UCLA Extension Course

Software Design Principles and Guidelines

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Design Principles and Guidelines Overview

- Design Principles
  - Important design concepts
  - Useful design principles
- Development Methodologies
  - Traditional approaches
  - Extreme programming
- Design Guidelines
  - Motivation
  - Common Design Mistakes
  - Design Rules

Motivation: Goals of the Design Phase

- Decompose System into Modules
  - *i.e.*, identify the software architecture
  - *Modules* are abstractions that should:
    - be independent,
    - have well-specified interfaces, and
    - have high cohesion and low coupling.
- Determine Relations Between Modules
  - Identify module dependencies
  - Determine the form of intermodule communication, *e.g.*,
    - global variables
    - parameterized function calls
    - shared memory
    - RPC or message passing

Motivation: Goals of the Design Phase (cont'd)

- Specify Module Interfaces
  - Interfaces should be well-defined
    - facilitate independent module testing
    - improve group communication
- Describe Module Functionality
  - *Informally*
    - *e.g.*, comments or documentation
  - *Formally*
    - *e.g.*, via module interface specification languages

Primary Design Phases

- *Preliminary Design*
  - External design describes the real-world model
  - Architectural design decomposes the requirement specification into software subsystems
- *Detailed Design*
  - Formally specify each subsystem
  - Further decomposed subsystems, if necessary
- Note: in design phases the orientation moves
  - from customer to developer
  - from *what* to *how*

Key Design Concepts and Principles

- Important design concepts and design principles include:
  - *Decomposition*
  - *Abstraction*
  - *Information Hiding*
  - *Modularity*
  - *Hierarchy*
  - *Separating Policy and Mechanism*
- Main purpose of these concepts and principles is to manage software system complexity and improve software quality factors.

Decomposition

- Decomposition is a concept common to all life-cycle and design techniques.
- Basic concept is very simple:

1. Select a piece of the problem (initially, the whole problem)
2. Determine its components using the mechanism of choice, *e.g.*, functional vs data structured vs object-oriented
3. Show how the components interact
4. Repeat steps 1 through 3 until some termination criteria is met (*e.g.*, customer is satisfied, run out of money, *etc.*;-))

Decomposition (cont'd)

- Some guiding decomposition principles
  - Because design decisions transcend execution time, modules might not correspond to execution steps . . .
  - Decompose so as to limit the effect of any one design decision on the rest of the system
  - Remember, anything that permeates the system will be expensive to change
  - Modules should be specified by all information needed to use the module and *nothing more*

Abstraction

- Abstraction provides a way to manage complexity by emphasizing essential characteristics and suppressing implementation details.
- Allows postponement of certain design decisions that occur at various levels of analysis, *e.g.*,
  - Representational/Algorithmic considerations
  - Architectural/Structural considerations
  - External/Functional considerations

Abstraction (cont'd)

- Three basic abstraction mechanisms
  - Procedural abstraction
    - *e.g.*, closed subroutines
  - Data abstraction
    - *e.g.*, ADTs
  - Control abstraction
    - iterators, loops, multitasking, *etc.*

Information Hiding

- Motivation: details of design decisions that are subject to change should be hidden behind abstract interfaces, *i.e.*, modules.
  - Information hiding is one means to enhance abstraction.
- Modules should communicate only through well-defined interfaces.
- Each module is specified by as little information as possible.
- If internal details change, client modules should be minimally affected (may require recompilation and relinking, however . . .)

Information Hiding (cont'd)

- Information to be hidden includes:
  - Data representations
    - *i.e.*, using abstract data types
  - Algorithms *e.g.*, sorting or searching techniques
  - Input and Output Formats
    - Machine dependencies, *e.g.*, byte-ordering, character codes
  - Policy/mechanism distinctions
    - *i.e.*, *when* vs *how*
    - *e.g.*, OS scheduling, garbage collection, process migration
  - Lower-level module interfaces
    - *e.g.*, Ordering of low-level operations, *i.e.*, process sequence

Modularity

- A *Modular System* is a system structured into highly independent abstractions called *modules*.
- Modularity is important for both design and implementation phases.
- Module prescriptions:
  - Modules should possess well-specified *abstract interfaces*.
  - Modules should have high *cohesion* and low *coupling*.

