Theory of Computation
Plaksha University, Semester No. 5 (2021 Batch)

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Course Overview. Occasionally several computational problems arise in computer science and mathematics. The very first question is whether all the computational problems are solvable by the existing computers. Which problems can be solved efficiently and which are not? This course addresses these questions. The theory of computation has three main areas, automata theory, computability theory and complexity theory. The course starts with automata theory, where a simple model of computation, called a *finite automaton*, is introduced, and then an improved model, called context-free grammar. As a part of the computability theory, the course teaches an advanced model of computation, called *Turing machine*. The course demonstrates that there are computational problems that cannot be solved by Turing machines. In the final part, the complexity theory, the concept of easy and hard problems will be introduced.

Course Rationale and Organization. This course is organized into five different modules. It starts with reviewing some necessary topics of discrete mathematics in module-1. In module-2, the course introduces a simple model of computation, finite state machine/automaton and its solving capabilities/limitations. Then, the course teaches an improved model of computation, context-free grammar and pushdown automaton in module-3. Module-4 covers a powerful model of computation, called Turing machine, decidability by Turing machines and computations by Turing machines. Although the Turing machine is a powerful model, it has some fundamental limitations. In fact, this course will demonstrate that Turing machines cannot solve many computational problems. Finally, in module-5, the students will get exposed to the classes of problems, P, NP and NP-Complete. By the end of this course the students will be able to:

- Explain the basic computation models, finite automata, pushdown automata, context-free grammars and Turing machines.
- Design a computational model for a given problem and formally validate the correctness of the model.
- Find some applications of regular expressions and context-free grammars.
- Explain difference between decidable and undecidable languages.
- Demonstrate some fundamental limitations of the existing computing devices using examples.
- Explain easy and hard problems using examples.

Grading Policy.

Evaluation Components	Contribution (%)
Attendance and class participation	10
Class test	10
Quizzes	30
Mid-term	20
Final	30

Week-wise Plan. The topics, readings and some internal evaluation componants for each week are given below.

Week-1.

- **Topics.** Review of discrete mathematics
- **Readings.**
  1. Comprehensive handouts
  2. Introduction to Theory of Computation by Michael Sipser.

Week-2.

- **Topics.** Review of discrete mathematics
- **Readings.**
  1. Comprehensive handouts
  2. Introduction to Theory of Computation by Michael Sipser.

Week-3.

- **Topics.**
  1. Review of discrete mathematics
  2. Alphabet, languages and operations on languages
  3. An overview on model of computation
- **Readings.**
  1. (Textbook). Introduction to Theory of Computation by Michael Sipser.
  2. (Reference book). Elements of the Theory of Computation by Harry Lewis and Christos Papadimitriou.
  3. (Reference book). Introduction to Automata Theory Languages and Computation by Hopcroft H.E. and Ullman J. D.

Week-4.

- **Topics.**
  1. Examples of deterministic finite automaton (DFA)
  2. Formal definition of DFA and languages accepted by DFAs
  3. Regular languages
- **Readings.** Same as above
- **Evaluation components: Quiz-1 (10%).** This will have 10-15 multiple-choice questions and will be conducted offline during class hours. Date of evaluation: **5th Sept** (tentative).

Week-5.

- **Topics.**
  1. Basic candidates of regular languages
  2. Closure property of regular languages under union, intersection and complement
  3. Nondeterministic finite automaton (NFA): motivation, examples, and definition
- **Readings.** Same as above

Week-6.

- **Topics.**
  1. Equivalence between DFAs and NFAs
  2. NFA with ϵ-transition
  3. Regular languages are closed under union, intersection, complement, reversal (using ϵ-NFA)
  4. Regular expressions: definition and examples
- **Readings.** Same as above
- **Evaluation components: Class test (10%).** This will have 4-6 descriptive-type questions and will be conducted offline during class hours. Date of evaluation: **19th Sept** (tentative).

Week-7.

- **Topics.**
  1. Equivalence between regular expressions and regular languages
  2. Pumping lemma and non-regular languages
- **Readings.** Same as above

Week-8.

- **Topics.**
  1. Context-free grammar (CFG) and context-free language (CFL): definition and examples
  2. Leftmost derivation and parse tree
  3. Relation between regular languages and CFLs
- **Readings.** Same as above

Week-9. Mid-term break

Week-10.

- **Topics.**
  1. Chomsky normal form
  2. Pushdown automaton (PDA): definition and examples
  3. Equivalence between CFGs and PDAs
- **Readings.** Same as above

Week-11.

- **Topics.**
  1. Properties of CFLs
  2. Non context-free language and pumping lemma
- **Readings.** Same as above
- **Evaluation components: Quiz-2 (10%).** This will have 10-15 multiple-choice questions and will be conducted offline during class hours. Date of evaluation: **26th Oct** (tentative).

Week-12.

- **Topics.**
  1. Turing machine: model, definition and examples
  2. Turing decidable/recognizable languages
  3. Variants of TMs
- **Readings.** Same as above

Week-13.

- **Topics.**
  1. Variants of TMs
  2. Hilbert's problems
  3. Church-Turing thesis
  4. Universal Turing machines
- **Readings.** Same as above
- **Evaluation components: Quiz-3 (10%).** This will have 10-15 multiple-choice questions and will be conducted offline during class hours. Date of evaluation: **7th Nov** (tentative).

Week-14.

- **Topics.**
  1. Diagonalization method
  2. Understanding undecidable languages
- **Readings.** Same as above

Week-15.

- **Topics.** Complexity classes: P and NP
- **Readings.** Same as above
- **Evaluation components:** Reserved for extra **Quiz/Class test.** Date of evaluation: **21st Nov** (tentative).

Week-16.

- **Topics.** Polynomial time reduction, NP-Completeness, cook's theorem.
- **Readings.** Same as above