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

Fall 2020

MIS Continued

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November 20, 2020

MIS Continued

- Start recording
- Administrative details
- Questions?
- Nonfunctional requirements
- Review: Records, Libraries, ADTs, Abstract Objects, Generic ADTs
- Example - Student data
- Exceptions
- Quality criteria
- Modules with external interaction, enviro variables
- GUI modules
- ADTs
- Generic modules
- OO design spec
- Examples

Administrative Details

- When developing your code, remember that your goal is for someone else to be able to compile and run it
- Upcoming classes
  - L16 - MIS Continued
  - L17 - POC + MG Presentations
  - L18 - MIS Presentations
- Mathematical review ([3] and separate slides)
- Potential software for drawing figures
  - draw.io
  - Tkiz

Administrative Details: Report Deadlines

MG + MIS (Traditional)	Nov 19
Drasil Code and Report (Drasil)	Nov 19
Final Documentation	Dec 9

- 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 deliverable, please ask
- You should inform your primary and secondary reviewers of the extension
- Two days after each major deliverable, your GitHub issues will be due

Admin Details: Presentation Schedule

- Proof of Concept Demonstrations (15 min)
  - **Thurs, Nov 12: Salah, John**
- MG Present (10 minutes)
  - **Thurs, Nov 12: John, Tiago, Leila, Xuanming, Andrea**
- MIS Present
  - Mon, Nov 16: Shayan, Parsa, Gaby, Sid, Xingzhi
- Drasil Project Present (20 min each)
  - Thurs, Nov 26: Andrea, Naveen, Ting-Yu

Presentation Schedule Continued

- Test or Impl. Present (15 min each)
  - Mon, Nov 30: John, Salah, Liz, Xingzhi, Leila
  - Thurs, Dec 3: Shayan, Naveen, Sid, Gaby, Seyed
  - Mon, Dec 7: Ting-Yu, Xuanming, Mohamed, Andrea, Tiago
- 4 presentations each
- If you will miss a presentation, please trade with someone else

Questions?

- Questions on administrative details?
- Questions about Module Guide?
- Questions about upcoming presentation?
- Questions about MIS?
- Other questions?

Nonfunctional Requirements

- Aim to be unambiguous
- Say the quality you want to achieve, not how you are going to achieve it
- Point to the Verification and Validation plan
- Added to the blank SRS template

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
- Singleton design pattern
- 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

Chemistry Example - Highlight Mathematics

- Problem Description
- Source Code

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 avoid 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*

Quality Criteria [3, p. 83]

- Consistent
  - Name conventions
  - Ordering of parameters in argument lists
  - Exception handling, etc.
- Essential - omit unnecessary features
- General - cannot always predict how the module will be used
- As implementation independent as possible
- Minimal - avoid access routines with two potentially independent services
- High cohesion - components are closely related
- Low coupling - not strongly dependent on other modules
- Opaque - information hiding

Modules with External Interaction

- In general, some modules may interact with the environment or other modules
- Environment might include the keyboard, the screen, the file system, motors, sensors, etc.
- Sometimes the interaction is informally specified using prose (natural language)
- Can introduce an environment variable
  - Name, type
  - Interpretation
- Environment variables include the screen, the state of a motor (on, direction of rotation, power level, etc.), the position of a robot

External Interaction Continued

- Some external interactions are hidden
  - Present in the implementation, but not in the MIS
  - An example might be OS memory allocation calls
- External interaction described in the MIS
  - Naming access programs of the other modules
  - Specifying how the other module's state variables are changed
  - The MIS should identify what external modules are used

MIS for GUI Modules

- Could introduce an environment variable
- window: sequence [RES_H][RES_V] of pixelT
  - Where window[r][c] is the pixel located at row r and column c, with numbering zero-relative and beginning at the upper left corner
  - Would still need to define pixelT
- Could formally specify the environment variable transitions
- More often it is reasonable to specify the transition in prose
- In some cases the proposed GUI might be shown by rough sketches

Display Point Masses Module Syntax

Exported Access Programs

Routine name	In	Out	Exc
DisplayPointMassesApplet		DisplayPointMassesApplet	
paint			

Display Point Masses Module Semantics

Environment Variables

win : 2D sequence of pixels displayed within a web-browser

DisplayPointMassesApplet():

- transition: The state of the abstract object ListPointMasses is modified as follows:
  ListPointMasses.init()
  ListPointMasses.add(0, PointMassT(20, 20, 10))
  ListPointMasses.add(1, PointMassT(120, 200, 20))
  ...

paint():

- transition *win* := Modify window so that the point masses in ListPointMasses are plotted as circles. The centre of each circles should be the corresponding x and y coordinates and the radius should be the mass of the point mass.

Specification of ADTs

- Similar template to abstract objects
- "Template Module" as opposed to "Module"
- "Exported Types" that are abstract use a ?
  - pointT = ?
  - pointMassT = ?
- Access routines know which abstract object called them
- Use "self" to refer to the current abstract object
- Use a dot "." to reference methods of an abstract object
  - *p*.xcoord()
  - *self*.*pt*.dist(*p*.point())
- Similar notation to Java
- The syntax of the interface in C is different

Syntax Line ADT Module

Template Module

lineADT

Uses

pointADT

Exported Types

lineT = ?

