CSC 408F/CSC2105F Lecture Notes

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ⓒDavid B. Wortman, 1999,2000,2001,2002,2003,2004

ⓒKersti Wain-Bantin, 2001

ⓒYijun Yu, 2004

What is Software Engineering

- The science and art of building *LARGE* Software Systems
  - On time
  - On budget
  - With Acceptable Performance
  - With Correct Operation
- *LARGE* means:
  - Many people, team not individual effort
  - Many $s spent on design and implementation
  - Over 75,000 lines of source code
  - Lifetime measured in years
  - Continuing modification and maintenance
- Software costs dominate hardware costs

Survey results

- Q2. Do you remember the LOC of the software?

  A < 1000 : 7 (15%)

  B $< 10,000$ 25 (54%)

  C $< 100,000$ 3 (6%)

  D $> 100,000$ 6 (14%)

  E Don’t know LOC 5 (11%)

- Q3. How many people were involved in the dev. team?

  A 1: 12 (26%)

  B 2-5 27 (37%)

  C other 7 (15%)

  C no answer 10 (22%)

- Q4. How long did it take to complete?

  A 1 day: 0 (0%)

  B 1 month 12 (17%)

  C 1 year 11 (24%)

  C other 23 (50%)

  D no answer 4 (9%)

- Q6. Which programming language was used?

  A C/C++ : 20 (43%)

  B Java 18 (41%)

  C other 10 (21%)

What Makes Large Software Different ?

Scale	Precludes total comprehension
Complexity	Number of functions, modules, paths
Team Effort	Continuingly changing body of programmers
Communication	Distribution of specifications and documentation
Continuing Change	During design & implementation
	During lifetime
Lifetime	Measured in years or decades
Imprecise goals	Conflicting or ambiguous, changing

Issues in Software Engineering

- Major concern is the construction of *large* programs.
- Central theme is *mastering complexity*.
- Software evolves over its lifetime.
- The efficiency of *software development* is of crucial importance
- Regular cooperation between people is an essential and unavoidable part of large software development.
- Software has to support its users effectively.
- Software Engineering is a field in which members of one culture (designers, programmers) create artifacts on behalf of members of another culture (end users).

The Ideal Goals of Software Engineering

- **Product Quality.** To produce software that is correct and has high quality in terms of user satisfaction.
- **Productivity**
  - To produce software with a minimum of effort.
  - To produce software at the lowest possible cost.
  - To produce software in the least possible time.
- **Profitability.** To maximize the profitability of the software production effort.
- **Maintenability.** To produce software that can be maintained with a minimum of effort.

In practice, none of these ideal goals is ever completely achievable. The challenge of Software Engineering is to see how close we can get to achieving these goals. The *art* of software engineering is achieving the best balance among these goals for a particular project.

Goodness (Quality) Goals Conflict

- All goodness attributes cost $s to achieve
- Interaction between attributes
  - High efficiency may degrade maintainability, reliability
  - More complex User Interface may degrade efficiency, maintainability, and reliability
  - Better documentation may divert effort from efficiency and reliability
- Software Engineering management has to trade-off satisfying goodness goals
- Software Development is (usually) done with a relatively inelastic upper bound on resources expended.

There **A**in't **N**o **S**uch **T**hing **A**s **A** **F**ree **L**unch

Need Different Approaches for Developing Large Software

- Need formal management of software production process
- Formal & detailed statement of requirements, specification and design
- Much more attention to modularity and interfaces
  Must be separable into manageable pieces
- Need configuration management and version control
- More emphasis of rigorous and thorough testing
- Need to plan for long term maintenance and modification
- Need much more documentation, internal and external

  ”A typical commercial software project involves creating more than 20 kinds of paper documents on such items as requirements and functional, logic, and data specifications. For civilian projects, at least 100 English words are produced for every source code statement in the software. For military software, about 400 words are produced for every source code statement. Many new software professionals are surprised when they spend more time producing words than code.”[a]

[a] Capers Jones, Gaps in programming education,IEEE Computer, April 1995 v.28 n.4, pg. 71

Laws of Software Evolution[a]

1. **Law of Continuing Change** A system that is being used undergoes continuous change until it is judged more cost effective to restructure the system of replace it by a completely new system.

