

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

Fall 2018

## 17 Math Review Plus MIS Example

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November 6, 2018



# Math Review

- Administrative details
- Questions?
- SRS feedback
- Math review introduction
- Review of sets, relations and functions
- Review of logic
- Review of types, sets, sequence and tuples
- Multiple assignment statement
- Conditional rules
- Finite State Machines
- Example MIS: 2D Data

# Administrative Details

- SRS grades on Avenue
- If follow feedback, final doc grades will be higher
- GitHub issues for colleagues
  - ▶ Assigned 1 colleague (see Repos.xlsx in repo)
  - ▶ Provide at least 3 issues on their MG
  - ▶ Grading as before
  - ▶ Due by Thursday, Nov 8, 11:59 pm
- MG marking scheme in Avenue
- MIS marking scheme in Avenue
- Updated MIS template in CAS 741 repo (soon)

# Administrative Details: Deadlines

<b>MIS Present</b>	Week 10	Week of Nov 12
<b>MIS</b>	Week 11	Nov 19
Unit VnV or Impl. Present	Week 12	Week of Nov 26
Unit VnV Plan	Week 13	Dec 3
Final Doc	Week 14	Dec 10

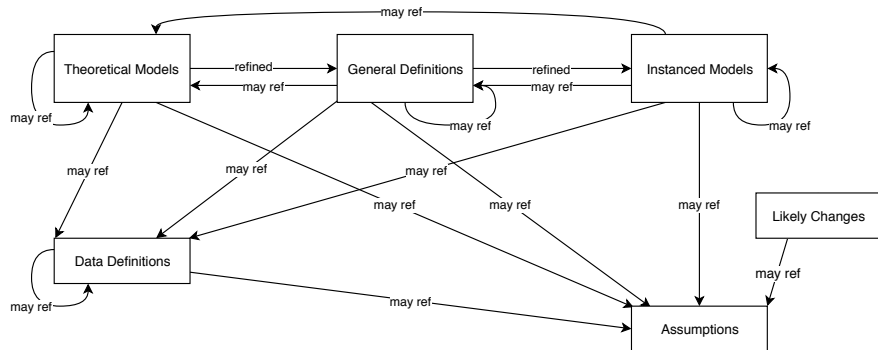
# Administrative Details: Presentation Schedule

- MIS Present
  - ▶ **Wednesday: Malavika, Robert**
  - ▶ **Friday: Hanane, Jennifer**
- Unit VnV Plan or Impl. Present
  - ▶ Wednesday: Brooks, Vajiheh
  - ▶ Friday: Olu, Karol

# Questions?

- Questions about Module Guides?
- Questions about MIS?

# SRS Feedback: Relationships Between Parts



# SRS Feedback

- \*.DS\_Store should be in .gitignore
- L<sup>A</sup>T<sub>E</sub>X and formatting rules
  - ▶ Variables are italic, everything else not, includes subscripts (link to document)
    - ▶ Conventions
    - ▶ Watch out for implied multiplication
  - ▶ Use BibTeX
  - ▶ Use cross-referencing
- Grammar and writing rules
  - ▶ Acronyms expanded on first usage (not just in table of acronyms)
  - ▶ “In order to” should be “to”



# SRS Feedback on Applying Template

- Difference between physical and software constraints
- Properties of a correct solution means *additional* properties, not a restating of the requirements (may be “not applicable” for your problem). If you have a table of output constraints, then these are properties of a correct solution.
- Assumptions have to be invoked somewhere
- “Referenced by” implies that there is an explicit reference
- Think of traceability matrix, list of assumption invocations and list of reference by fields as automatically generatable
- If you say the format of the output (plot, table etc), then your requirement could be more abstract
- For families the notion of binding time should be introduced
- Think of families as a library, not as a single program

# Mathematical Review: Introduction

- The material in these slides should hopefully be review, or reasonably easy to pick up
- Shows the simple mathematics that can be used to build your MIS
- Shows a syntax that you can use
- The presentation follows [2] (Chapter 3) and [1]

# Sets, Relations and Functions

- A set is an unordered collection of elements
- A binary relation is a set of ordered pairs
- A function is a relation in which each element in the domain appears exactly once as the first component in the ordered pair

# Sets

- An element either belongs to a set or it does not
- $x \in S$  versus  $x \notin S$
- Defining a set
  - ▶ Enumerate  $\{x_1, x_2, x_3, \dots, x_n\}$
  - ▶ Logical condition (rule)  $\{x | p(x)\}$
  - ▶ Notation from [1]  $\{x : X | R : E\}$
  - ▶ An integer range  $[2..4] = \{2, 3, 4\}$ ,  $[7..4] = \{\}$
- Examples
  - ▶  $S = \{1, 7, 6\}$
  - ▶  $S = \{x | x \text{ is an integer between 1 and 4 inclusive} \}$
  - ▶  $S = \{x : \mathbb{N} | 0 \leq x \leq 4 : x \}$
- Does  $\{1, 7, 6\} = \{7, 1, 6\}$ ?

