

# CAS 741 (Development of Scientific Computing Software)

Winter 2023

## Module Interface Specification (MIS)

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# Module Interface Specification (MIS)

- Administrative details
- Questions?
- Module guide example
- MIS example
- Integration testing
- MIS overview
- Modules with external interaction
- Abstract objects
- Abstract data types
- Generic MIS
- Inheritance

# Administrative Details

- Mathematical review
  - ▶ [\[3\]](#)
  - ▶ [Review Slides](#)
  - ▶ [MIS Format](#)
- Potential software for drawing figures
  - ▶ [draw.io](#)
  - ▶ [Tkiz](#)

# Administrative Details: Report Deadlines

**MG + MIS**                      Week 09    Mar 17

**Drasil Code**                      Week 09    Mar 17

Final Documentation    Week 13    Apr 12

- The written deliverables will be graded based on the repo contents as of 11:59 pm of the due date
- If you need an extension for a **written** doc, please ask
- When ready, assign issues to your primary and secondary reviewers
- GitHub issues due two days after assignment deadlines
- From Drasil Code onward, Drasil projects no longer need to maintain traditional SRS

# Administrative Details: Presentations

<b>POC Demo</b>	Week 06, 07	Week of Feb 13, 27
<b>MG + MIS Syntax</b>	Week 09	Week of Mar 13
<b>MIS Semantics</b>	Week 09	Week of Mar 13
Unit VnV/Implement	Week 11/12	Week of Mar 27, Apr 3
Drasil	Week 11/12	Week of Mar 27, Apr 3

- Specific schedule depends on final class registration
- Informal presentations with the goal of improving everyone's written deliverables
- Domain experts and secondary reviewers (and others) will ask questions

# Presentation Schedule

- Proof of Concept Demonstrations (25 min)
  - ▶ **Mar 2: Maryam, Deesha, Karen**
- MG Present (Drasil SRS Code) (15 minutes)
  - ▶ **Mar 15: Maryam, Joachim, Karen, Sam, Volunteer?**
- MIS Present (Drasil SRS Code) (15 min)
  - ▶ Mar 16: Jason, Lesley, Deesha, Mina
- Drasil Project Present (25 min each)
  - ▶ Mar 29: Volunteer?, Sam, Jason

# Presentation Schedule

- Test or Impl. Present (25 min each)
  - ▶ Apr 5: Lesley, Karen, Deesha
  - ▶ Apr 6: Mina, Joachim, Maryam
- 4 presentations each (please check)
- If you will miss a presentation, please trade with someone else

# MG and MIS Presentations

- MG Presentation
  - ▶ Likely Changes
  - ▶ Decomposition Hierarchy Figure
  - ▶ Uses Relation Hierarchy
  - ▶ Secrets of Most Important Modules
- MIS Presentations
  - ▶ Uses Relation Hierarchy
  - ▶ Syntax
    - ▶ Access Programs (types of inputs and outputs)
    - ▶ State Variables
    - ▶ Environment Variables
    - ▶ Type of module (record, library, abstract object, ADT, generic)
  - ▶ Semantics - don't get caught up with them at this point
    - ▶ What modules cause state or environment transitions?
    - ▶ Can you describe access program behaviour in words?

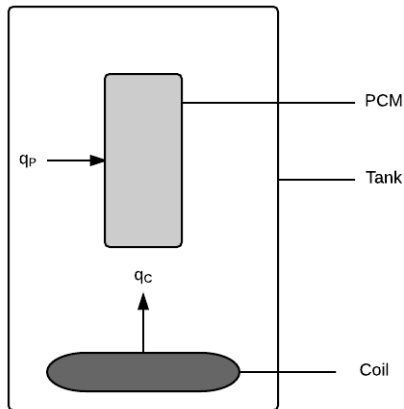


# Questions?

- Questions on administrative details?
- Questions about Module Guide?
- Questions about upcoming presentation?
- Questions about design?
- Questions about anything (course related)?

# 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 Parameters Module Output Format Module Temperature ODEs Module Energy Equations Module Control Module Specification Parameters
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 Parameters Module

**Secrets:** The data structure for input parameters, how the values are input and how the values are verified. The load and verify secrets are isolated to their own access programs (like submodules).

