CAS 741, CES 741 (Development of Scientific Computing Software)

Fall 2017

13 Modular Design

Dr. Spencer Smith

Faculty of Engineering, McMaster University

October 23, 2017

Modular Design

- Administrative details
- Questions?
- Feedback on SRS
- Overview of design
- Modular decomposition: advantagages, guidelines etc.
- Module guide
- Module guide example
- Integration Testing

Administrative Details

- GitHub issues
  - When closing issues give the hash for the corresponding commit
  - Everyone should have an issue to review my comments on their SRS or CA
- For MG presentation, we'll try to use my laptop only
- Grading scheme for VnV now available on Avenue
- Template for MG updated in repo

Administrative Details: Deadlines

V&V Plan	Week 07	Oct 25
MG Present	Week 08	Week of Oct 30
MG	Week 09	Nov 8
MIS Present	Week 10	Week of Nov 13
MIS	Week 11	Nov 22
Impl. Present	Week 12	Week of Nov 27
Final Documentation	Week 13	Dec 6

Administrative Details: Presentation Schedule

- MG Present
  - **Tuesday: Xiaoye, Shusheng, Devi, Keshav, Alex P, Paul**
  - **Friday: Yuzhi, Jason, Geneva, Alex S, Isobel, Steven**
- MIS Present
  - Tuesday: Isobel, Keshav, Paul
  - Friday: Shusheng, Xiaoye, Devi
- Impl. Present
  - Tuesday: Alexander S., Steven, Alexandre P.
  - Friday: Jason, Geneva, Yuzhi

Questions?

- Questions about Verification and Validation plan?

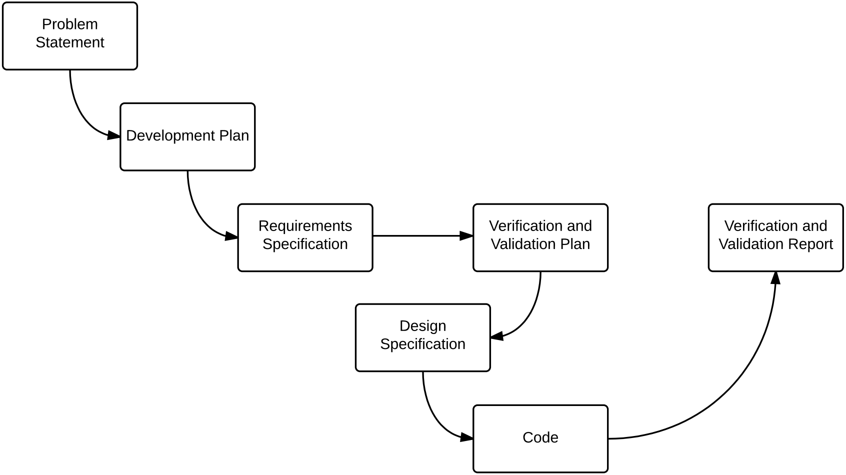
Feedback on SRS

- Overall well done!
- Don't need padding (**Watch for MG!**)
  - Don't make more complicated than it is
  - Don't add assumptions that the data will be in the correct format, or of the correct type
- For the characteristics of intended reader try to be more specific about the education. What degree? What course areas? What level?
- If you have a reference by entry, then the referenced by chunk (or its derivation) should actually reference the chunk that has it as an entry.
- Functional requirements should reference the instance models
- Add more for nonfunctional requirements
- Introduce type information when it will help clarify spec

LaTeX Related Feedback

- The text is better for version control, and for reading in other editors, if you use a hard-wrap at 80 characters
- Use `` ``quote'' `` to get correct quotation marks
- Spell check!
- Check for extra and missing spaces
- LaTeX often inserts two spaces after a period, use `Dr.\ Jeckyl` or `Dr.~Jeckyl`
- For $ABC_{Average}$ in an equation use `$\mathit{ABC}_{\text{Average}}$` ($\mathit{ABC}_{\text{Average}}$)
- Use BibTeX. You should mention the source of the template [9, 10]
- Cite all sources!

Review of our "Faked" Rational Design Process



What is Design?

- Your requirements document identifies "What," now we begin to look at "How"
- Your system should meet both your functional and nonfunctional requirements
- There is no unique "optimal" design
  - Different goals will lead to different designs
  - There is a mix of art and science in design
  - Even with fully formal requirements specification there does not yet exist a systematic way to obtain a design
  - Favour art in some areas and favour science in others

What is Design Continued?

