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

Fall 2019

17 Math Review Plus MIS Example

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Math Review

- Administrative details
- Questions?
- SRS feedback
- Motivating example: Chemical reactions
- 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 for MG+MIS
  - Assigned 1 colleague (see `Repos.xlsx` in repo)
  - Provide at least 3 issues on their MG
  - Grading as before
  - Due within 2 days of being assigned the review issue
- MG marking scheme in Avenue
- MIS marking scheme in Avenue

Administrative Details: Report Deadlines

MG + MIS	Week 10	Nov 25
Final Documentation	Week 14	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, please ask
- Two days after each major deliverable, your GitHub issues will be due
- Domain expert code due 1 week after MIS deadline

Administrative Details: Presentations

MIS Semantics Present	Week 11	Week of Nov 18
Unit VnV or Impl. Present	Week 12/13	Week of Nov 28

- Informal presentations with the goal of improving everyone's written deliverables
- Domain experts and secondary reviewers (and others) will ask questions (listed in Repos.xlsx file)

Administrative Details: Presentation Schedule

- **MIS Syntax + Semantics Present**
  - Monday: Zhi, Peter, *Sasha*
  - Thursday: Sharon, Ao, ?
- Unit VnV Plan or Impl. Present
  - Monday: Bo, Sasha, ?
  - Thursday: Zhi, Peter, Ao, ?

Optional presentation in italics.
Room for more volunteers. :-)

Questions?

- Questions about Module Guides?
- Questions about MIS?

SRS Feedback on Applying Template

- Assumptions have to be invoked somewhere
- "Referenced by" implies that there is an explicit reference

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 $\{x_1, x_2, x_3, ..., x_n\}$
  - 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 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 $< x, y >$ denote an ordered pair
  - $dom(R) = \{x| < x, y > \in R\}$
  - $ran(R) = \{y| < x, y > \in R\}$
- Defining a relation
  - Enumerate $\{< 0, 1 >, < 0, 2 >, < 2, 3 >\}$
  - Rule $\{< x, y > \mid x$ and y are integers and $x < y\}$
  - $\{x, y : \mathbb{N}| \ x < y : < x, y >\}$

Functions

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

$\text{rank}(a, A) : \mathbb{R} \times \mathbb{R}^n \to \mathbb{R}$
$\text{rank}(a, A) \equiv \text{avg}(\text{indexSet}(a, \text{sort}(A)))$

$\text{indexSet}(a, B) : \mathbb{R} \times \mathbb{R}^n \to \text{ set of } \mathbb{N}$
$\text{indexSet}(a, B) \equiv \{j : \mathbb{N} | j \in [1..|B|] \wedge B_j = a : j\}$

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

$\text{count}(a, A) : \mathbb{R} \times \mathbb{R}^n \to \mathbb{N}$
$\text{count}(a, A) \equiv +(x : \mathbb{R} | x \in A \wedge x = a : 1)$

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

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
  - $x_1, x_2, ..., x_n : T$
  - $x : integer$
  - $a, b, c : string$
- Type definition
  - $T = d$
  - $float = real$
  - $colour = \{red, white, blue\}$
  - $testtype = \{uniaxial, biaxial, shear\}$
  - $x : testtype$
  - $motionT = \{forward, backward, stop\}$

Primitive Types

- Integer
  - $\{... -2, -1, 0, 1, 2, ...\}$
  - $+, -, \times, /$
  - $=, \neq$
  - $<, \leq, \geq, >$
- Real
  - $\{\mathit{all\ \ real\ \ numbers}\}$
  - $+, -, \times, /, \text{sin}(), \text{cos}(), \text{exp}()$ 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 ith 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
  - $T = set\ of\ \{red, green, blue\}$ defines type T as the power set of $\{red, green, blue\}$
  - $x : set\ of\ integer$
- What are some possible values for $x : set\ of\ integer$?

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
- $< x_0, x_1, ..., x_n >$ for $n \geq 0$ for a sequence with elements $x_0, x_1, ..., x_n$
- $<>$ is the empty sequence
- Position in a sequence is zero relative

Sequences Continued

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

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 ith 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* $(f_1 : T_1, f_2 : T_2, ..., f_n : T_n)$ with $n \geq 1$
  - f_i is the name of the ith field
  - T_i is the type of the ith field
  - *tuple of* $(f_1, f_2, ..., f_n : T)$ if all fields are of the same type

Example Tuples

- Examples
  - $pair = tuple\ of\ (id : integer, val : string)$
  - $experimentT = tuple\ of\ (b_{cond} : bcondT, control : controlT)$
- Define the value of a tuple by using an expression of the form
  - $< x_1, x_2, ..., x_n >$
  - $< 4, ''cat'' >$ 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

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

Multiple Assignment Statement

- $v_1, v_2, ..., v_n := e_1, e_2, ..., , e_n$ with $n \geq 1$
- The v_is 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

- $(c_1 \Rightarrow r_1|...|c_n \Rightarrow r_n)$, where $n \geq 1$
- c_is are the logical expressions
- r_is are the rules
- $c_i \Rightarrow r_i$ is the ith 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
- $min(x, y) = (x \leq y \Rightarrow x | x > y \Rightarrow y)$
- To define the meaning of a program
  - If $(x < y)$ then $z := x$ else $z := y$
  - $(x < y \Rightarrow z := x | x \geq y \Rightarrow z := y)$
  - $(x < y \Rightarrow x, y := x, y | x \geq y \Rightarrow x, y := y, x)$
- 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.
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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.