2. **Law of Increasing Complexity** A program that is changed becomes less and less structured (*entropy increases*) and thus becomes more complex. One has to invest extra effort in order to avoid increasing complexity.

3. **Law of Program Evolution** The growth rate of global system attributes may seem locally stochastic, but is in fact self-regulating with statistically determinable trends.

4. **Law of Invariant Work Rate** The global progress in software development projects is statistically invariant.

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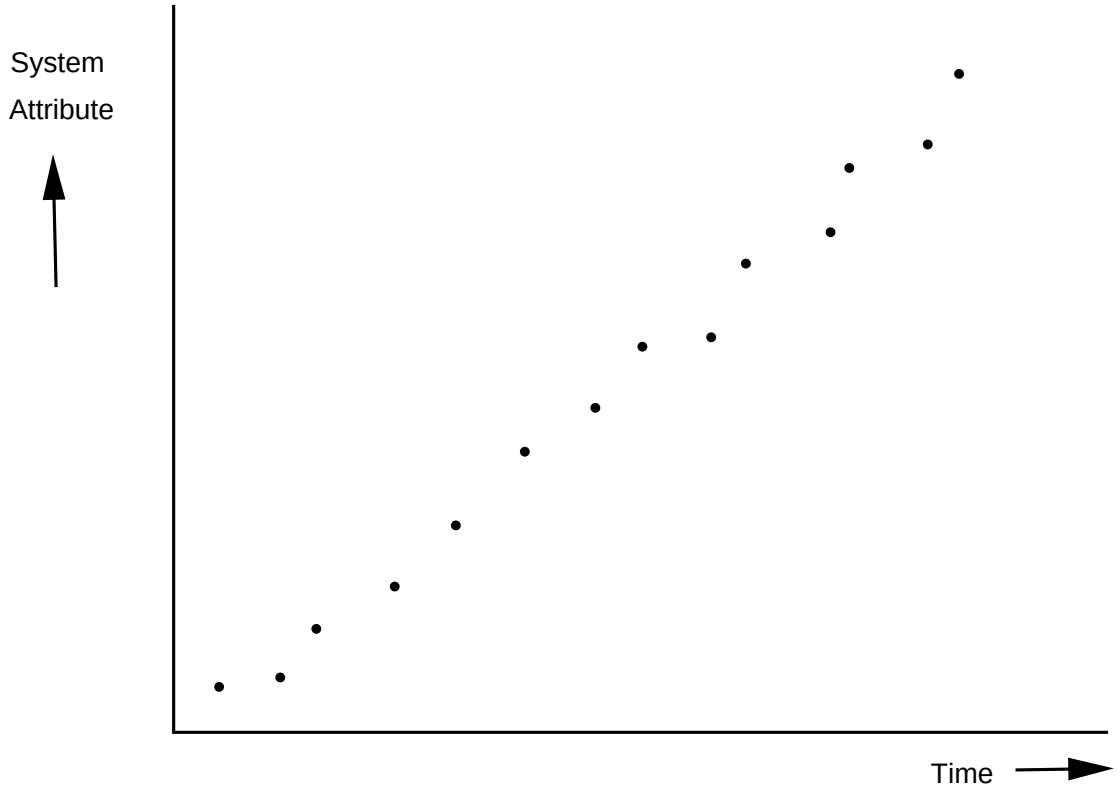
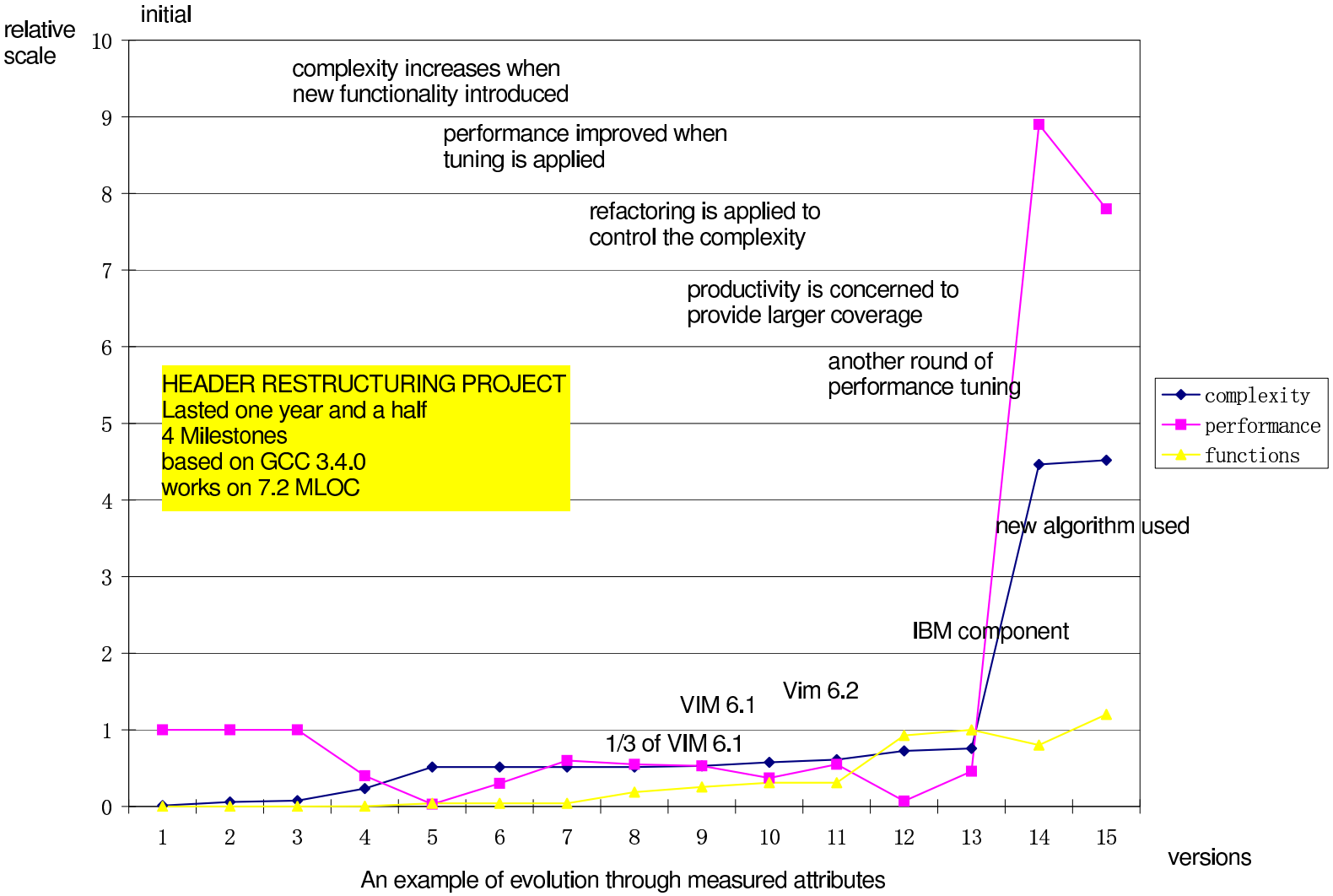
[a] M.M. Lehman and L.A. Belady *Program Evolution, - Processes of Software Change*, Academic Press, 1985