- Provides structure to any artifact
- Decomposes system into parts, assigns responsibilities, ensures that parts fit together to achieve a global goal
- Design refers to
  - Activity
    - Bridge between requirements and implementation
    - Structure to an artifact
  - Result of the activity
    - System decomposition into modules (module guide)
    - Module interface specification (MIS)

Why Decompose Into Modules?

- Separation of concerns
- Cannot understand all of the details
- All engineering fields use decomposition
- Modules will act as "work assignments"
- Decomposition needs to follow a systematic procedure (as for SRS)
- Need to ensure that modules when fit together achieve our global goals
- Document in a Software Design Document (Module Guide)

Benefits of Modularity

- Shorter development time
- Improved verification
- Reduced maintenance costs
- Easier to understand
  - Small modules
  - An abstract interface
- Modules can be developed independently
- Modules can be tested independently
- Modules can be reused
- Software is easy to change, extend, maintain
- This requires identifying the anticipated changes in the design and in the requirements

Two Important Goals for Decomposition

- Design for change (Parnas) [5, 6]
  - Designers tend to concentrate on current needs
  - Special effort needed to anticipate likely changes
  - Changes can be in the design or in the requirements
  - Too expensive to design for all changes, but should design for likely changes
- Product families (Parnas) [4, 7]
  - Think of the current system under design as a member of a program family
  - Analogous to product lines in other engineering disciplines
  - Example product families include automobiles, cell phones, etc.
  - Design the whole family as one system, not each individual family member separately

Use Design Principle of Information Hiding

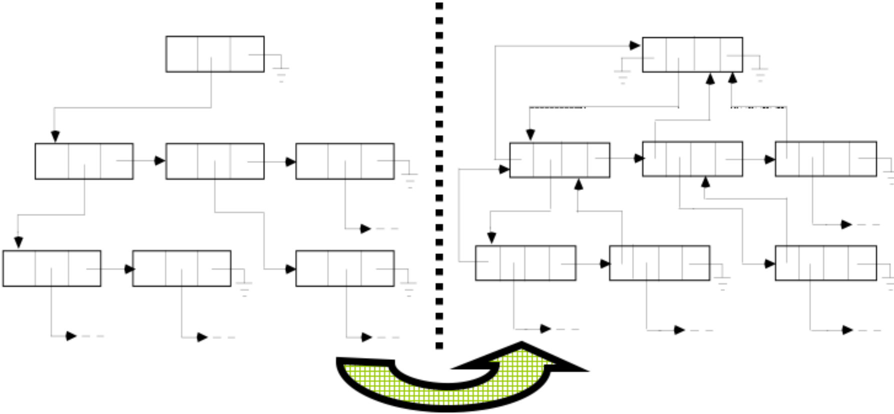
Sample Likely Changes

What are some examples of likely changes for software?

Sample Likely Changes [2]

- Algorithms – like replacing inefficient sorting algorithm with a more efficient one
- Change of data representation
  - From binary tree to threaded tree
  - Array implementation to a pointer implementation
  - Approx. 17% of maintenance costs attributed to data representation changes (Lientz and Swanson, 1980)
- Change of underlying abstract machine
  - New release of operating system
  - New optimizing compiler
  - New version of DBMS
  - etc.
- Change of peripheral devices

Binary Tree to Threaded Tree



Sample Likely Changes

- Change of “social” environment
  - Corresponds to requirements changes
  - New tax regime
  - EURO versus national currency in EU
  - New language for user interface
  - y2k
- Change due to development process (prototype transformed into product)

Components of a Module

- A software modules has two components
  1. An interface that enables the module's clients to use the service the module provides
  2. An implementation of the interface that provides the services offered by the module

The Module Interface

- A module's interface can be viewed in various ways
  - As a set of services
  - As a contract between the module and its clients
  - As a language for using the module's services
- The interface is exported by the module and imported by the module's clients
- An interface describes the data and procedures that provide access to the services of the module

The Module Implementation

- A module's implementation is an implementation of the module's interface
- The implementation is hidden from other modules
- The interface data and procedures are implemented together and may share data structures
- The implementation may utilize the services offered by other modules