# Relations

- Let  $\langle x, y \rangle$  denote an ordered pair
  - ▶  $\text{dom}(R) = \{x \mid \langle x, y \rangle \in R\}$
  - ▶  $\text{ran}(R) = \{y \mid \langle x, y \rangle \in R\}$
- Defining a relation
  - ▶ Enumerate  $\{\langle 0, 1 \rangle, \langle 0, 2 \rangle, \langle 2, 3 \rangle\}$
  - ▶ Rule  $\{\langle x, y \rangle \mid x \text{ and } y \text{ are integers and } x < y\}$
  - ▶  $\{x, y : \mathbb{N} \mid x < y : \langle x, y \rangle\}$

# Functions

- Let  $\langle x, y \rangle$  denote an ordered pair
- Each element of the domain is associated with a unique element of the range
- Defining a function
  - ▶ Enumerate  $\{\langle 0, 1 \rangle, \langle 1, 2 \rangle, \langle 2, 3 \rangle\}$
  - ▶ Rule  $\{\langle x, y \rangle \mid x \text{ and } y \text{ are integers and } y = x^2\}$
- Notation
  - ▶  $f(a) = b$  means  $\langle a, b \rangle \in f$
  - ▶  $f(x) = x^2$
  - ▶  $f : T_1 \rightarrow T_2$
  - ▶  $\{\langle \langle x_1, x_2 \rangle, y \rangle \mid x_1, x_2 \text{ are integers and } y = x_1 + x_2\}$
- Is  $\{\langle 0, 1 \rangle, \langle 0, 2 \rangle, \langle 2, 3 \rangle\}$  a function?
- Is  $\{\langle x, y \rangle \mid x \text{ and } y \text{ are integers and } y^2 = x\}$ ?

# Logic

- A logical expression is a statement whose truth values can be determined ( $6 < 7?$ )
- Truth values are either *true* or *false*
- Complex expressions are formed from simpler ones using logical connectives ( $\neg, \wedge, \vee, \rightarrow, \leftrightarrow$ )
- Truth tables
- Evaluation
  - ▶ Decreasing order of precedence:  $\neg, \wedge, \vee, \rightarrow, \leftrightarrow$
  - ▶ Evaluate from left to right
  - ▶ Use rules of boolean algebra

# Quantifiers

- Variables are often used inside logical expressions
- Variables have types
- A type is a set of values from which the variable can take its value
- Often quantify a logical expression over a given variable
  - ▶ Universal quantification
  - ▶ Existential quantification



# Quantifiers Continued

- Prefer [1, p. 143] notation for quantification (and set building)
- $(*x : X | R : P)$  means application of the operator  $*$  to the values  $P$  for all  $x$  of type  $X$  for which range  $R$  is true. In the above equations, the  $*$  operators include  $\forall$ ,  $\exists$  and  $+$  are used
- Example on next slide for rank function specification

$$\text{rank}(a, A) : \mathbb{R} \times \mathbb{R}^n \rightarrow \mathbb{R}$$

$$\text{rank}(a, A) \equiv \text{avg}(\text{indexSet}(a, \text{sort}(A)))$$

$$\text{indexSet}(a, B) : \mathbb{R} \times \mathbb{R}^n \rightarrow \text{set of } \mathbb{N}$$

$$\text{indexSet}(a, B) \equiv \{j : \mathbb{N} | j \in [1..|B|] \wedge B_j = a : j\}$$

$$\text{sort}(A) : \mathbb{R}^n \rightarrow \mathbb{R}^n$$

$$\text{sort}(A) \equiv B : \mathbb{R}^n, \text{ such that}$$

$$\forall(a : \mathbb{R} | a \in A : \exists(b : \mathbb{R} | b \in B : b = a) \wedge \text{count}(a, A) = \text{count}(b, B)) \wedge \forall(i : \mathbb{N} | i \in [1..|A| - 1] : B_i \leq B_{i+1})$$

$$\text{count}(a, A) : \mathbb{R} \times \mathbb{R}^n \rightarrow \mathbb{N}$$

$$\text{count}(a, A) : +(x : \mathbb{R} | x \in A \wedge x = a : 1)$$

$$\text{avg}(C) : \text{set of } \mathbb{N} \rightarrow \mathbb{R}$$

$$\text{avg}(C) \equiv +(x : \mathbb{N} | x \in C : x) / |C|$$

# Quantifiers Continued

- Bound variables appear in the scope of the quantifier
- Free variables are not bound to any quantifier
- Free variables in an expression often mean that we cannot determine the truth value of the expression

