CS3063 Theory of Computing

Semester 4 (20 Intake), Feb – Jun 2023

Lecture 1

1. Course Details
2. Introduction to Theory of Computing

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Announcements

- This Lecture 1 is online on Zoom
- The rest in **flipped-classroom model**
  - Video recorded lecture and slides on Moodle; students study these privately in their own time
  - Interactive session physically every week from Week 3 (13th March), on Mondays, by dividing the students into 2 Groups
    - Start with a 5-6 minute online Quiz on the previous week's lecture
    - Group 1: Monday 10.15am – 11.00am in L2 Lab
    - Group 2: Monday 11.15am – 12.00 noon in L2 Lab

Announcements

- Lecture 1: online on Zoom
  - Today’s password for Attendance marking on Moodle: ianidw

Today's Outline

Lecture 1

- Course Details
  - Objectives
  - Syllabus and Calendar
  - Evaluation
- Introduction to Theory of Computing
  - Overview
  - Mathematical Background

PART 1

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Course Details

- On Moodle: https://online.uom.lk/course/view.php?id=20231

- Videos and slides made available on Moodle
- Interactive sessions, starting with a Quiz, on Mondays

- Details

PART 2

Today's Outline

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- Course Details
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- **Introduction to Theory of Computing**
  - **Overview**
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Subjects of Interest…

- What are the fundamental **capabilities** and **limitations** of a computer?

- Above can be discussed in the contexts of
  - Complexity theory
  - Computability theory
  - Automata theory

What is *Computation*?

- One possible answer
  - Consists of executing an algorithm
    - Inputs + step-by-step procedure → result
- One might say: a ***step*** in computation is an operation a computer can perform

- What kind of ***computers*** will we consider?

What are *Computers*?

- The computers we consider are not real ones
  - Will a theory based on an actual piece of current hardware be useful?
  - Real computers are too complex for theoretical study
- We consider (simpler) ***abstract machines*** or ***models of computation***
  - Defined mathematically (several of them)
  - Can be as powerful as real computers

Decision Problems

- We mainly consider ***decision problems***
  - Computational problems for which the answer is either “yes” or “no”

- E.g., given an integer $n > 0$, is n prime?
  - n is encoded as a string of digits
  - This string will be the input to the problem

Languages

- Input to "is n prime?" problem is a string
- This is a ***language recognition*** problem
  - [What is a *language* ? → a set of strings]
  - For an arbitrary string of digits, determine whether it is one of the strings in the language of all strings that represent primes

- A decision problem can be stated as a problem of recognizing a language

Models of Computation & Languages

- Different types of abstract models can recognize languages of different complexity → *hierarchy of language types*

- Types of abstract machines
  - Finite automata
  - Pushdown automata
  - Linear-bounded automata
  - Turing machines

The *Chomsky Hierarchy*

Type	Abstract Machine	Languages (Grammars)
3	Finite automaton	Regular
2	Pushdown automaton	Context-free
1	Linear-bounded automaton	Context-sensitive
0	Turing machine	Recursively enumerable (unrestricted, phrase-structure)

Finite Automata

- A finite automaton (FA) is a finite-state machine
  - At each moment, in one of finite number of states
  - Moves among states in a predictable way responding to inputs
  - Recognizes a regular language

Pushdown Automata

- The limitation of an FA: little or no memory
  - It can only keep track of its current state
  - So, can recognize only simple languages
- Context-free languages can be recognized by pushdown automata
  - An FA with an auxiliary stack memory
  - Context-free grammars: important because they can describe syntax of programming languages

Turing Machines

- A pushdown automaton cannot be a general model of computation
- Turing machine: general computing device
  - Can do any step-by-step procedure
  - More general languages than other two
- A Turing machine can do anything a computer can do

Is Every Problem Solvable?

- Turing machines can still have limits
  - But there is no more powerful machine

- There are ***unsolvable problems***, no matter how much time and resources we have
  - **Computability theory** addresses this
  - Discussed using Turing machine as the computational model

Kinds of Solvable Problems

- There are ***intractable problems***
  - Problems that are solvable theoretically
  - But practical issues due to huge time/resource requirements
  - **Complexity theory** addresses this

- E.g., why are some problems computationally easy and others hard?