Information Hiding

- Made explicit by Parnas [5]
- Basis for design (that is modular decomposition (Module Guide))
- Implementation secrets are hidden to clients
- Secret can be changed freely if the change does not affect the interface
- Try to encapsulate changeable design decisions as implementation secrets within module implementations

Examples of Modules [2]

- Record
  - Consists of only data
  - Has state but no behaviour
- Collection of related procedures (library)
  - Has behaviour but no state
  - Procedural abstractions
- Abstract object
  - Consists of data (fields) and procedures (methods)
  - Consists of a collection of constructors, selectors, and mutators
  - Has state and behaviour

Examples of Modules Continued

- Abstract data type (ADT)
  - Consists of a collection of abstract objects and a collection of procedures that can be applied to them
  - Defines the set of possible values for the type and the associated procedures that manipulate instances of the type
  - Encapsulates the details of the implementation of the type
- Generic Modules
  - A single abstract description for a family of abstract objects or ADTs
  - Parameterized by type
  - Eliminates the need for writing similar specifications for modules that only differ in their type information
  - A generic module facilitates specification of a stack of integers, stack of strings, stack of stacks etc.

Questions

- What relationships are there between modules?
- Are there desirable properties for these relations?

Relationships Between Modules

- Let S be a set of modules

$$S = \{M_1, M_2, ..., M_n\}$$

- A binary relation r on S is a subset of $S \times S$
- If M_i and M_j are in S, $< M_i, M_j > \in r$ can be written as $M_i r M_j$

Relations

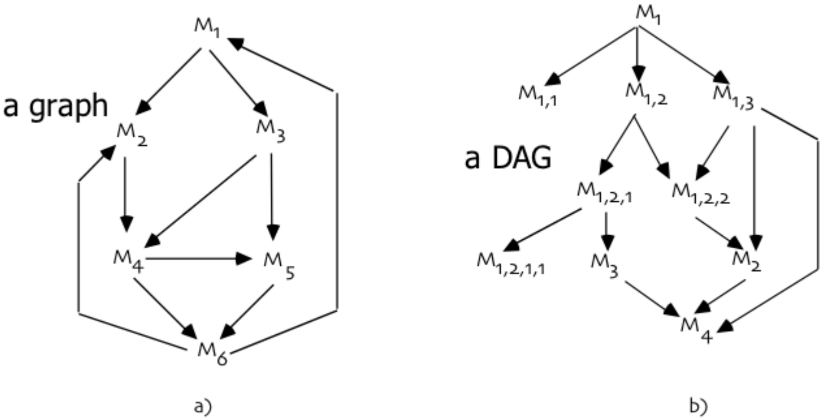
- Transitive closure r^+ of r

  $M_i r^+ M_j$ iff $M_i r M_j$ or $\exists M_k$ in S such that $M_i r M_k$ and $M_k r^+ M_j$

- r is a hierarchy iff there are no two elements M_i, M_j such that $M_i r^+ M_j \wedge M_j r^+ M_i$

Relations Continued

- Relations can be represented as graphs
- A hierarchy is a DAG (Directed Acyclic Graph)



Why do we prefer the uses relation to be a DAG?

Desirable Properties

- USES should be a hierarchy [6]
  - Hierarchy makes software easier to understand
  - We can proceed from the leaf nodes (nodes that do not use other nodes) upwards
  - They make software easier to build
  - They make software easier to test
- Low coupling
- Fan-in is considered better than Fan-out: WHY?

DAG Versus Tree

Is a DAG a tree? Is a tree a DAG?

DAG Versus Tree

Would you prefer your uses relation is a tree?

Hierarchy

- Organizes the modular structure through levels of abstraction
- Each level defines an abstract (virtual) machine for the next level
- Level can be defined precisely
  - M_i has level 0 if no M_j exists such that $M_i r M_j$
  - Let k be the maximum level of all nodes M_j such that $M_i r M_j$, then M_i has level $k+1$