5. **Law of Incremental Growth Limit** A system develops a characteristic growth increment. When this increment is exceeded, problems concerning quality and usage will result.



Header restructuring project



An example of evolution through measured attributes

Significance of Lehman & Belady's Work

- *Unless* proactive steps are taken
  - the maintainablilty of a software system will decrease over time
  - the complexity of a system will increase over time
  - disorder in the system will increase over time
- Change is inevitable, we must learn to accommodate it.
- The amount of maintenance that can be done in a given period of time cannot be (on average) significantly increased by the addition of more resources.
- Attempting to make too large a change in a system will lead to lower quality software

Large Software Development

- The requirements, specification and design of a software system are written by a team of developers.

  A hierarchical approach is often used, with sub-systems being developed by different teams.

- Individual modules (source files) are written, debugged, tested and documented by small teams of programmers.

- The modules in a system exist in some arbitrary *client-server* configuration. Some form of *interface* documents the connection between each server and its clients.

- All of the modules in a system *evolve* over time, due to enhancements and the correction of errors.

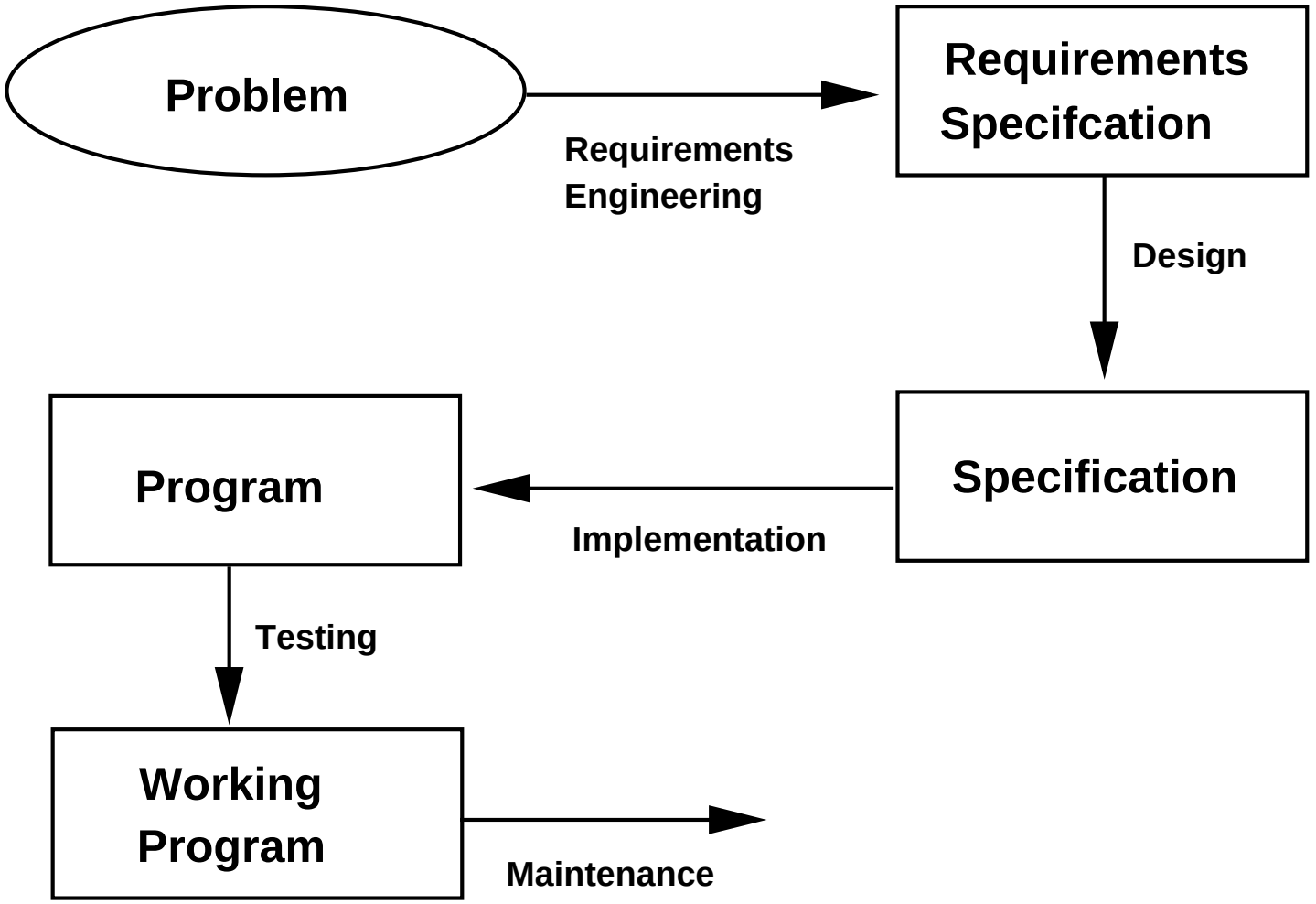
- The cost and time to compile an entire system is sufficiently large that separate compilation and independent subsystem development are essential.