# Types, Sets, Sequence and Tuples

- A type is a set of values, so any precisely defined set is a type
- Primitive types are often integer, boolean, character, string and real
- Types can include functions ( $T_1 \rightarrow T_2$ )
- User-defined types
  - ▶ The set of values has to be given
  - ▶ Often use type constructors
- Useful type constructors
  - ▶ Set
  - ▶ Sequence
  - ▶ Tuple

# Types

- Specify the type of a variable
  - ▶  $x_1, x_2, \dots, x_n : T$
  - ▶  $x : \textit{integer}$
  - ▶  $a, b, c : \textit{string}$
- Type definition
  - ▶  $T = d$
  - ▶  $\textit{float} = \textit{real}$
  - ▶  $\textit{colour} = \{\textit{red}, \textit{white}, \textit{blue}\}$
  - ▶  $\textit{testtype} = \{\textit{uniaxial}, \textit{biaxial}, \textit{shear}\}$
  - ▶  $x : \textit{testtype}$
  - ▶  $\textit{motion}T = \{\textit{forward}, \textit{backward}, \textit{stop}\}$

# Primitive Types

- Integer

- ▶  $\{\dots - 2, -1, 0, 1, 2, \dots\}$
- ▶  $+, -, \times, /$
- ▶  $=, \neq$
- ▶  $<, \leq, \geq, >$

- Real

- ▶  $\{\textit{all real numbers}\}$
- ▶  $+, -, \times, /, \sin(), \cos(), \exp()$  etc.
- ▶  $=, \neq$
- ▶  $<, \leq, \geq, >$

# Primitive Types Continued

- Boolean type
  - ▶  $\{true, false\}$
  - ▶  $\neg, \wedge, \vee, \rightarrow, \leftrightarrow$
- Char type
  - ▶ Set of ASCII characters
  - ▶ Character values appear in quotes  $'a', 'b', 'c'$ , etc.
  - ▶  $=, \neq$

# Primitive Types Continued

- String type

- ▶ All finite sequences of characters
- ▶ String constants are in double quotes `"abc"`
- ▶  $s[i..j]$  is the substring of  $s$  from position  $i$  to position  $j$
- ▶  $s_1 || s_2$  concatenates strings  $s_1$  and  $s_2$
- ▶  $=, \neq$  for is equal and not equal
- ▶  $\in, \notin$  for is member and not a member
- ▶  $s[i]$  is the  $i$ th character of  $s$
- ▶  $|s|$  is the length of  $s$
- ▶ Positions in strings are zero relative



# Sets

- A set is an unordered collection of elements of the same type
- Declare a set of type  $T$  as *set of  $T$*
- Example
  - ▶  $T = \text{set of } \{\text{red}, \text{green}, \text{blue}\}$  defines type  $T$  as the power set of  $\{\text{red}, \text{green}, \text{blue}\}$
  - ▶  $x : \text{set of integer}$
- What are some possible values for  $x : \text{set of integer}$ ?

# Operations on Sets

- $\cup$  union
- $\cap$  intersection
- $-$  difference
- $\times$  Cartesian product
- $=, \neq$  equal, not equal
- $\in, \notin$  member, non-member
- $|s|$  size of set  $s$

# Sequences

- A sequence is an ordered collection of elements of the same type
  - ▶ Elements can occur more than once
  - ▶ Sometimes referred to as a list
  - ▶ Similar to an array
- Declare a sequence of type  $T$  by *sequence of  $T$*
- $\langle x_0, x_1, \dots, x_n \rangle$  for  $n \geq 0$  for a sequence with elements  $x_0, x_1, \dots, x_n$
- $\langle \rangle$  is the empty sequence
- Position in a sequence is zero relative

# Sequences Continued

- Examples
  - ▶  $T = \text{sequence of } \{\text{red}, \text{green}, \text{blue}\}$  defines the type  $T$  as the set of all sequences of elements from  $\{\text{red}, \text{green}, \text{blue}\}$
  - ▶  $x : \text{sequence of integer}$
- Fixed-length sequence of type  $T$  with length  $l$ 
  - ▶  $\text{sequence } [l] \text{ of } T$
  - ▶  $l$  is a positive integer
  - ▶  $\text{sequence } [l_1, l_2, \dots, l_n] \text{ of } T$  is a shorthand for  $\text{sequence } [l_1] \text{ of sequence } [l_2] \text{ of } \dots \text{sequence } [l_n] \text{ of } T$