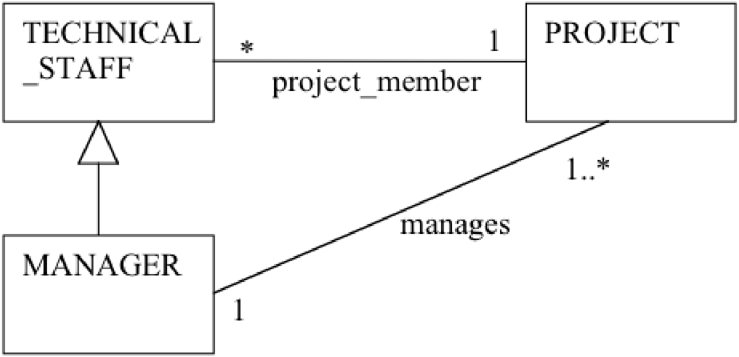
Static Definition of Uses Relation

Your program has code like:
`if cond then ServiceFromMod1 else ServiceFromMod2`

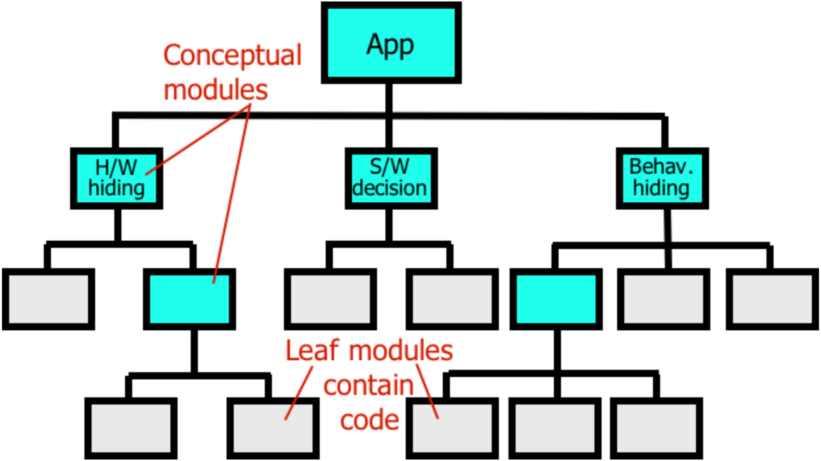
This is the only place where each module is used. Does this mean the uses relation depends on the dynamic execution of the program?

Question about Association and DAG

Is the uses relation here a DAG?



Module Decomposition (Parnas)



Module Decomposition (Parnas)

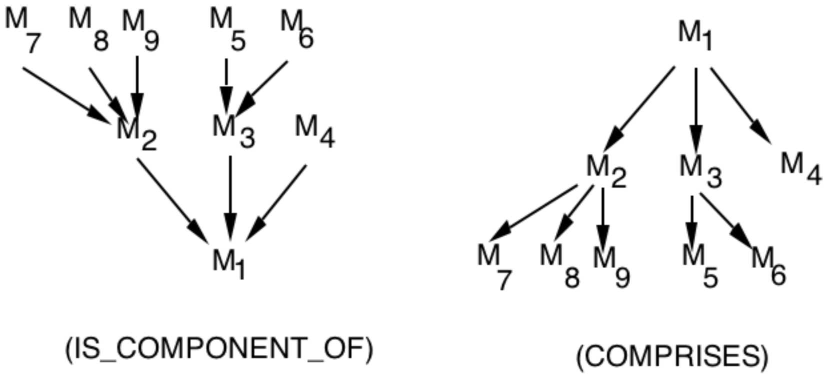
For the module decomposition on the previous slide:

- Does it show a Uses relation?
- Is it a DAG?
- Is it a tree?

IS_COMPONENT_OF

- The Parnas decomposition by secrets gives an IS_COMPONENT_OF relationship
- Used to describe a higher level module as constituted by a number of lower level modules
- A IS_COMPONENT_OF B means B consists of several modules of which one is A
- B COMPRISES A
- $M_{S,i} = \{M_k | M_k \in S \wedge M_k$ IS_COMPONENT_OF $M_i\}$ we say that $M_{S,i}$ IMPLEMENTS M_i
- How is IS_COMPONENT_OF represented in UML?