Modularity (cont'd)

- Modularity facilitates certain software quality factors, *e.g.*:
  - *Extensibility* - well-defined, abstract interfaces
  - *Reusability* - low-coupling, high-cohesion
  - *Compatibility* - design "bridging" interfaces
  - *Portability* - hide machine dependencies
- Modularity is an important characteristic of good designs because it:
  - allows for *separation of concerns*
  - enables developers to reduce overall system complexity via *decentralized* software architectures
  - enhances *scalability* by supporting independent and concurrent development by multiple personnel

Modularity (cont'd)

- A module is
  - A software entity encapsulating the representation of an abstraction, *e.g.*, an ADT
  - A vehicle for hiding at least one design decision
  - A "work" assignment for a programmer or group of programmers
  - a unit of code that
    - has one or more names
    - has identifiable boundaries
    - can be (re-)used by other modules
    - encapsulates data
    - hides unnecessary details
    - can be separately compiled (if supported)

Modularity (cont'd)

- A module interface consists of several sections:
  - Imports
    - Services requested from other modules
  - Exports
    - Services provided to other modules
  - Access Control
    - not all clients are equal! (*e.g.*, C++'s distinction between protected/private/public)
  - Heuristics for determining interface specification
    - define one specification that allows multiple implementations
    - anticipate change
    - *e.g.*, use structures and classes for parameters

Modularity Dimensions

- Modularity has several dimensions and encompasses specification, design, and implementation levels:
  - Criteria for evaluating design methods with respect to modularity
    - *Modular Decomposability*
    - *Modular Composability*
    - *Modular Understandability*
    - *Modular Continuity*
    - *Modular Protection*
  - Principles for ensuring modular designs:
    - *Language Support for Modular Units*
    - *Few Interfaces*
    - *Small Interfaces (Weak Coupling)*
    - *Explicit Interfaces*
    - *Information Hiding*

Principles for Ensuring Modular Designs

- *Language Support for Modular Units*
  - Modules must correspond to syntactic units in the language used.
- *Few Interfaces*
  - Every module should communicate with as few others as possible.
- *Small Interfaces (Weak Coupling)*
  - If any two modules communicate at all, they should exchange as little information as possible.

Principles for Ensuring Modular Designs (cont'd)

- *Explicit Interfaces*
  - Whenever two modules A and B communicate, this must be obvious from the text of A or B or both.
- *Information Hiding*
  - All information about a module should be private to the module unless it is specifically declared public.

The Open/Closed Principle

- A satisfactory module decomposition technique should yield modules that are *both* open and closed:
  - *Open Module*: is one still available for extension. This is necessary because the requirements and specifications are rarely completely understood from the system's inception.
  - *Closed Module*: is available for use by other modules, usually given a well-defined, stable description and packaged in a library. This is necessary because otherwise code sharing becomes unmanageable because reopening a module may trigger changes in many clients.

The Open/Closed Principle (cont'd)

- Traditional design techniques and programming languages do not offer an elegant solution to the problem of producing modules that are *both* open and closed.
- Object-oriented methods utilize inheritance and dynamic binding to solve this problem.

Hierarchy

- Motivation: reduces module interactions by restricting the topology of relationships
- A relation defines a hierarchy if it partitions units into levels (note connection to virtual machines)
  – Level 0 is the set of all units that use no other units
  – Level i is the set of all units that use at least one unit at level $< i$ and no unit at level $\geq i$.
- Hierarchical structure forms basis of design
  – Facilitates independent development
  – Isolates ramifications of change
  – Allows rapid prototyping

Hierarchy (cont'd)

- Relations that define hierarchies:
  – *Uses*
  – *Is-Composed-Of*
  – *Is-A*
  – *Has-A*
- The first two are general to all design methods, the latter two are more particular to object-oriented design and programming.

The Uses Relation

- *X* Uses *Y* if the correct functioning of *X* depends on the availability of a correct implementation of *Y*
- Note, *uses* is not necessarily the same as *invokes*:
  – Some invocations are not uses
    ∗ *e.g.*, error logging
  – Some uses don't involve invocations
    ∗ *e.g.*, message passing, interrupts, shared memory access
- A *uses* relation does not necessarily yield a hierarchy (avoid cycles . . .)

The Is-Composed-Of Relation

- The *is-composed-of* relationship shows how the system is broken down in components.
- X *is-composed-of* $\{x_i\}$ if X is a group of units x_i that share some common purpose
- The system structure graph description can be specified by the *is-composed-of* relation such that:
  - non-terminals are "virtual" code
  - terminals are the only units represented by "actual" (concrete) code

The Is-Composed-Of Relation, (cont'd)

- Many programming languages support the *is-composed-of* relation via some higher-level module or record structuring technique.
- Note: the following are not equivalent:

1. level (virtual machine)
2. module (an entity that hides a secret)
3. a subprogram (a code unit)

- Modules and levels need not be identical, as a module may have several components on several levels of a uses hierarchy.