**Services:** Gets input from user (including material properties, processing conditions, and numerical parameters), stores input and 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

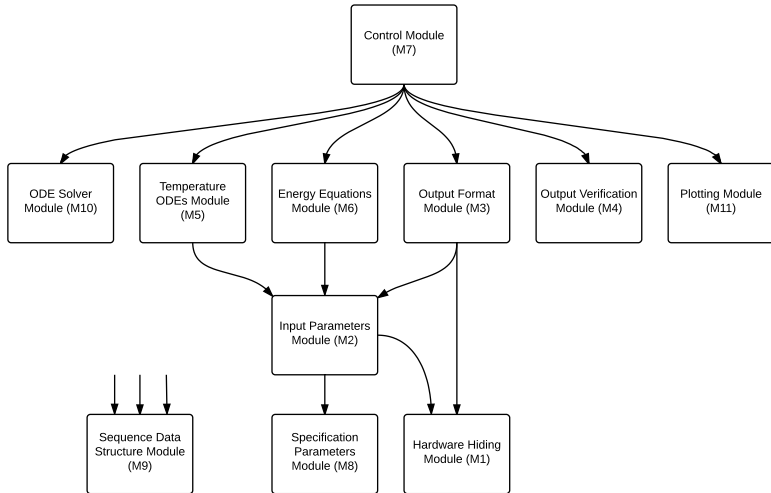
**Secrets:** The algorithm to solve a system of first order ODEs initial value problem from a given starting time until the given event function shows termination.

**Services:** Solves an ODE using the governing equation, initial conditions, event function and numerical parameters.

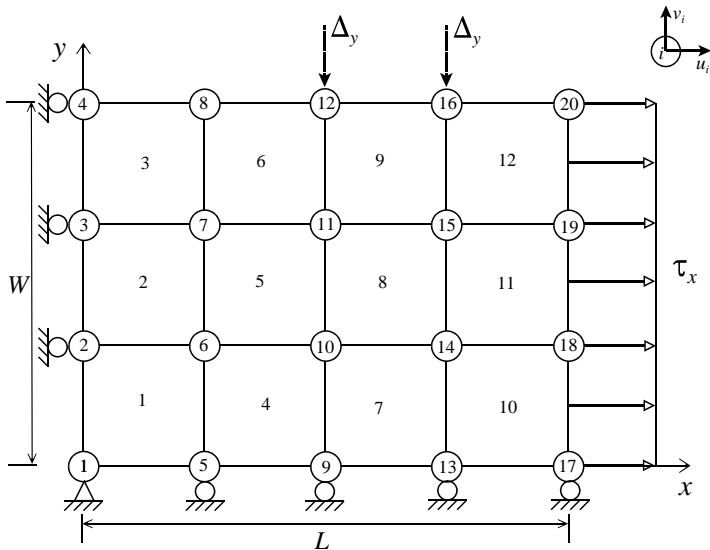
**Implemented By:** Matlab



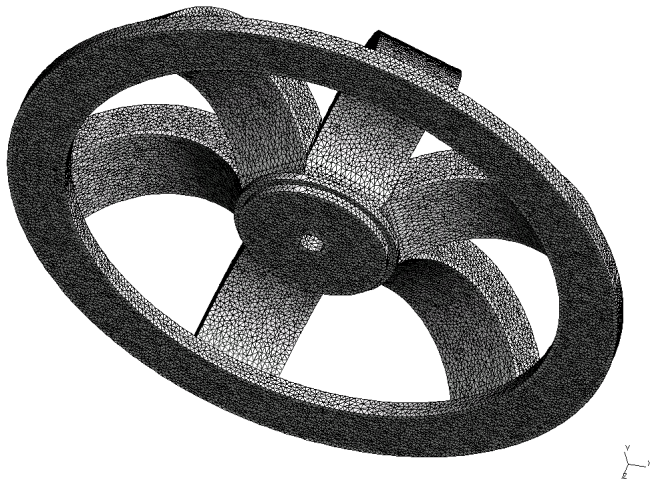
# SWHS Uses Hierarchy (approximately)



# Mesh Generator Example



# Mesh Generator Complex Circular Geometry



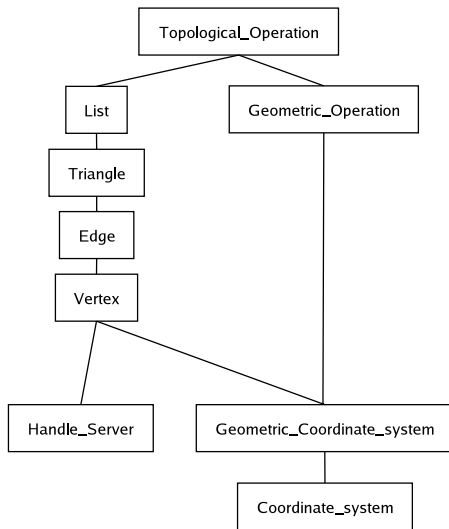
# Mesh Generator Example: Design Goals

- 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]