A Graphical View



They are a hierarchy

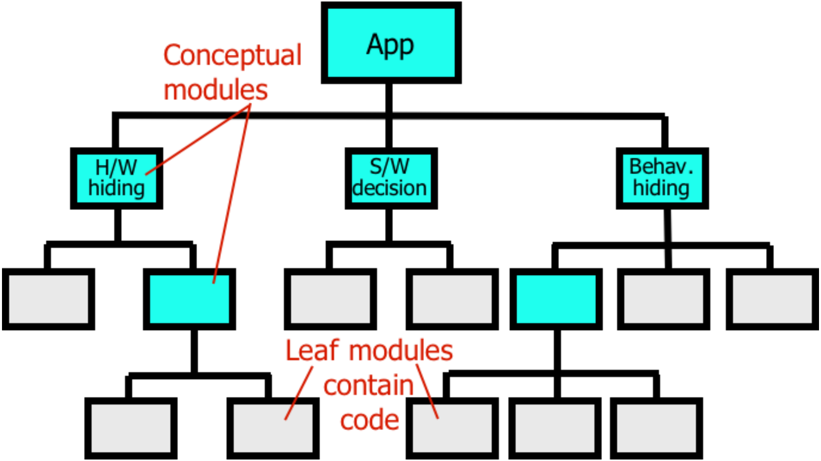
Module Guide [8]

- Part of Parnas' Rational Design Process (RDP)
- When decomposing the system into modules, we need to document the module decomposition so that developers and other readers can understand and verify the decomposition
- Helps future maintainers find appropriate module
- Parnas proposed a Module Guide (MG) based on the decomposition module tree shown earlier
- Decomposition is usually three to five levels deep

Three Top Conceptual Modules in an RDP MG

What are the three groups of modules in a typical information-hiding decomposition?

Module Decomposition (Parnas)



RDP - MG

- The MG consists of a table that documents each module's service and secret
- Conceptual modules will have broader responsibilities and secrets
- Following a particular branch, the secrets at lower levels "sum up" to the secret at higher levels
- The leaf modules that represent code will contain much more precise services and secrets
- Only the leaf modules are actually implemented
- The MG should list the likely and unlikely changes on which the design is based

Module Details

- For each module
- Module name
- Secret (informal description)
- Service or responsibility (informal description)
- For "leaf" modules add
  - Associated requirement
  - Anticipated change
  - Module prefix (optional)

RDP - MG

- Criteria for a good secret
  - One module one secret, especially for leaf modules (watch for "and")
  - Secrets should often be nouns (data structure, algorithm, hardware, ...)
  - Secrets are often phrased as "How to ... "

Good Secret?

Is the following a good module secret: "The file format for the map and the rules for validating that the map satisfies the environmental constraints."

Typical Modules [3]

- What are the typical secrets for an input variable?
  - You have an input in the environment, how to get it into your system?
  - What format is the input data?
- What are the secrets for an output variable?
  - How to get an output from inside the system to the external environment?
  - How will the output be determined?
  - What format will the output have?
- What are the secrets for a state variable?
  - What rules are there governing the state transitions?
  - What data structures or algorithms are needed?

Typical Modules [3]

- Input variables
  - Machine-hiding from hardware or OS service
  - Behaviour-hiding input format
- Output variables
  - Machine-hiding
  - Behaviour-hiding output format
  - Behaviour-hiding (calculation)
- State variables
  - Software decision hiding for data structure/algorithm
  - Behaviour-hiding state-drive
- Judgement is critical
- Often combine variables into the same module
- For non-embedded systems, machine hiding for input-output is often combined

RDP - Views

- As well as the MG, the modular decomposition should be displayed using a variety of views
- An obvious one is the Uses Hierarchy
- The Uses Hierarchy is updated once the MIS for all modules is complete
- The Uses Hierarchy can be represented
  - Graphically (if it isn't too large and complex)
  - Using a binary matrix – What would the binary matrix look like?

MG Template

- Table of contents
- Introduction
- Anticipated and unlikely changes
- Module hierarchy
- Connection between requirements and design
- Module decomposition
  - Hardware hiding modules
  - Behaviour hiding modules
  - Software decision hiding modules
- Traceability matrices
- Uses hierarchy between modules

Traceability Matrices

- Traceability matrix help inspect the design
- Check for completeness, look at from a different viewpoint

Req.	**Modules**
R1	M1, M2, M3, M7
R2	M2, M3
...	...

AC	**Modules**
AC1	M1
AC2	M2
...	...

