COMS W3261: Computer Science Theory

Class time: Tuesdays and Thursdays 2:40 - 3:55 PM Class location: MUDD 833 Instructor: Allison Lewko Office hours for Instructor: Tuesdays 10:00 AM - 12:00 PM in CSB 519 Instructor email: alewko@cs.columbia.edu

1 TAs

- Arka Bhattacharya, ab3899@columbia.edu, Office hours: Friday 5-7PM
- Luke Kowalczyk, ltk2112@columbia.edu, Office hours: Mon 11:00 AM 1 PM
- Sam Frank, smf2147@columbia.edu, Office hours: Mon/Fri 10-11 AM
- Sagar Sarda, ss4355@columbia.edu, Office hours: Mon 4:30-6:30 PM

All TA office hours will be in the TA Room, 122 Mudd. The hours listed above are subject to change.

2 Course Description

This course is an introduction to models of computation, computability, and complexity. We will ask questions like: How do we define the abstract notion of "computation" or a "computer"? What problems can be computed? What problems can be computed efficiently? Can we prove that some problems can never be computed, no matter how fast our computers become? The course is highly mathematical and abstract; in particular, there will be no programming assignments and homework problems will frequently involve proving or disproving various assertions. Students are expected to be comfortable with the material covered in Discrete Math (W3203) or the equivalent.