Syntax Line ADT Module Continued

Routine name	**In**	**Out**	**Exceptions**
new lineT	pointT, pointT	lineT	
start		pointT	
end		pointT	
length		real	
midpoint		pointT	
rotate	real		

Semantics Line ADT Module

State Variables

s: pointT
e: pointT

State Invariant

None

Assumptions

None

Access Routine Semantics Line ADT Module

new lineT (p_1, p_2):

- transition: $s, e := p_1, p_2$
- output: $out := self$
- exception: none

start:

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

end:

- output: $out := e$
- exception: none

Access Routine Semantics Continued

length:

- output: $out := s.\mathrm{dist}(e)$
- exception: none

midpoint:

- output: $out :=$

  $$\text{new pointT}(\mathrm{avg}(s.\mathrm{xcoord}, e.\mathrm{xcoord}), \mathrm{avg}(s.\mathrm{ycoord}, e.\mathrm{ycoord}))$$

- exception: none

rotate (φ):
φ is in radians

- transition: $s.\mathrm{rotate}(\varphi), e.\mathrm{rotate}(\varphi)$
- exception: none

Line ADT Local Functions

Local Functions

avg: real $\times$ real $\rightarrow$ real
avg$(x_1, x_2) \equiv \frac{x_1+x_2}{2}$

Generic Modules

- What if we have a sequence of integers, instead of a sequence of point masses?
- What if we want a stack of integers, or characters, or pointT, or pointMassT?
- Do we need a new specification for each new abstract object?
- No, we can have a single abstract specification implementing a family of abstract objects that are distinguished only by a few variabilities
- Rather than duplicate nearly identical modules, we parameterize one generic module with respect to type(s)
- Advantages
  - Eliminate chance of inconsistencies between modules
  - Localize effects of possible modifications
  - Reuse

Generic Stack Module Syntax

Generic Module

Stack(T)

Exported Constants

MAX_SIZE = 100

Exported Access Programs

Routine name	In	Out	Exceptions
...	...	...	...

Stack Module Syntax

Exported Access Programs

Routine name	In	Out	Exceptions
s_init			
s_push	T		FULL
s_pop			EMPTY
s_top		T	EMPTY
s_depth		integer	

Semantics

State Variables

s: sequence of T

State Invariant

$|s| \leq$ MAX_SIZE

Assumptions

s_init() is called before any other access routine

Access Routine Semantics

s_init():

- transition: $s := <>$
- exception: none

s_push(x):

- transition: $s := s || < x >$
- exception: $exc := (|s| = \text{MAX\_SIZE} \Rightarrow \text{FULL})$

s_pop():

- transition: $s := s[0..|s| - 2]$
- exception: $exc := (|s| = 0 \Rightarrow \text{EMPTY})$

Access Routine Semantics Continued

s_top():

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

s_depth():

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

Stack Module Properties

$\{true\}$

s_init()

$\{|s'| = 0\}$

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

s_push(x)

$\{|s'| = |s| + 1 \wedge s'[|s'| - 1] = x \wedge s'[0..|s| - 1] = s[0..|s| - 1]\}$

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

s_push(x)

s_pop()

$s' = s$

Object Oriented Design

- One kind of module, ADT, called class
- A class exports operations (procedures) to manipulate instance objects (often called methods)
- Instance objects accessible via references
- Can have multiple instances of the class (class can be thought of as roughly corresponding to the notion of a type)

Inheritance

- Another relation between modules (in addition to USES and IS_COMPONENT_OF)
- ADTs may be organized in a hierarchy
- Class B may specialize class A
  - B inherits from A
  - Conversely, A generalizes B
- A is a superclass of B
- B is a subclass of A

Template Module Employee

Routine name	**In**	**Out**	**Except**
Employee	string, string, moneyT	Employee	
first_Name		string	
last_Name		string	
where		siteT	
salary		moneyT	
fire			
assign	siteT		

Inheritance Examples

Template Module Administrative_Staff **inherits** Employee

Routine name	In	Out	Exception
do_this	folderT		

Template Module Technical_Staff **inherits** Employee

Routine name	In	Out	Exception
get_skill		skillT	
def_skill	skillT		

Inheritance Continued

- A way of building software incrementally
- Useful for long lived applications because new features can be added without breaking the old applications
- A subclass defines a subtype
- A subtype is substitutable for the parent type
- Polymorphism - a variable referring to type A can refer to an object of type B if B is a subclass of A
- Dynamic binding - the method invoked through a reference depends on the type of the object associated with the reference at runtime
- All instances of the sub-class are instances of the super-class, so the type of the sub-class is a subtype
- All instances of Administrative_Staff and Technical_Staff are instances of Employee

Dynamic Binding

- Many languages, like C, use static type checking
- OO languages use dynamic type checking as the default
- There is a difference between a type and a class once we know this
  - Types are known at compile time
  - The class of an object may be known only at run time

Point ADT Module

Template Module

PointT

Uses

N/A

Syntax

Exported Types

PointT = ?