Verification

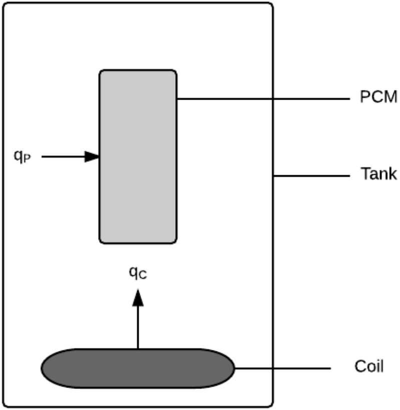
- Well formed (consistent format/structure)
  - Follows template
  - Follows rules (one secret per module, nouns etc.)
- Feasible (implementable at reasonable cost)
  - Difficult to assess
  - Try sketches of MIS
- Flexible
  - Again try sketches of MIS
  - Thought experiment as if likely change has occurred
  - Low coupling
  - Encapsulate repetitive tasks
- May sometimes have to sacrifice information hiding

Object Oriented Design Versus Modular Desiogn

- OO-design and OO-languages are different
- OO-design
  - Classes and methods
  - Classes are like modules (state variables and access functions (methods))
  - An object is an instance of a class
  - Polymorphism
  - Inheritance - use carefully
- Implementation of modules using an OO-lang is natural

Solar Water Heating System Example

- https://github.com/smiths/swhs
- Solve ODEs for temperature of water and PCM
- Solve for energy in water and PCM
- Generate plots



Anticipated Changes?

What are some anticipated changes?

Hint: the software follows the Input $\rightarrow$ Calculate $\rightarrow$ Output design pattern

Anticipated Changes

- The specific hardware on which the software is to run
- The format of the initial input data
- The format of the input parameters
- The constraints on the input parameters
- The format of the output data
- The constraints on the output results
- How the governing ODEs are defined using the input parameters
- How the energy equations are defined using the input parameters
- How the overall control of the calculations is orchestrated
- The implementation of the sequence data structure
- The algorithm used for the ODE solver
- The implementation of plotting data

Module Hierarchy by Secrets

Level 1	**Level 2**
Hardware-Hiding Module	
Behaviour-Hiding Module	Input Format Module Input Parameters Module Output Format Module Temperature ODEs Module Energy Equations Module Control Module
Software Decision Module	Sequence Data Structure Module ODE Solver Module Plotting Module

Table: Module Hierarchy

Example Modules from SWHS

Hardware Hiding Modules

Secrets: The data structure and algorithm used to implement the virtual hardware.

Services: Serves as a virtual hardware used by the rest of the system. This module provides the interface between the hardware and the software. So, the system can use it to display outputs or to accept inputs.

Implemented By: OS

Example Modules from SWHS

Input Verification Module

Secrets: The rules for the physical and software constraints.

Services: Verifies that the input parameters comply with physical and software constraints. Throws an error if a parameter violates a physical constraint. Throws a warning if a parameter violates a software constraint.

Implemented By: SWHS

Example Modules from SWHS

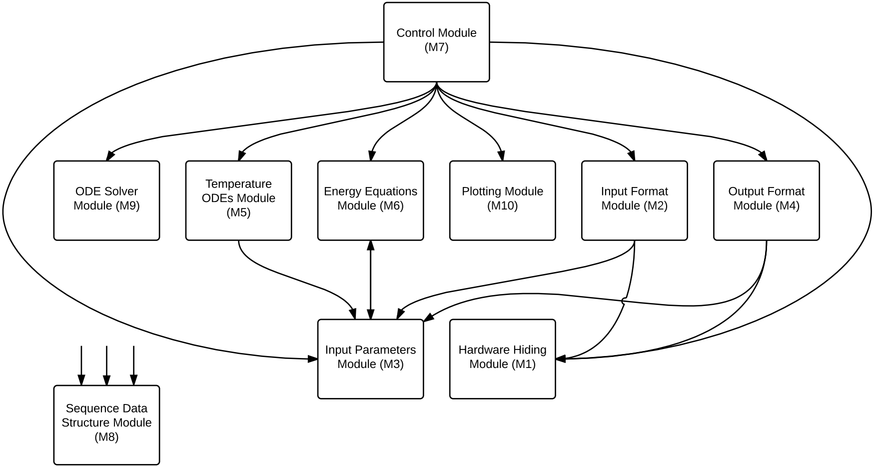
ODE Solver Module

Secrets: The algorithm to solve a system of first order ODEs.