| 2 $1/23$ Deterministic Finite AutomataCh. 2.13 $1/28$ Nondeterministic Finite AutomataCh. 2.34 $1/30$ NFA w/ epsilon transitions; Conversion to NFA, DFACh. 2.35 $2/4$ Regular expressions; Conversion to/from automataCh. 3.16 $2/6$ Properties of regular expressions; Conversion to/from automataCh. 3.3, 37 $2/11$ Pumping lemma; Myhill-Nerode theoremCh. 4.38 $2/13$ Algorithms for regular languages; Equivalence, minimization of automataCh. 6.49 $2/18$ Context-free grammarsCh. 5.210 $2/20$ Parse trees, ambiguous grammarsCh. 6.112 $2/27$ Equivalence of PDA and CFGCh. 6.313 $3/4$ Deterministic PDA; Pumping lemma for CFLCh. 6.414 $3/6$ Closure properties of CFL; AlgorithmsCh. 7.315 $3/11$ Chomsky normal formCh. 7.1 $3/18$ Spring Recess3/20Spring Recess16 $3/25$ CFL Membership Algorithm; ComputabilityCh. 8.317 $3/27$ Turing machines; Recursive and RE languagesCh. 8.520 $4/8$ Undecidability; Diagonalization; Properties of Recursive and R.E. languagesCh. 9.121 $4/10$ Universal language and TM, ReductionsCh. 9.222 $4/15$ More reductions, PCP, Undecidable problemsCh. 9.323 $4/17$ Complexity classes, the classes P, NP, coNPCh. 10.124 $4/22$ NP | | Date | Topic | Reading (HMU) |
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| 3 $1/28$ Nondeterministic Finite AutomataCh. 2.34 $1/30$ NFA w/ epsilon transitions; Conversion to NFA, DFACh. 2.55 $2/4$ Regular expressions; Conversion to/from automataCh. 3.16 $2/6$ Properties of regular expressions; Closure properties of regular languagesCh. 3.3, 37 $2/11$ Pumping lemma; Myhill-Nerode theoremCh. 4.38 $2/13$ Algorithms for regular languages; Equivalence, minimization of automataCh. 4.39 $2/18$ Context-free grammarsCh. 5.210 $2/20$ Parse trees, ambiguous grammarsCh. 6.112 $2/27$ Equivalence of PDA and CFGCh. 6.313 $3/4$ Deterministic PDA; Pumping lemma for CFLCh. 6.414 $3/6$ Closure properties of CFL; AlgorithmsCh. 7.13/13Midterm exam in class3/18Spring Recess3/20Spring Recess3/20Spring Recess18 $4/1$ Programming tricks; Multitape TMs; Nondeterministic TMsCh. 8.519 $4/3$ More variants of TMs, simulationsCh. 8.520 $4/8$ Undecidability; Diagonalization; Properties of Recursive and R.E. languagesCh. 9.121 $4/10$ Universal language and TM, ReductionsCh. 9.222 $4/15$ More variants of TMs, simulationsCh. 9.123 $4/17$ Complexity classes, the classes P, NP, coNPCh. 10.124 $4/22$ NP-completeness, SatisfiabilityCh. 10.223< | L | 1/21 | Course overview; automata, languages | Ch. 1 |
| 41/30NFA w/ epsilon transitions; Conversion to NFA, DFACh. 252/4Regular expressions; Conversion to/from automataCh. 3.162/6Properties of regular expressions; Closure properties of regular languages; Equivalence, minimization of automataCh. 3.3, 372/11Pumping lemma; Myhill-Nerode theoremCh. 4.382/13Algorithms for regular languages; Equivalence, minimization of automataCh. 4.392/18Context-free grammarsCh. 5.2102/20Parse trees, ambiguous grammarsCh. 5.1122/27Equivalence of PDA and CFGCh. 6.3133/4Deterministic PDA; Pumping lemma for CFLCh. 6.4143/6Closure properties of CFL; AlgorithmsCh. 7.1153/11Chomsky normal formCh. 7.13/13Midterm exam in class3/18Spring Recess163/25CFL Membership Algorithm; ComputabilityCh. 7.4173/27Turing machines; Recursive and RE languagesCh. 8.5204/8Undecidability; Diagonalization; Properties of Recursive and R.E. languagesCh. 9.1214/10Universal language and TM, ReductionsCh. 9.3224/15More reductions, PCP, Undecidable problemsCh. 9.3234/17Complexity classes, the classes P, NP, coNPCh. 10.1244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.2< | 2 | 1/23 | Deterministic Finite Automata | Ch. 2.1, 2.2 |
| 5 $2/4$ Regular expressions; Conversion to/from automataCh. 3.16 $2/6$ Properties of regular expressions; Closure properties of regular languagesCh. 3.3, 3 Closure properties of regular languages7 $2/11$ Pumping lemma; Myhill-Nerode theoremCh. 4.3 Equivalence, minimization of automata9 $2/18$ Context-free grammarsCh. 5.210 $2/20$ Parse trees, ambiguous grammarsCh. 6.112 $2/27$ Equivalence of PDA and CFGCh. 6.313 $3/4$ Deterministic PDA; Pumping lemma for CFLCh. 6.414 $3/6$ Closure properties of CFL; AlgorithmsCh. 7.315 $3/11$ Chomsky normal formCh. 7.1 $3/13$ Midterm exam in class $3/25$ CFL Membership Algorithm; Computability16 $3/25$ CFL Membership Algorithm; ComputabilityCh. 7.417 $3/27$ Turing machines; Recursive and RE languagesCh. 8.3 Nondeterministic TMS19 $4/3$ More variants of TMs, simulationsCh. 8.520 $4/8$ Undecidability; Diagonalization; Properties of Recursive and R.E. languagesCh. 9.121 $4/10$ Universal language and TM, ReductionsCh. 9.323 $4/17$ Complexity classes, the classes P, NP, coNPCh. 10.124 $4/22$ NP-completeness, SatisfiabilityCh. 10.325 $4/24$ Reductions, NP-complete problemsCh. 9.124 $4/29$ Lambda calculus27 | 3 | 1/28 | Nondeterministic Finite Automata | Ch. 2.3, 2.4 |