Computing Vs The Theory of …

- Computation by humans has a long history
- But the current state of pervasive computing is a new phenomenon
- Theory of computing older than computers
  - Pioneers (Turing *et al*) saw the power of computers
  - Conceptual models very useful
  - Important field of study relevant to other areas

PART 3

Today's Outline

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Assumed Background: Basics

- Sets: basic set theory, notations
- Logic: propositional logic, implication, equivalence, quantifiers $\forall$ and $\exists$
- Functions
- Relations
- Mathematical induction and proofs
- Recursion and recursive definitions
- **READ Chapters 1, 2**

Languages (again)

- A **language**
  - A ***set of strings*** where the symbols are drawn from an alphabet
- An **alphabet**
  - A finite ***set of symbols***, denoted by Σ
- **Length** of a string x over Σ
  - Number of symbols in x, denoted by $|x|$

Languages ...contd

- **Null string** (string of length 0) is a string over Σ
  - Denoted by Λ
  - No matter what Σ is

- For any alphabet Σ, the set of all strings over Σ is denoted by Σ*
  - A language over Σ is a subset of Σ*

Languages ...contd

- Example: if $\Sigma=\{a, b\}$, then:
  - Some strings over Σ are a, baa, aba, $aabba$
  - $|a|=1$, $|baa| = |aba| = 3$, $|aabaa| = 5$
  - $\Sigma^*=\{\Lambda, a, b, aa, ab, ba, bb, aaa, aab, aba, \ldots\}$
  - A few languages over Σ are:

    $\{\Lambda, a, aa, aab\}$

    $\{x \in \{a, b\}^* \mid |x| \text{ is odd}\}$

    $\{x \in \{a, b\}^* \mid |x| \leq 8\}$

Languages ...contd

- New languages can be constructed using **set operations** (because languages are sets of strings)
- For any two languages over an alphabet Σ:
  - Their union, intersection, difference are also languages over Σ
- **Complement** L' of a language L over Σ
  - $L' = \Sigma^* - L$
- Language over Σ is a subset of Σ^*

Languages ...contd

- If $L_1 \subseteq \Sigma_1^*$ and $L_2 \subseteq \Sigma_2^*$ then both L_1 and L_2 are subsets of $(\Sigma_1 \cup \Sigma_2)^*$
- New languages can also be created using **concatenation**
  - If x and y are elements of Σ^*, concatenation of x and y is the string xy
  - For any string x, $x\Lambda = \Lambda x = x$
  - For any strings x, y and z, $(xy)z = x(yz)$

Languages ...contd

- A string x is a substring of a string y if there are strings w and z (either or both can be null) so that $y = wxz$
- A prefix of a string is an initial substring
  - E.g., Λ, a, ab, abb and $abba$ → prefixes of $abba$
- A suffix is a final substring
  - E.g., Λ, a, ba, bba and $abba$ → suffixes of $abba$

Languages ...contd

- If $L_1 \subseteq \Sigma^*$ and $L_2 \subseteq \Sigma^*$ then
  $L_1L_2 = \{xy \mid x \in L_1 \text{ and } y \in L_2\}$
- For any language L, $L\{\Lambda\} = \{\Lambda\}L = L$
- We use exponential notation to indicate the number of items concatenated
  – Items can be symbols, strings or languages

Languages ...contd

- If Σ is an alphabet, $a \in \Sigma$, $x \in \Sigma^*$, $L \subseteq \Sigma^*$

$$a^k = aa\cdots a$$

$$x^k = xx\cdots x$$

$$\Sigma^k = \Sigma\Sigma\cdots\Sigma = \{x \in \Sigma^* \mid |x|=k\}$$

$$L^k = LL\cdots L$$

- Special cases:

$$a^0 = \Lambda \qquad x^0 = \Lambda$$

$$\Sigma^0 = \{\Lambda\} \qquad L^0 = \{\Lambda\}$$

Languages ...contd

- Unit of concatenation is Λ
- Set of all strings obtained by concatenating any number of elements of *L*:

$$\left.L^* = \bigcup_{i=0}^{\infty} L^i \right\} \text{Kleene star}$$

- The set of all strings obtained by concatenating one or more elements of *L*:

$$L^+ = \bigcup_{i=1}^{\infty} L^i$$

Languages ...contd

- Note that $L^+ = L^*L = L\ L^*$
- The way we describe how to construct an arbitrary string in a language may also be used to recognize a string in the language
- Recognition of languages is considered in the context of abstract machines

Conclusion

- In this session we discussed ...
  - Course Details
  - Introduction to the Theory of Computing
    - Overview
    - Mathematical background

- Next time…
  - Regular Languages, Regular Expressions, Finite Automata