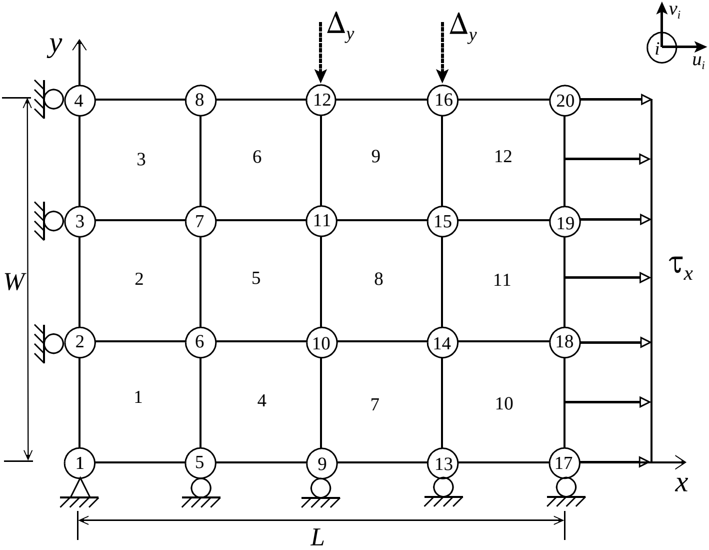
Services: Provides solvers that take the governing equation, initial conditions, and numerical parameters, and solve them.

Implemented By: Matlab

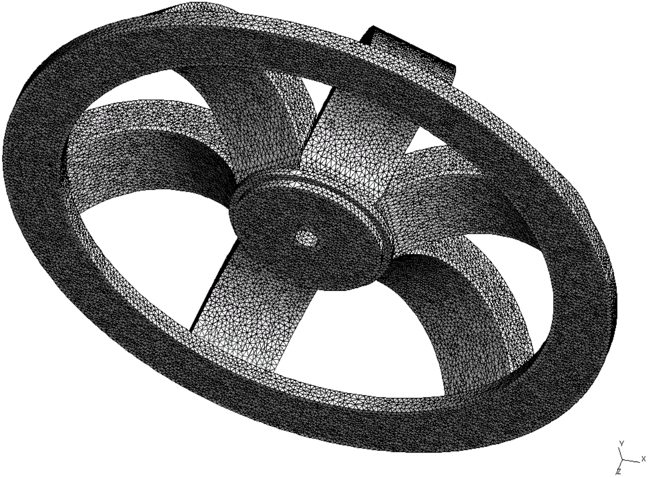
SWHS Uses Hierarchy



Mesh Generator Example



Mesh Generator Complex Circular Geometry



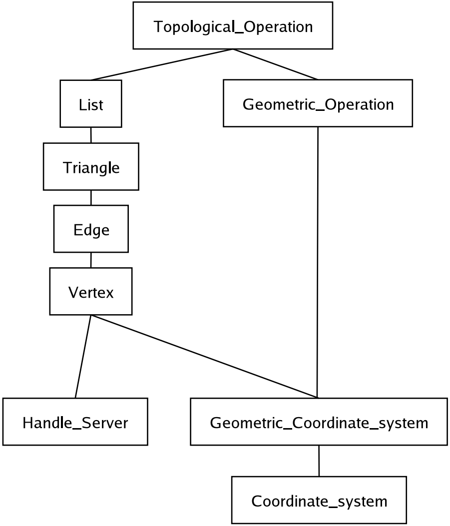
Mesh Generator Example: Design Goals

- Independent and flexible representation for each mesh entity
- Complete separation of geometric data from the topology
- The mesh generator should work with different coordinate systems
- A flexible data structure to store sets of vertices, edges and triangles
- Different mesh generation algorithms with a minimal amount of local changes

Example Mesh Gen Modular Decomposition

Link

Another Mesh Generator Uses Hierarchy [1]



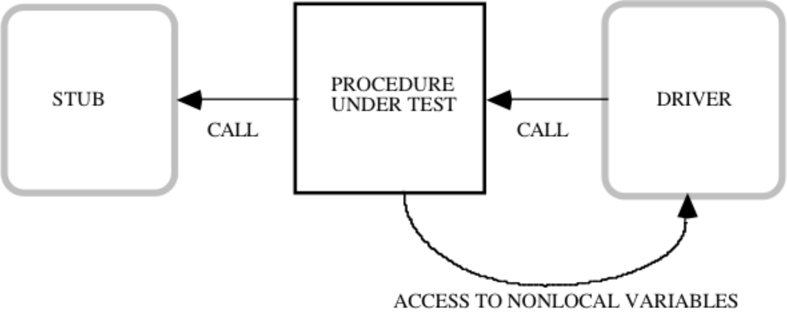
Module Testing

Is it possible to begin testing before all of the modules have been implemented when there is a use relation between modules?

