariant.

(2) Technically, private methods are not required to preserve the invariant - so long as public methods call them in such a way as to restore the invariant before the public method completes.

c) That is, the class invariant must be satisfied only in states which are visible to other classes. It may temporarily become false while a public method is being executed.

B. An example of method preconditions and postconditions plus class invariants: David Gries' Coffee Can problem

1. Explain the problem

2. DEMO

3. HANDOUT: CoffeeCan.java

a) Note preconditions and postconditions of the various methods

b) Note class invariant

c) It turns out that the question "what is the relationship between the initial conditions and the color of the final bean?" can be answered by discovering an additional component of the invariant.

ASK CLASS TO THINK ABOUT:

(1) Relationship between initial contents of can and final bean color.

(2) A clause that could legitimately be added to the invariant which makes this behavior obvious.

IV. Designing the Implementation of a class

A. Once we have designed the interface for a class, including its invariant and the preconditions and postconditions of its methods, it is time to design the implementation. This involves two major tasks:

1. Identifying the attributes

2. Implementing the methods

B. Identifying attributes

1. One task we must perform is listing the attributes each object of a given class must have. To do this, we can ask two basic questions:

a) What must each object of the class *know* about itself? (What must it know?)

b) What objects must each object of the class *relate to*? (Who must it know?)

We will illustrate both of these from class `CashDispenser`.

PROJECT design again - note attributes

2. The first question (what must it know) involves thinking about the responsibilities of the class and what it needs to know to fulfill them.

a) EXAMPLE: `cashOnHand` represents something a `CashDispenser` must know to do its job. This is is implicit in the responsibilities given to the class.

SHOW CRC Card

b) In other cases, a needed attribute may explicitly appear in a sequence diagram. However, not every variable appearing in a sequence diagram should be an attribute!

EXAMPLE: SHOW interaction diagram for class `Session`. What variables appear in this diagram?

ASK - list on board

Now show detailed design for class `Session`. Note that only some show up as attributes. Why?

ASK

Only those pieces of information that are part of the permanent state of the object (and which are typically accessed by more than one method) show up as attributes - the rest can be local variables of a particular method. (Sometimes this will be apparent when doing the design; sometimes, the need to make some variable an instance variable rather than a simple local variable will only be discovered while writing the code. A design can be altered as needed.)

c) In the case of entity objects, we may need think about the kind of information the entity represents.

EXAMPLE: In the video store system, what must a `Customer` object know? (Note: we're asking about what the object must know, not about what the human being must know!)

ASK

d) In the case of class hierarchies, we need to think about what *level* in the hierarchy each attribute belongs on.

(1) EXAMPLE: What must <u>any</u> `Transaction` object know? (Information common to all transactions, not just one type)

ASK

SHOW : design for `Transaction` class

(2) EXAMPLE: What additional information must a `Withdrawal` object know?

ASK

SHOW design for `Withdrawal` class. Note that, in addition to the attributes just listed, a `Withdrawal` also inherits all the attributes of a `Transaction`.

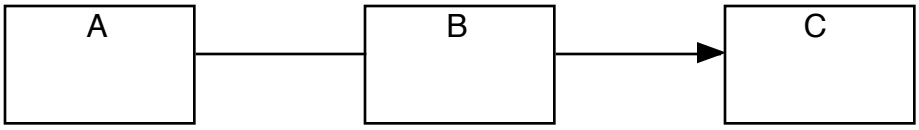
(3) An important consideration in class design when generalization is involved is that attributes need to be put at the appropriate level in the class hierarchy. Basically, any attribute that is common to <u>all</u> the subclasses belongs in the base class; any attribute that is unique to a single subclass, or a subset of subclasses, belongs in the individual subclasses. (However, if there are is an identifiable subset that has several attributes in common not shared by the other subclasses, we <u>may</u> need a new level in the hierarchy. This needs to be considered with caution, however. E.g. we might

add a level for transactions that have an amount (everything but Inquiry), but this probably introduces more complexity than it removes!

3. The second question (who must it know) can be answered directly from the *associations* in the class diagram.

   a) An object needs an attribute for each relationship it knows about.

   EXAMPLE:



   Each "A" object needs an attribute to record the B object(s) to which it is related. Each "B" object needs an attribute to record the "A" object(s) to which it is related and another attribute to record the "C" objects to which it is related. A "C" object does not need an attribute to record the "B" objects to which it is related, because the navigability on this association is from B to C only. (A "C" object does not know about its "B" object(s)).

   Example: *SHOW* detailed design for class `CashDispenser`. One attribute represents an association the `CashDispenser` is part of

   (1) Which one?

   ASK

   (2) SHOW: Class diagram - note that a `CashDispenser` is part of *two* associations. Why does just one show up as an attribute in the class?

   ASK

   Both associations happen to be unidirectional. But `CashDispenser` is only on the "knowing" end of one of them. The `CashDispenser` does need to know about the `Log`, but not about the `ATM`.

   (Of course, in general, a class can have any number of attributes representing associations.)

b) Normally, an attribute representing an association will be either a *reference* or a *collection*.

(1) It will be a reference it he multiplicity at the other end of the association is either 1 or 0..1 - i.e. it must know at most one other object in this particular association. (The reference will be null if the multiplicity is 0..1 and there is currently no object with which it is associated.)

