Theory of Computation

CSE 5313

LECTURE 1

Theory of Computation

- Course information
- Overview of the area
- Finite Automata

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Course information

1. **Instructor**
2. **Course website**
3. **Prerequisites**
4. **Lectures**
5. **Textbook**
6. **Syllabus**
7. **Homework**
8. **Grading policy**
9. **Collaboration policy**
10. **Exams and grading**

What is Theory of Computation?

- You've learned about computers and programming
- Much of this knowledge is specific to particular computing environment

What is Theory of Computation?

- Theory
  - General ideas that apply to many systems
  - Expressed simply, abstractly, precisely
- ***Abstraction*** suppresses inessential details
- ***Precision*** enables rigorous analysis
  - Correctness proofs for algorithms and system designs
  - Formal analysis of complexity
    - Proof that there is no algorithm to solve some problem in some setting (with certain cost)

This course

- Theory basics
  - Models for ***machines***
  - Models for the ***problems*** machines can be used to solve
  - ***Theorems*** about what kinds of machines can solve what kinds of problems, and at what cost
  - Theory needed for sequential single-processor computing
- Not covered:
  - Parallel machines
  - Distributed systems
  - Quantum computation
  - Real-time systems
  - Mobile computing
  - Embedded systems
  - …

Machine models

- **Finite Automata (FAs):** machines with fixed amount of unstructured memory.
  - useful for modeling chips, communication protocols, adventure games, some control systems, …
- **Pushdown Automata (PDAs):** FAs with unbounded structured memory in the form of a pushdown stack
  - useful for modeling parsing, compilers, some calculations
- **Turing Machines (TMs)**: FAs with unbounded tape
  - Model for general sequential computation (real computer).
  - ***Equivalent*** to RAMs, various programming languages models
  - Suggests general notion of ***computability***.

Machine models

- **Resource-bounded TMs** (time and space bounded):
  - "not that different" on different models: "within a polynomial factor"
- **Probabilistic TMs**: extension of TMs that allows random choices

Most of these models have ***nondeterministic*** variants:
can make nondeterministic "guesses"

Problems solved by machines

1. **What is a problem?**

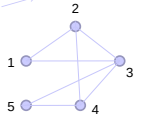
In this course, problem is a language.
A ***language*** is a set of strings over some "alphabet"

2. **What does it mean for a machine to "solve" a problem?**

Examples of languages

- L_1= {binary representations of natural numbers divisible by 2}
- L_2= {binary representations of primes} alphabet = {0,1}
- L_3= {sequences of decimal numbers, separated by commas, that can be divided into 2 groups with the same sum}
  - (5,3,1,3) ∈ L_3, (15,7,5,9,1) ∉ L_3. alphabet = {0,1,…,9,comma}
- L_4= {C programs that loop forever when run}
- L_5= {representations of graphs containing a ***Hamiltonian cycle***}

visits each node exactly once



  - {(1,2,3,4,5); (1,2),(1,3),(2,3),…}

vertices edges

alphabet = all symbols: digits, commas, parens

Theorems about classes of languages

We will define classes of languages and prove theorems about them:

- **inclusion**: Every language recognizable (i.e., solvable) by a FA is also recognizable by a TM.
- **non-inclusion**: Not every language recognizable by a TM is also recognizable by a FA.
- **completeness**: "Hardest" language in a class
- **robustness**: alternative characterizations of classes
  - e.g., FA-recognizable languages by regular expressions (UNIX)

Why study theory of computation?

- a ***language*** for talking about program behavior
- feasibility (what can and cannot be done)
  - halting problem, NP-completeness
- analyzing correctness and resource usage
- computationally hard problems are essential for cryptography
- computation is fundamental to understanding the world
  - cells, brains, social networks, physical systems all can be viewed as computational devices
- IT IS **FUN**!!!