Module Testing [2]

- Scaffolding needed to create the environment in which the module should be tested
- Stubs - a module used by the module under test
- Driver - module activating the module under test

Testing a Functional Module [2]



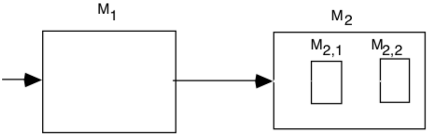
Integration Testing

- Big-bang approach
  - First test individual modules in isolation
  - Then test integrated system
- Incremental approach
  - Modules are progressively integrated and tested
  - Can proceed both top-down and bottom-up according to the USES relation

Integration Testing and USES relation

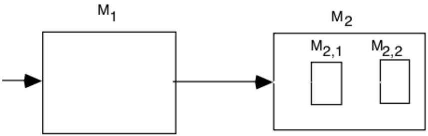
- If integration and test proceed bottom-up only need drivers
- Otherwise if we proceed top-down only stubs are needed

Example [2]



- M_1 USES M_2 and M_2 IS_COMPOSED_OF $\{M_{2,1},\ M_{2,2}\}$
- In what order would you test these modules?

Example [2]



- M_1 USES M_2 and M_2 IS_COMPOSED_OF $\{M_{2,1}, M_{2,2}\}$
- Case 1
  - Test M_1 providing a stub for M_2 and a driver for M_1
  - Then provide an implementation for $M_{2,1}$ and a stub for $M_{2,2}$
- Case 2
  - Implement $M_{2,2}$ and test it by using a driver
  - Implement $M_{2,1}$ and test the combination of $M_{2,1}$ and $M_{2,2}$ (i.e. M_2) by using a driver
  - Finally implement M_1 and test it with M_2 using a driver for M_1

References I

- Ahmed H. ElSheikh, W. Spencer Smith, and Samir E. Chidiac.
  Semi-formal design of reliable mesh generation systems.
  Advances in Engineering Software, 35(12):827–841, 2004.

- Carlo Ghezzi, Mehdi Jazayeri, and Dino Mandrioli.
  Fundamentals of Software Engineering.
  Prentice Hall, Upper Saddle River, NJ, USA, 2nd edition, 2003.

- Daniel M. Hoffman and Paul A. Strooper.
  Software Design, Automated Testing, and Maintenance: A Practical Approach.
  International Thomson Computer Press, New York, NY, USA, 1995.

References II

David Parnas.
On the design and development of program families.
IEEE Transactions on Software Engineering, SE-2(1):1–9, 1976.

David L. Parnas.
On the criteria to be used in decomposing systems into modules.
Comm. ACM, 15(2):1053–1058, December 1972.

David L. Parnas.
On a 'buzzword': Hierarchical structure.
In *IFIP Congress 74*, pages 336–339. North Holland Publishing Company, 1974.

References III

- David L. Parnas.
  Designing software for ease of extension and contraction.
  IEEE Transactions on Software Engineering, pages 128–138, March 1979.

- D.L. Parnas, P.C. Clement, and D. M. Weiss.
  The modular structure of complex systems.
  In *International Conference on Software Engineering*, pages 408–419, 1984.

References IV

W. Spencer Smith and Lei Lai.
A new requirements template for scientific computing.
In J. Ralyté, P. Ȧgerfalk, and N. Kraiem, editors, *Proceedings of the First International Workshop on Situational Requirements Engineering Processes – Methods, Techniques and Tools to Support Situation-Specific Requirements Engineering Processes, SREP'05*, pages 107–121, Paris, France, 2005. In conjunction with 13th IEEE International Requirements Engineering Conference.

References V

W. Spencer Smith, Lei Lai, and Ridha Khedri.
Requirements analysis for engineering computation: A systematic approach for improving software reliability.
Reliable Computing, Special Issue on Reliable Engineering Computation, 13(1):83–107, February 2007.