Point ADT Module Continued

Exported Access Programs

Routine name	In	Out	Exceptions
new PointT	real, real	PointT	
xcoord		real	
ycoord		real	
dist	PointT	real	

Semantics

State Variables

xc: real
yc: real

Point Mass ADT Module

Template Module

PointMassT **inherits** PointT

Uses

PointT

Syntax

Exported Types

PointMassT = ?

Point Mass ADT Module Continued

Exported Access Programs

Routine name	In	Out	Exceptions
new PointMassT	real, real, real	PointMassT	NegMassExcep
mval		real	
force	PointMassT	real	
fx	PointMassT	real	

Semantics

State Variables

ms: real

Point Mass ADT Module Semantics

new PointMassT(x, y, m):

- transition: $xc, yc, ms := x, y, m$
- output: $out := self$
- exception: $exc := (m < 0 \Rightarrow \text{NegativeMassException})$

force(p):

- output:

$$out := \text{UNIVERAL\_G}\frac{self.ms \times p.ms}{self.\text{dist}(p)^2}$$

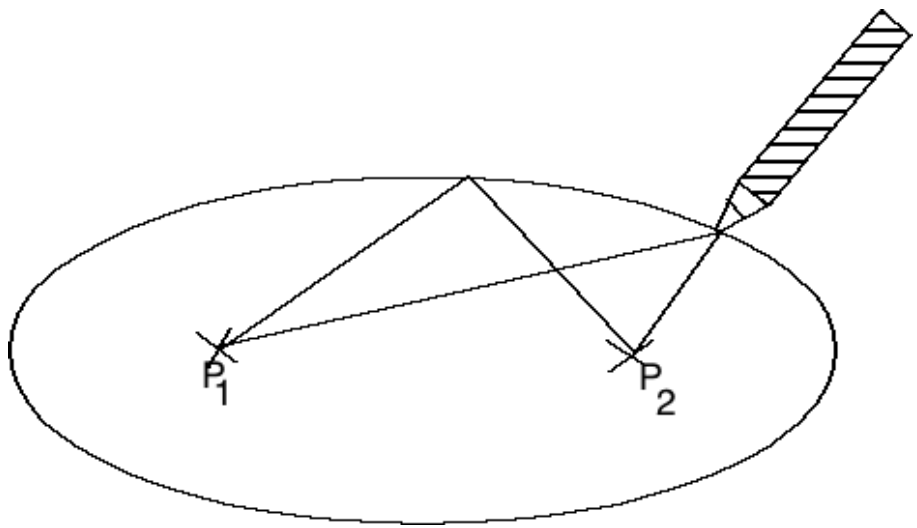
- exception: none

Classification of Specification Styles

- Informal, semi-formal, formal
- Operational
  - Behaviour specification in terms of some abstract machine
  - Not specifying how to implement, even though it looks this way
- Descriptive
  - Behaviour described in terms of properties
  - Prefer this because if its inherent abstraction
- The module state machine specification that we use is a mix of operational and descriptive specification - Why?

Example Operational Specification

- Specification of a geometric figure E
- E can be drawn as follows
  1. Select two points P_1 and P_2 on a plane
  2. Get a string of a certain length and fix its ends to P_1 and P_2
  3. Position a pencil as shown in the next figure
  4. Move the pen clockwise, keeping the string tightly stretched, until you reach the point where you started drawing



Example Descriptive Specification

Geometric figure E is described by the following equation

$$ax^2 + by^2 + c = 0$$

where a, b and c are suitable constants

Judging Appropriate Abstraction

- If an MIS is too abstract, it won't capture enough information for someone to do the implementation
- In some cases an MIS is not abstract enough
  - This can happen when someone is reverse engineering their spec from exisiting code
  - Can happen with an operational specification, as opposed to a descriptive specification
- Judge the abstraction level by
  - If a change in how your code works requires a change in your specification, look for a better abstraction
  - If writing and maintaining the spec is exceedingly frustrating, the spec could be too concrete
- The goal is to provide a descriptive, formal mathematical spec of eveything, but at times we sacrifice this goal in the name of practicality

Examples

- Solar Water Heating System
- Example Point Line and Circle
- Example Robot Path
- Example Vector Space
- Example Othello Program
- Example Maze Formal Specification (Dr. v. Mohrenschildt)
- Mustafa ElSheikh Mesh Generator [1]
- Wen Yu Mesh Generator [4]
- Sven Barendt Filtered Backprojection
- Sanchez sDFT

References I

Jacques Carette, Mustafa ElSheikh, and W. Spencer Smith.
A generative geometric kernel.
In *ACM SIGPLAN 2011 Workshop on Partial Evaluation and Program Manipulation (PEPM'11)*, pages 53–62, January 2011.

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

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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.

W. Spencer Smith and Wen Yu.
A document driven methodology for improving the quality of a parallel mesh generation toolbox.
Advances in Engineering Software, 40(11):1155–1167, November 2009.