- Specific compiled version of individual modules are linked together to form an instance of the complete software system.

Software Factories (Product-line Families)

- Many software producing organizations do not produce individual software systems, they produce *product families*
  - the same product implemented for different hardware platforms.
  - the same product implemented for different operating system environments.
  - similar products with different levels of functionality and price.
  - similar products heavily customized to the environment of each customer.
- Cost minimization considerations imply that the development and implementation of a product family must be integrated
  - Use (and reuse) common software modules
  - Use common development tools and testing
  - Use common documentation
- The coordination and communication required to build product families makes the development of the individual products much more complicated.

Software Development Process



Major Software Production Tasks

Requirements Analysis	Analyze software system requirements in detail
Specification	Develop a detailed specification for the software
Design	Develop detailed design for the software
	Data structures, software architecture
	procedural detail, interfaces
Coding	Transform design into one or more programming language(s)
Testing	test internal operation of the system
	test externally visible operations & performance
	perform Software Quality Assurance on the system
Release	package and deliver software to users
Maintenance	Error correction and enhancement after system
	has been put into use

Software Development Phases

Phase	Documents	Effort
Project Planning	Project Plan	
Requirements Analysis	System Requirements	10%
	System Specification	10%
Design	System Architecture Description	
	Detailed Software Design	15%
Implementation	Source Code	20%
	Internal documentation	
Testing	Test Plan	45%
	Test case suite, test results log	

Allocation of Effort

- A typical project follows the 40-20-40 rule:

  40% on requirements, specification, architecture, design

  20% on coding, debugging

  40% on testing

- Boem's successful projects followed the 60-15-25 rule:

  60% on requirements, specification, architecture, design

  15% on coding, debugging

  20% on testing

- After a software system in put into use, long term maintenance and modification effort is typically 50% .. 75% of the initial effort.

Requirements Analysis

- A software project will never be successful (i.e. on time, on budget) if the developers do not have a clear idea of what the software should be.
  The requirements should provide this clear idea.
- Requirements analysis should focus on what the client **needs** not what the client **wants**.
- Requirements are one means of communication
  - Between the client and the developer.
  - Between marketing and development.
  - Within the development organization.
- Requirements documents should be organized to accommodate change.
  - Each requirement should be independent.
  - Requirements should be individually modifiable.
    i.e. without requiring changes in other requirements.
- Changes in requirements should be managed and controlled.

Why Requirements are Important

- Significant percentage of all project failure and/or errors in system are due to errors in requirements analysis.
- The further an error propagates the more it costs to repair.
  - $1 during requirements definition
  - $5 during software design
  - $10 during implementation
  - $20 during unit testing
  - $200 after delivery of the system
- A large percentage of **all** software project failures can be related to a failure to get the requirements right.

Good Software Design Principles

- Abstraction
- Modularity
  - **K**eep **I**t **S**imple **S**tupid
  - **D**on’t **R**epeat **Y**ourself
- Information Hiding
- Functional Independence
  - High Cohesion
  - Low Coupling
- Traceability

Abstraction

- Abstractions are generalizations or simplifications of the design that suppress detail
- Being able to view (think about) the design at different levels of abstraction facilitates understanding
- *Pseudo code* or graphical techniques are often used to represent an abstract design
- Abstraction is related to the design process *refinement*
- Develop procedural and data abstractions at different levels in the design
- Need to be careful that high level abstractions don’t preclude consideration of design alternatives at a lower level

Modularity

- Modularity is **a key factor** in successful design
- Modularity assists in:
  - Understanding
  - Development
  - Testing
  - Portability
  - Maintenance
- *Always* develop software using the module concept even when implementing in a programming language without a module construct (e.g. C)
- KISS principle should be applied to module interfaces
- Selecting an appropriate modularization for a system is one of **the most important tasks** in software design

Information Hiding

- Keep knowledge of representation of data as localized as possible. i.e. **hide** information about the representation of data from all those who do not have an unavoidable *need to know*
- Modules in Modula-3, Classes in C++, Packages in Ada are mechanisms for hiding information.
- Strict information hiding takes a *lot* of effort. Need control every where that a data item might get created or modified.
- Information hiding is essential if modules are to be used as plug-replaceable software components
- C++ has a very comprehensive set of mechanisms for information hiding and controlled information disclosure