The Is-A and Has-A Relations

- These two relationships are associated with object-oriented design and programming languages that possess inheritance and classes.
- *Is-A* or *Descendant* relationship
  - class X possesses *Is-A* relationship with class Y if instances of class X are specialization of class Y.
  - *e.g.*, a square is a specialization of a rectangle, which is a specialization of a shape . . .
- *Has-A* or *Containment* relationship
  - class X possesses a *Has-B* relationship with class Y if instances of class X contain one or more instance(s) of class Y.
  - *e.g.*, a car has an engine and four tires . . .

Separating Policy and Mechanism

- Very important design principle, used to separate concerns at both the design and implementation phases.
- Multiple policies can be implemented by shared mechanisms.
  - *e.g.*, OS scheduling and virtual memory paging
- Same policy can be implemented by multiple mechanisms.
  - *e.g.*, FIFO containment can be implemented using a stack based on an array, or a linked list, or . . .
  - *e.g.*, reliable, non-duplicated, bytestream service can be provided by multiple communication protocols.

Program Families and Subsets

- Program families are a collection of related modules or subsystems that form a *framework*
  - *e.g.*, BSD UNIX network protocol subsystem.
  - Note, a framework is a set of *abstract* and *concrete* classes.
- Program families are natural way to detect and implement subsets.
  - Reasons for providing subsets include cost, time, personnel resources, *etc.*
  - Identifying subsets:
    - Analyze requirements to identify minimally useful subsets.
    - Also identify minimal increments to subsets.

A General Design Process

- Given a requirements specification, design involves an iterative decision making process with the following general steps:
  - List the difficult decisions and decisions likely to change
  - Design a module specification to hide each such decision
    - Make decisions that apply to whole program family first
    - Modularize *most likely* changes first
    - Then modularize remaining difficult decisions and decisions likely to change
    - Design the *uses* hierarchy as you do this (include reuse decisions)

A General Design Process (cont'd)

- General steps (cont'd)
  - Treat each higher-level module as a specification and apply above process to each
  - Continue refining until all design decisions are:
    - hidden in a module
    - contain easily comprehensible components
    - provide individual, independent, low-level implementation assignments

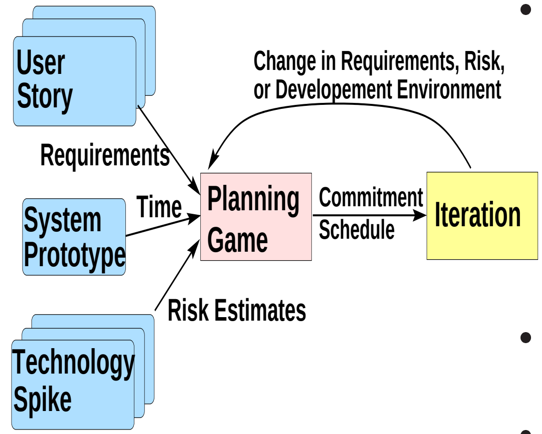
Traditional Development Methodologies

- Waterfall Model
  - Specify, analyze, implement, test **(in sequence)**
  - Assumes that requirements can be specified up front
- Spiral Model
  - Supports iterative development
  - Attempts to assess risks of changes
- Rapid Application Development
  - Build a prototype
  - Ship it :-)

eXtreme Programming

- Stresses customer satisfaction, and therefore, involvement
  - Provide what the customer wants, as quickly as possible
  - Provide *only* what the customer wants
- Encourages changes in requirements
- Relies on testing
- XP Practices
  - Planning, designing, coding, testing

eXtreme Programming: Planning



based on http://www.extremeprogramming.org/rules/planninggame.html

- Start with *user stories*
  - Written by customers, to specify system requirements
  - Minimal detail, typically just a few sentences on a card
  - Expected development time: 1 to 3 weeks each, roughly
- Planning game creates commitment schedule for entire project
- Each iteration should take 2-3 weeks

eXtreme Programming: Designing

- Defer design decisions as long as possible
- Advantages:
  - Simplifies current task (just build what is needed)
  - You don't need to maintain what you haven't built
  - Time is on your side: you're likely to learn something useful by the time you need to decide
  - Tomorrow may never come: if a feature isn't needed now, it might never be needed
- Disadvantages:
  - Future design decisions may require rework of existing implementation
  - Ramp-up time will probably be longer later
    - Therefore, always try to keep designs as simple as possible

eXtreme Programming: Coding

- *Pair programming*
  - *Always* code with a partner
  - *Always* test as you code
- Pair programming pays off by supporting good implementation, reducing mistakes, and exposing more than one programmer to the design/implementation
- If any deficiencies in existing implementation are noticed, either fix them or note that they need to be fixed.