| | 1 | 1/30 | NFA w/ epsilon transitions; Conversion to NFA, DFA | Ch. 2.5 |
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| Image: Nondeterministic TMsNondeterministic TMs194/3More variants of TMs, simulationsCh. 8.5204/8Undecidability; Diagonalization; Properties of Recursive and R.E. languagesCh. 9.1214/10Universal language and TM, ReductionsCh. 9.2224/15More reductions, PCP, Undecidable problemsCh. 9.3234/17Complexity classes, the classes P, NP, coNPCh. 10.1244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | 17 | 3/27 | Turing machines; Recursive and RE languages | Ch. 8.2 |
| 194/3More variants of TMs, simulationsCh. 8.5204/8Undecidability; Diagonalization; Properties of Recursive and R.E. languagesCh. 9.1214/10Universal language and TM, ReductionsCh. 9.2224/15More reductions, PCP, Undecidable problemsCh. 9.3234/17Complexity classes, the classes P, NP, coNPCh. 10.1244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | 18 | 4/1 | Programming tricks; Multitape TMs; | Ch. 8.3, 8.4 |
| 204/8Undecidability; Diagonalization; Properties of Recursive and R.E. languagesCh. 9.1214/10Universal language and TM, ReductionsCh. 9.2224/15More reductions, PCP, Undecidable problemsCh. 9.3234/17Complexity classes, the classes P, NP, coNPCh. 10.1244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | | | Nondeterministic TMs | |
| Properties of Recursive and R.E. languages214/10Universal language and TM, ReductionsCh. 9.2224/15More reductions, PCP, Undecidable problemsCh. 9.3234/17Complexity classes, the classes P, NP, coNPCh. 10.1244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | 19 | 4/3 | More variants of TMs, simulations | Ch. 8.5, 8.6 |
| 214/10Universal language and TM, ReductionsCh. 9.2224/15More reductions, PCP, Undecidable problemsCh. 9.3234/17Complexity classes, the classes P, NP, coNPCh. 10.1244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | 20 | 4/8 | | Ch. 9.1, 9.2 |
| 224/15More reductions, PCP, Undecidable problemsCh. 9.3234/17Complexity classes, the classes P, NP, coNPCh. 10.1244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | | | Properties of Recursive and R.E. languages | |
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| 244/22NP-completeness, SatisfiabilityCh. 10.2254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | 22 | 4/15 | More reductions, PCP, Undecidable problems | Ch. 9.3-9.5 |
| 254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | | | | Ch. 10.1, 11.1 |
| 254/24Reductions, NP-complete problemsCh. 10.3264/29Lambda calculus27275/1Lambda calculus27 | 24 | 4/22 | NP-completeness, Satisfiability | Ch. 10.2, 10.3 |
| 27 5/1 Lambda calculus | 25 | 4/24 | Reductions, NP-complete problems | Ch. 10.3, 10.4 |
| | | 4/29 | Lambda calculus | |
| | 27 | 5/1 | Lambda calculus | |
| 5/15 Final exam | | 5/15 | Final exam | |

Schedule of Topics to be Covered (*Subject to Change)

3 Grading

There will be several homework assignments throughout the semester. Homeworks will be posted on courseworks and announced in class and via email. They will be due at the beginning of class on their due date.

Collaboration Policy Students are allowed to work together on the homework assignments but must write up their solutions individually (while alone, not looking at anyone else's writeup). It will be considered an honor code violation to consult solutions from previous years, from the web or elsewhere, in the event that homework problems have been previously assigned or solu-

tions are available elsewhere. The CS department web page,

http://www.cs.columbia.edu/education/honesty, lists the department's academic honesty policies. All students are expected to abide by these policies.

Late Homework Policy Late homework will penalized by 10% for each day late. If a homework is > 0 but \leq 24 hours late, it is penalized as one day. If it is > 24 but \leq 48 hours late, it is penalized as two days, etc.

The course grade will be based on:

- 30% homework assignments
- 35% midterm exam
- 35% final exam

4 Textbook

Required Textbook Introduction to Automata Theory, Languages and Computation, by John Hopcroft, Rajeev Motwani, and Jeffrey Ullman.

Additional Reference (optional) Introduction to the Theory of Computation, by Michael Sipser.