(2) It will be a collection of some sort if the range of the multiplicity at the other end of the association is greater than 1. In this case, we must choose what kind of collection is most appropriate.

(a) Often, we will use one of the standard Java collections, based on how we will be accessing the elements:

i) A `HashSet`, if there is no inherent order to the collection.

ii) A `TreeSet`, if there is some natural basis for organizing the associated objects in "alphabetical" order. (Note that a TreeSet constructor takes as a parameter a Comparator object that knows how to figure out this order.)

iii) An `ArrayList` or `LinkedList` if we need to control the sequence of the associated objects (e.g. "first-come first-served").

iv) A `HashMap` or `TreeMap` if we need to be able to access the associated object by some key - e.g. a name or an id number - i.e. if it is a qualified association.

(b) If the number of objects at the other end is fixed, or has a small fixed upper bound, an array or even distinct variables may be appropriate.

EXAMPLE: Consider developing a "dungeon" sort of game in which we have Rooms linked together. Suppose each Room is allowed to potentially have neighbors in each of the four directions (north, east, south, west). We could implement this in a number of different ways:

ASK

i) We could use four variables called northNeighbor, eastNeighbor , southNeighbor, and westNeighbor.

ii) We could use an ordinary array, with element 0 being, say the north neighbor (null if none), element 1 being the east neighbor, etc.

iii) We could use a list, with the list elements being stored in the order north, east, south, west (and a null being stored in a position if there is no neighbor this way.) (Note that this is quite similar to the array representation, since we will use indices 0, 1 etc. to access the neighbor in a specific direction.)

iv) We could use a map, with the strings "North", "East", "South" and "West" serving as keys and the corresponding rooms being the values.

v) We could <u>not</u> use a set. Why?

ASK

A set is inherently unordered. In this case, it is vital to know whether a given room is the north neighbor or the south neighbor.

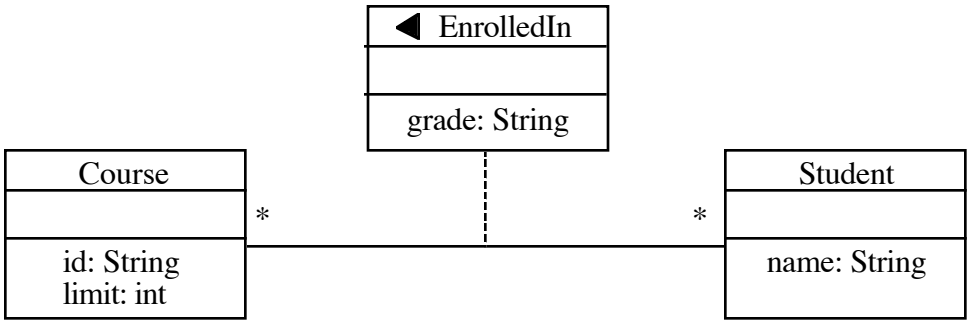
vi) In this case, the simple array may be the best choice, assuming a run time variable (the direction in which the player wants to move) will be used to select a Room. The various collections introduce additional overhead that doesn't really do anything for us here.

(c) What do we do if we have an association that requires an association class?

i) The association class object will have a simple reference to each of the objects it is associating.

ii) Each of the objects participating in the association will have some sort of collection of association class objects.

EXAMPLE: The `EnrolledIn` association from the Registration system labs



This association involves attributes in three classes: Course, Student, and EnrolledIn:

```
// In Course: map keyed on student name; value is
// an EnrolledIn object
private TreeMap enrollments = new TreeMap();

// In Student: map keyed on course id; value is
// an EnrolledIn object
private TreeMap enrollments = new TreeMap();

// In EnrolledIn.  Note that each EnrolledIn object
// relates to one Course and one Student:
Course course;
Student student;
```

(d) Note that this part of the design is driven by the class diagram - if the class diagram is done well, then identifying association variables is straightforward. The only tricky part may be deciding what type of collection to use.

4. Ordinarily, attributes should be declared as private ("-" in UML). However, if a class is the base of a class hierarchy, and subclasses have legitimate need to access the attribute, then it may need to be declared as protected ("#" in UML).

C. Once we have designed the implementation of a class, of course, we then need to implement its methods.

1. If the class has been designed correctly, and each method has been specified via preconditions and postconditions, this is usually straightforward. (Title of talk at OOPSLA Educator's symposium in 1999 - "Teach design - everything else is SMOP (a simple matter of programming)").

2. Sometimes, in implementing methods, we discover that it would be useful to introduce one or more *private* methods that facilitate the tasks of the public methods by performing well-defined subtasks.

D. A final consideration is the *physical arrangement* of the source code for a class. A reasonable way to order the various methods and variables of a class is as follows:

1. Immediately precede the class declaration with a class comment that states the purpose of the class.

2. Put public members (which are part of the interface) first - then private members. That way a reader of the class who is interested in its interface can stop reading when he/she gets to the implementation details in the private part.

3. Organize the public interface members in the following order:

   a) Class constants (if any)

   b) Constructor(s)

   c) Mutators

   d) Accessors

4. In the private section, put method first, then variables.

5. If the class contains any test driver code, put this last.