# Operations on Sequences

- $s[i..j]$  is the subsequence of  $s$  from position  $i$  to position  $j$
- $s[i..j]$  is undefined if  $i \notin [0..|s| - 1] \vee j \notin [0..|s| - 1]$
- $s_1 || s_2$  concatenates sequences  $s_1$  and  $s_2$
- $=, \neq$  for is equal and not equal
- $\in, \notin$  for is member and not a member
- $s[i]$  is the  $i$ th element of  $s$
- $s[i]$  is undefined if  $i \notin [0..|s| - 1]$
- $|s|$  is the length of  $s$
- A string is a sequence of characters

# Tuples

- A tuple is a collection of elements of possibly different types
- Each tuple has one or more fields
- Each field has a unique identifier called the field name
- Similar to a record or a structure
- To declare a tuple use
  - ▶ *tuple of*  $(f_1 : T_1, f_2 : T_2, \dots, f_n : T_n)$  with  $n \geq 1$
  - ▶  $f_i$  is the name of the  $i$ th field
  - ▶  $T_i$  is the type of the  $i$ th field
  - ▶ *tuple of*  $(f_1, f_2, \dots, f_n : T)$  if all fields are of the same type

# Example Tuples

- Examples
  - ▶ *pair* = tuple of (*id* : integer, *val* : string)
  - ▶ *experimentT* = tuple of (*b<sub>cond</sub>* : *bcondT*, *control* : *controlT*)
- Define the value of a tuple by using an expression of the form
  - ▶  $\langle x_1, x_2, \dots, x_n \rangle$
  - ▶  $\langle 4, "cat" \rangle$  is a value of type *pair*

# Operations on Tuples

- $=, \neq$  equal, not equal
- $t.f$  is the value of field  $f$  of tuple  $t$



# Using Type Constructors

- $bcondT = \{uniaxial, biaxial, multiaxial, shear\}$
- $controlT = \{load\_controlled, displacement\_controlled\}$
- $experimentT = \text{tuple of } (b_{cond} : bcondT, control : controlT)$
- $experiment : experimentT$
- $directionT = \{clockwise, counterclockwise\}$
- $powerT = [MIN\_POWER...MAX\_POWER]$
- $motorT = \text{tuple of } (powerOn : Boolean, direction : directionT, powerLevel : powerT)$

# Multiple Assignment Statement

- $v_1, v_2, \dots, v_n := e_1, e_2, \dots, e_n$  with  $n \geq 1$
- The  $v_i$ s are distinct variables and each  $e_i$  is an expression of the same type as  $v_i$
- Compute the values of all the expression  $e_i$  and then assign these values simultaneously
- Example
  - ▶  $x, y := 0, 10$
  - ▶  $x, y := 10, x$
  - ▶  $x, y := y, x$
- Convenient for defining the meaning of pieces of code
- Use as a function on the state space of a program

# Conditional Rules

- $(c_1 \Rightarrow r_1 | \dots | c_n \Rightarrow r_n)$ , where  $n \geq 1$
- $c_i$ s are the logical expressions
- $r_i$ s are the rules
- $c_i \Rightarrow r_i$  is the  $i$ th component of the rule
- The first  $c_i$  that evaluates to true applies rule  $r_i$
- If no condition is true then the conditional rule is undefined

# Uses of Conditional Rules

- To define the value of a function
- $\min(x, y) = (x \leq y \Rightarrow x \mid x > y \Rightarrow y)$
- To define the meaning of a program
  - ▶ If  $(x < y)$  then  $z := x$  else  $z := y$
  - ▶  $(x < y \Rightarrow z := x \mid x \geq y \Rightarrow z := y)$
  - ▶  $(x < y \Rightarrow x, y := x, y \mid x \geq y \Rightarrow x, y := y, x)$
- Conditional rules can be expressed in tables

# Finite State Machines

- A FSM is a tuple  $(S, s_0, I, O_E, O_O, T, E, C)$  where
- $S$  is a finite set of states
- $s_0$  is the initial state in  $S$  ( $s_0 \in S$ )
- $I$  is a finite set of inputs
- $T : S \times I \rightarrow S$  is the transition function
- $O_E$  is a finite set of event outputs
- $E : S \times I \rightarrow O_E$  is the event output
- $O_C$  is a finite set of condition outputs
- $C : S \rightarrow O_C$  is the condition output

# Example 2D Data

- Problem Description
- Source Code

# References I



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*A logical approach to discrete math.*  
Springer-Verlag Inc., New York, 1993.



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.