Functional Independence

- Want modules that implement a *single function* related to the system requirements
- Design by successive refinement helps achieve this goal
- Design to minimize interactions between modules
- Design to keep module interfaces simple

  Minimize number of exported items

  Exported functions and procedures should have small number parameters
- Functional independence helps with
  - Communication between module developers and users
  - Maintenance using modules as units of change
  - Concurrent development and testing of modules
  - Tracking source code back to specification and requirements
  - Containing the effects of software errors

Cohesion

- Cohesion is a measure of the *self containedness* of a module, i.e. to what degree does it perform a *single* task
- **High cohesion** is desirable as it maximizes separability and functional independence
- Levels of cohesion for operations exported by a module

Coincidental	together by chance, i.e. unrelated
Logical	perform logically related operations
Temporal	perform operations related by time
Procedural	operations related by processing requirements
Communicational	operations communicate via common data
Sequential	operations must be performed in specified order
Functional	operations implement a single specific function

Coupling

- Coupling is a measure of the degree of interconnection among modules in a software system
- **Low coupling** is desirable as it maximizes separability and functional independence
- Levels of coupling among modules in a system

None	No direct coupling
Data	Modules communicate via simple data parameters
Stamp	Modules communicate via complex data parameters
Control	Modules communicate via control flags
External	Modules communicate via external media (e.g. files)
Common	Modules communicate via shared global data
Content	Module uses data maintained by another module or one module branches into another module

Advantages of Low Coupling and High Cohesion

- Communication between developers becomes simpler.
- Correctness proofs are easier to derive.
- It is less like that changes in one module will affect other modules making maintenance easier.
- Increases the reusability of modules.
- Increases the comprehensibility of modules.
  This makes maintenance easier and facilitates training new programmers to work on the software.
- Empirically low coupling and high cohesion leads to fewer errors in the software.

Traceability

- An important tool in managing the development of a software system.
- An aid to understanding the *how* and *why* in a complicated system design.
- Forward traceability

  Requirements $\rightarrow$ Specification $\rightarrow$ Design $\rightarrow$ Code $\rightarrow$ Test Cases $\rightarrow$ Product

- Backward traceability

  Requirements $\leftarrow$ Specification $\leftarrow$ Design $\leftarrow$ Code $\leftarrow$ Test Cases $\leftarrow$ Product

- Traceability aids in achieving correctness.

  Traceability facilitates long term system maintenance.

Software Maintenance Activities

Type	Purpose	Effort
corrective	Repair of errors	21%
adaptive	Adapt to environment changes	25%
perfective	Adapt to changes in requirements	50%
	Improve performance or user interface	
	Add new functionality	
preventative	Increase future maintainability	4%
	Updating documentation	
	Improving system modularity/structure	

Course Project

- Reengineering a large software system
- Work in teams
- Three Phase Project
  A. Study a large legacy software and specify new requirements, 15%
  B. Partial implementation, 15%
  C. Swap software and complete implementation, 20%
- http://www.cs.toronto.edu/∼yijun/csc408h/handouts/software.pdf

The OmniEditor Project

- Text editors are friends of programmers, they have advanced editing features
  A. C/C++: VIM, Emacs, NEdit, etc.
  B. Java: Eclipse, jEdit, etc.
  C. Commercial: MS Word, Notepad, UltraEdit, etc.
- To edit as a group, we need groupwares, they have limited editing features
  A. Messenger: MSN, Yahoo!, AOL, etc.
  B. Bulletin Board: BBS, firebird, etc.
  C. Bloggers: Blogger, Webblog, etc.
- **How to combine the heterogenous editors into one groupware?**

Why choose this project for CSC408H?