# 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.



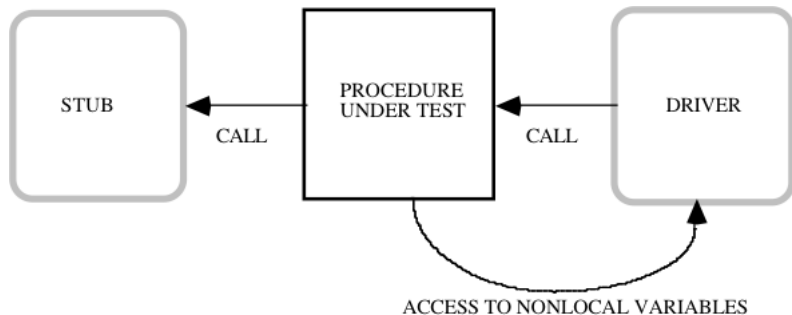
# Module Testing

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]



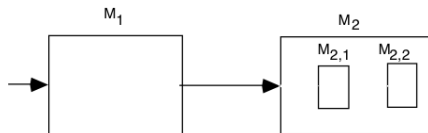
# Integration Testing

- 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

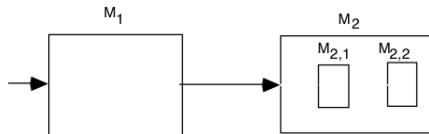
- If integration and test proceed bottom-up only need drivers
- Otherwise if we proceed top-down only stubs are needed

## 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  $M_1$

# Overview of MIS

- See Hoffman and Strooper [3]
- The MIS precisely specifies the modules observable behaviour - what the module does
- The MIS does not specify the internal design
- The idea of an MIS is inspired by the principles of software engineering
- Advantages
  - ▶ Improves many software qualities
  - ▶ Programmers can work in parallel
  - ▶ Assumptions about how the code will be used are recorded
  - ▶ Test cases can be decided on early, and they benefit from a clear specification of the behaviour
  - ▶ A well designed and documented MIS is easier to read and understand than complex code
  - ▶ Can use the interface without understanding details



# Overview of MIS

- Options for specifying an MIS
  - ▶ Trace specification
  - ▶ Pre and post conditions specification
  - ▶ Input/output specification
  - ▶ Before/after specification - module state machine
  - ▶ Algebraic specification
- Best to follow a template

# MIS Example: SWHS

- <https://github.com/smiths/swhs>
- Has some constant values
- Input parameters
- Solve ODEs for temperature of water and PCM
- Solve for energy in water and PCM
- Output results
- Generate plots

# MIS Template

- Uses
  - ▶ Imported constants, data types and access programs
- Syntax
  - ▶ Exported constants and types
  - ▶ Exported functions (access routine interface syntax)
- Semantics
  - ▶ State variables
  - ▶ State invariants
  - ▶ Assumptions
  - ▶ Access routine semantics
  - ▶ Local functions
  - ▶ Local types
  - ▶ Local constants
  - ▶ Considerations

# MIS Uses Section

- Specify imported constants
- Specify imported types
- Specify imported access programs
- The specification of one module will often depend on using the interface specified by another module
- When there are many modules the uses information is very useful for navigation of the documentation
- Documents the use relation between modules

# MIS Syntax Section

- Specify exported constants
- Specify exported types
- Specify access routine names, the input and output parameter types and exceptions
- Show access routines in tabular form
  - ▶ Important design decisions are made at this point
  - ▶ The goal is to have the syntax match many implementation languages

# Syntax of a Sequence Module

## Exported Constants

`MAX_SIZE = 100`

# Syntax of a Sequence Module Continued

## Exported Access Programs

<b>Routine name</b>	<b>In</b>	<b>Out</b>	<b>Exceptions</b>
seq_init			
seq_add	integer, integer		FULL, POS
seq_del	integer		POS
seq_setval	integer, integer		POS
seq_getval	integer	integer	POS
seq_size		integer	

# MIS Semantics Section

- State variables
  - ▶ Give state variable(s) name and type
  - ▶ State variables define the state space
  - ▶ If a module has state then it will have “memory”
- State invariant
  - ▶ A predicate on the state space that restricts the “legal” states of the module
  - ▶ After every access routine call, the state should satisfy the invariant
  - ▶ Cannot have a state invariant without state variables
  - ▶ Just stating the invariant does not “enforce” it, the access routine semantics need to maintain it
  - ▶ Useful for understandability, testing and for proof



# Semantics Section Continued

- Local functions, local types and local constants
  - ▶ Declared for specification purposes only
  - ▶ Not available at run time
  - ▶ Helpful to make complex specifications easier to read
- Considerations
  - ▶ For information that does not fit elsewhere
  - ▶ Useful to tell the user if the module violates a quality criteria