eXtreme Programming: Testing

- Unit tests are written *before* code.
- Code **must** pass both its unit test **and** all regression tests before committing.
- In effect, the test suite defines the system requirements.
  - Significant difference from other development approaches.
  - If a bug is found, a test for it **must** be added.
  - If a feature isn't tested, it can be removed.

eXtreme Programming: Information Sources

- Kent Beck, *Extreme Programming Explained: Embrace Change*, Addison-Wesley, ISBN 0201616416, 1999.
- Kent Beck, "Extreme Programming", *C++ Report* 11:5, May 1999, pp. 26–29+.
- John Vlissides, "XP", interview with Kent Beck in the Pattern Hatching Column, *C++ Report* 11:6, June 1999, pp. 44-52+.
- Kent Beck, "Embracing Change with Extreme Programming", *IEEE Computer* 32:10, October 1999, pp. 70-77.
- `http://www.extremeprogramming.org/`
- `http://www.xprogramming.com/`
- `http://c2.com/cgi/wiki?ExtremeProgrammingRoadmap`

Rules of Design

- *Make sure that the problem is well-defined*
  - All design criteria, requirements, and constraints, should be enumerated before a design is started.
  - This may require a "spiral model" approach.
- *What comes before how*
  - *i.e.*, define the service to be performed at every level of abstraction before deciding which structures should be used to realize the services.
- *Separate orthogonal concerns*
  - Do not connect what is independent.
  - Important at many levels and phases . . .

Rules of Design (cont'd)

- *Design external functionality before internal functionality.*
  - First consider the solution as a black-box and decide how it should interact with its environment.
  - Then decide how the black-box can be internally organized. Likely it consists of smaller black-boxes that can be refined in a similar fashion.
- *Keep it simple.*
  - Fancy designs are buggier than simple ones; they are harder to implement, harder to verify, and often less efficient.
  - Problems that appear complex are often just simple problems huddled together.
  - Our job as designers is to identify the simpler problems, separate them, and then solve them individually.

Rules of Design (cont'd)

- *Work at multiple levels of abstraction*
  - Good designers must be able to move between various levels of abstraction quickly and easily.
- *Design for extensibility*
  - A good design is "open-ended," *i.e.*, easily extendible.
  - A good design solves a class of problems rather than a single instance.
  - Do not introduce what is immaterial.
  - Do not restrict what is irrelevant.
- *Use rapid prototyping when applicable*
  - Before implementing a design, build a high-level prototype and verify that the design criteria are met.

Rules of Design (cont'd)

- Details should depend upon abstractions
  - Abstractions should not depend upon details
  - Principle of Dependency Inversion
- The granule of reuse is the same as the granule of release
  - Only components that are released through a tracking system can be effectively reused
- Classes within a released component should share common closure
  - That is, if one needs to be changed, they all are likely to need to be changed
  - *i.e.*, what affects one, affects all

Rules of Design (cont'd)

- Classes within a released component should be reused together
  - That is, it is impossible to separate the components from each other in order to reuse less than the total
- The dependency structure for released components must be a DAG
  - There can be no cycles
- Dependencies between released components must run in the direction of stability
  - The dependee must be more stable than the depender
- The more stable a released component is, the more it must consist of abstract classes
  - A completely stable component should consist of nothing but abstract classes

Rules of Design (cont'd)

- Where possible, use proven patterns to solve design problems
- When crossing between two different paradigms, build an interface layer that separates the two
  - Don't pollute one side with the paradigm of the other

Rules of Design (cont'd)

- Software entities (classes, modules, etc) should be open for extension, but closed for modification
  - The Open/Closed principle – Bertrand Meyer
- Derived classes must usable through the base class interface without the need for the user to know the difference
  - The Liskov Substitution Principle

Rules of Design (cont'd)

- *Make it work correctly, then make it work fast*
  - Implement the design, measure its performance, and if necessary, optimize it.
- *Maintain consistency between representations*
  - *e.g.*, check that the final optimized implementation is equivalent to the high-level design that was verified.
  - Also important for documentation . . .
- Don't skip the preceding rules!
  - Clearly, this is the most frequently violated rule!!! ;-)