- It tackles a real problem: until now, there is not much work on bridging the editors. One noteable solution is VIM/NetBeans or VIM/VisioStudio combinations. However, the VIM/Eclipse combination is rather weak. Can you have a general and strong solution?
- It involves large software systems: nowadays text editors are no longer toy systems. They are tools that have been engineered for years.
- It requires new technologies: Web services, middleware
- It is tractable within our course: by divide and conquor

Size of editors

Table 1: LOC of popular open-source editors

editor	version	lines of code	language
VIM	6.3	260,623	C
Emacs	21.3	306,746	C
		263,178	Lisp
XEmacs	21.5.4	353,045	C
		140,830	Lisp
jEdit	4.1	114,117	Java
Eclipse	3.0	1,585,873	Java

Phase A. Understanding legacy software and Requirements Analysis

- Pick 4 partners to form a project team
- Describe the people in the team, allocation of tasks
- Pick one editor (VIM or Eclipse) to study, document the discussions why and how you choose the editor
- Discover why we shall use Web Services to bridge hetergeneous editors
- Describe the architecture of the OmniEditor project
- Plan the project as an iterative process and proposes a test plan

Phase A. Project Requirements

http://www.cs.toronto.edu/∼yijun/csc408h/handouts/project.pdf

- You must have a reasonable solution: Finally at least any two different editors can synchronize the contents with each other through a pair of editing operations.
- You don't reinvent the wheel: try to reuse existing editor as much as possible
- You don't implement everything: spirit of divide and conquor between teams
- You don't all implement the simplest features
- You must be responsible for the product quality

$$\textit{phaseMark} = \textit{projectMark} \times (1 + \max\{0, 0.02 \times \textit{nSelectors} - 0.001 \times \textit{nNetBugs}\})$$

Deliverables after Phase A by Sept. 30

- Documents
  - What is the architecture of the legacy editor and Why
  - What is the architecture of the OmniEditor and Why
  - What is the project plan of the OmniEditor and Why
  - What is the risk of project failure and How to prevent
  - What is your test plan
- Project team
  - Who are the team members and Who is the team leader
  - Skills and Preferences
  - Tasks and allocations
  - Team synchronizations and coordinations

Phase B. Develop the OmniEditor Web Service

- Web service is good for interoperatability and reuse
- Understand the three elements of Web services
  - SOAP – Simple Object Access Protocol
  - WSDL – Web Service Description Language
  - UDDI – Universal Description, Discovering and Integration
- Define the WSDL description of your web service
- Implement the operations as a web service
- Install a web server for web services
  - Java: Apache/Tomcat/Axis or webMethods glue
  - C/C++: Apache/Axis-C or gSOAP
- Deploy the web service on the web server

Deliverables for Phase B by Nov 4

- Source code
  - WSDL and server URL[a]
  - Web service implementation, optional
  - Unit Test cases
- Documentation
  - User's Guide
  - Installation and Deployment
  - Traceability: Requirements, Design and Implementation
  - Bug Report and Maintenance plan

[a] The instructor will assign a unique port number to the web service

Phase C. Integrate the OmniEditorWS with an Editor

- Invoke the web service when it is required by the editor to perform cooperative tasks
- Discover bugs in the web service and communicate with the developers
- Help them to fix the bug and also fix the bug that others found in your deliverable in Phase B

Deliverables for Phase C by Dec 2

- Source code
  - An OmniEditor editor client implementation
  - Integration test scenarios
- Documentation
  - User's Guide
  - Installation and Deployment
  - Bug Report and Fixed Bugs
  - Measured software metrics during software evolution, optional
- **Note** that the Instructuor and Tutors may conduct a system test to find outstanding bugs in your deliverables. So try not to be too ambitious in number of features to keep bugs in bay.

Tutorials

1. Web Services: What is web service, Examples, HowTo's
2. VIM editor: Architecture, Features, How to integrate VIM with IDE?
3. Eclipse: Plugin Architecture, Plugin development, CVS, Text Editor
4. Unit Tests: JUnit, CppUnit, How to test a web service
5. Measure Software Quality: Complexities, Reliability
6. Team Presentation 1 (by end of Phase B)
7. Web services registry (UDDI): Publish/Subscribe, Repository, Advertise/Evaluation
8. Quality of Service: Customer Satisfaction and Defects Fixing
9. Team Presentation 2 (by end of Phase C)
10. Team Presentation 2 (by end of Phase C)
11. Q/A