# Sequence MIS Semantics

## State Variables

$s$ : sequence of integer

## State Invariant

$|s| \leq \text{MAX\_SIZE}$

## Assumptions

`seq_init()` is called before any other access program

# Sequence MIS Semantics Continued

## Access Routine Semantics

`seq_init()`:

- transition:  $s := \langle \rangle$
- exception: none

`seq_add( $i, p$ )`:

- transition:  $s := s[0..i-1] || \langle p \rangle || s[i..|s|-1]$
- exception:  
 $\text{exc} := (|s| = \text{MAX\_SIZE} \Rightarrow \text{FULL} \mid i \notin [0..|s|] \Rightarrow \text{POS})$

# Access Routine Semantics Continued

$\text{seq\_del}(i)$ :

- transition:  $s := s[0..i-1] || s[i+1..|s|-1]$
- exception:  $\text{exc} := (i \notin [0..|s|-1] \Rightarrow \text{POS})$

$\text{seq\_setval}(i, p)$ :

- transition:  $s[i] := p$
- exception:  $\text{exc} := (i \notin [0..|s|-1] \Rightarrow \text{POS})$

$\text{seq\_getval}(i)$ :

- output:  $\text{out} := s[i]$
- exception:  $\text{exc} := (i \notin [0..|s|-1] \Rightarrow \text{POS})$

# Access Routine Semantics Continued

seq\_size():

- output:  $out := |s|$
- exception: none

# Exception Signalling

- Useful to think about exceptions in the design process
- Will need to decide how exception signalling will be done
  - ▶ A special return value, a special status parameter, a global variable
  - ▶ Invoking an exception procedure
  - ▶ Using built-in language constructs
- Caused by errors made by programmers, not by users
- Write code so that it avoids exceptions
- Exceptions will be particularly useful during testing

# Assumptions versus Exceptions

- The assumptions section lists assumptions the module developer is permitted to make about the programmer's behaviour
- Assumptions are expressed in prose
- Use assumptions to simplify the MIS and to reduce the complexity of the final implementation
- Interface design should provide the programmer with a means to check so that they can avoid exceptions
- When an exceptions occurs no state transitions should take place, any output is *don't care*

## Examples of Modules: Record [2]

- Consists of only data
- Has state but no behaviour
- Example
  - ▶ Specification Parameters Module in SWHS



# Examples of Modules: Library [2]

- Collection of related procedures (library)
- Has behaviour but no state
- Procedural abstractions
- Example
  - ▶ Library of trigonometric functions
  - ▶ ODE Solver Module in SWHS
  - ▶ Sequence Services Module

# Examples of Modules: Abstract Object [2]

- Consists of data (**fields**) and procedures (**methods**)
- Consists of a collection of **constructors**, **selectors**, and **mutators**
- Has state and behaviour
- There is only ONE
- Example
  - ▶ Input Parameters Module for SWHS
  - ▶ Logger

# Examples of Modules: Abstract Data Type [2]

- What you are used to for OO programming
- 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
- Multiple instances of the object
- Keyword **Template** in MIS
- Example
  - ▶ [Curve ADT Module](#)

# Examples of Modules: Generic [2]

- 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.
- Example
  - ▶ Generic Sequence ADT Module

# Getting Started

1. Find a similar example to your problem as use that as a starting point
2. Draft module names and secrets
3. For each module sketch out:
  - ▶ Classify module type (record, library, abstract object, abstract data type, generic ADT)
  - ▶ Access program syntax
  - ▶ State variables (if applicable)
4. Iterate on design

# Appendix: Information Hiding Examples

- Hoffman and Strooper (1995) textbook on software development: The running example is of a symbol table. A very complete example. There is a complete chapter on the module guide in the text. It is well explained there.
- Parnas Et Al (1984) “The Module Structure of Complex Systems” : This example is right back to the source. The example focuses on the A7E military fighter jet.
- Parnas (1979) “Designing Software For Ease of Extension and Contraction”
- von Mohrenschildt (2005) “The Maze Tracing Robot A Sample Specification”: This is a small and complete example.

# Appendix Cont'd: Information Hiding Examples

- Jegatheesan and MacLachlan (2018), Module Guide for Solar Water Heating Systems Incorporating Phase Change Material
- Liu (2020) Module Guide for Radio Signal Strength Calculator
- Key points
  - ▶ One module, one secret
  - ▶ Secrets are often nouns (data structure, algorithm, hardware, etc.)
  - ▶ Secrets are sometimes phrased with “How to ...”
  - ▶ Secrets ideally will have a one to one mapping with the anticipated changes for the software

# References I



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