1. Basics

Course details:	CS 254 (Computability and Complexity); Spring 2017, Carleton College
Meeting times:	5a (MW 13:50–15:00, F 14:20–15:20); CMC 301
Instructor:	Jed Yang, CMC 324, x4473, `jyang@carleton.edu`
Office hours:	Mon. 15:00–16:00 (in CMC 306), Wed. 11:00–12:00, Fri. 12:35–13:35; or by appointment
Webpage:	`http://cs.carleton.edu/faculty/jyang/cs254.17s/`

2. Course information

Official course description. An introduction to the theory of computation. What problems can and cannot be solved efficiently by computers? What problems cannot be solved by computers, period? Topics include formal models of computation, including finite-state automata, pushdown automata, and Turing machines; formal languages, including regular expressions and context-free grammars; computability and uncomputability; and computational complexity, particularly NP-completeness.

Prerequisites. *Officially:* CS 111 (Introduction to CS) and either CS 202 (Math of CS) or Math 236 (Math Structures). *Unofficially:* familiarity and comfort with recursion and proofs by mathematical induction, reasonable facility with binary arithmetic and basic data structures like stacks, and "mathematical maturity." If you're concerned about your background, please come talk to me in the first week.

Course goals. This course addresses the question of what precisely we mean by "computation." What *is* a computer? What is a computer capable of doing? What problems are so hard that no computer can solve them (no matter how long you give a programmer to write a program to solve them, no matter how long you let that program run)? What computational resources—mostly, time and space (memory)—do we need to solve a particular problem?

To discuss these questions, we will consider a sequence of formal mathematical models of computers. For each model, we will discuss problems that can and cannot be solved by that "computer." By talking about models of computation with several levels of complexity, we will see how our assumptions affect what problems can be solved. We will discover problems that cannot be solved even by our most general model of computation. In the final third of the course, we will talk about classes of problems that can or cannot be solved efficiently.

By the time you have completed the course, you will be able to:

- Explain the difference between several models of computation (finite automata, pushdown automata, and Turing machines) and prove results about what languages may be recognized by each model.
- Explain what different time and space complexity classes refer to (*e.g.*, P, NP, PSPACE) and prove that particular languages are in each class.
- Explain what it means for a question to not be decidable by a computer, and give examples of undecidable problems.
- Relate the theoretical topics we discussed to more applied questions that come up in computer science. For example, why would it be useful to know that a problem you are trying to solve is NP-complete?

This course focuses on big, abstract ideas in computer science, and it will be quite mathematical in flavour. Whether or not you are interested in computer science theory, this class should help you see why theory results have profound impacts for computer science as a whole.

The results that we explore in *Computability and Complexity* are amazingly elegant, but to appreciate them you will have to *think*. It is therefore important that you keep up with the course material, so please get in touch with me promptly if you are having trouble.

Textbook. *Introduction to the Theory of Computation*, 3rd edition, Michael Sipser, 2013.

We will follow the textbook fairly closely (up to Section 8.3, skipping Section 2.4 and Chapter 6).

3. Universal Learning

I am committed to the principle of universal learning. This means that our classroom, our virtual spaces, our practices, and our interactions will be as inclusive as possible. Mutual respect, civility, and the ability to listen and observe others carefully are crucial to universal learning.

Carleton College is committed to providing equitable access to learning opportunities for all students. The Disability Services office (Burton Hall 03) is the campus office that collaborates with students who have disabilities to provide and/or arrange reasonable accommodations. If you have, or think you may have, a disability (*e.g.*, mental health, attentional, learning, autism spectrum disorders, chronic health, traumatic brain injury and concussions, sensory, or physical), please contact Chris Dallager, Director of Disability Services, by calling 507-222-5250 or sending an email to `cdallager@carleton.edu` to arrange a confidential discussion regarding equitable access and reasonable accommodations.

4. Course requirements

Attendance and participation. I expect you to attend class. You may not notice me taking attendance during class meetings, but I will notice if you are not in class. Occasional absences will not impact your grade because what I look for is not mere attendance, but engagement and participation.

Indeed, coming to class is not just about showing up; it is also about being fully engaged in the learning experience. If you have a question, others in the class may also be wondering the same thing. So, please speak up and ask questions anytime you need to. Not only will you be helping yourself, but also you will be helping your peers. Attending office hours is another great opportunity to ask questions.

Be mindful of others. Refrain from using mobile phones or laptops for activities unrelated to the learning process. If you prefer to use laptops to take notes, please kindly sit in the back, as the screen may distract others.[1] There is research that suggests taking notes by hand is better for long-term retention.[2]

Reading. Read the book! (Our text is very good—particularly at explaining the idea behind a proof.)

Homework. Problem sets will be assigned regularly throughout the term. The goal of the homework is to give you an opportunity to continuously engage directly with the material. The homework questions are meant to be challenging and to stretch you; simply put, I believe that the homework is where you will do the vast majority of your learning in this class. Grapple with the questions; talk to classmates about solution strategies if you are feeling stuck; do the homework. I strongly encourage you to start on homeworks early. See below for more detailed policy regarding homework.

Exams. There are two in-class midterm exams (tentatively scheduled for **Monday of Week 5** and **Monday of Week 8**), weighted equally. The second exam will mainly focus on the material covered since the first exam, but can include previous material too. There will be a final exam during our final exam period covering the entire course. (I reserve the right to make the final self-scheduled.)

Time outside of class. Like other Carleton courses, I expect that you should be spending about 10–12 hours per week on this course outside of class. Some students need to spend a bit more than that (which is okay). If you are spending more than 15 hours per week on this course outside of class time, please come talk to me so we can find ways to help you learn the material without spending so much time.

Illness. You should make every effort to attend class when you are healthy. If you become ill, for your well-being and the well-being of the rest of the class, you should not come to class. (Nor should you show up in my office with your germs!) Yes, this sounds like common sense, but it is tempting to try and power through as normal so as not to fall behind, particularly at a place like Carleton. If you become ill, or know that you will need to miss class for some reason, please contact me as soon as you are able, and we will work together to plan how you will keep up and/or make up any missed work.

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[1] See `http://tinyurl.com/laptops-degrade-nbrs-grades`.

[2] P. A. Mueller and D. M. Oppenheimer, The pen is mightier than the keyboard: advantages of longhand over laptop note taking, *Psychological Science* **25** (2014), 1159–1168.

5. Grading

Your grade will be determined by a weighted arithmetic mean of various components with weights listed in the table on the right. In more detail: (a) I record a numerical score for each component (possibly adjusted so that different components are on comparable scales). (b) For each student, I calculate the weighted arithmetic mean with both schemes. (c) The higher score from the two schemes will be automatically chosen for each student as the overall score. (Think of Scheme 1 as default and Scheme 2 as an opportunity to catch up from poor midterm performances.) (d) I sort these overall scores in descending order. (e) Except in very unusual circumstances (*e.g.*, medical or other personal-life issues that affected a particular score) I assign letter grades strictly based on this sorted order.

component	Scheme 1	Scheme 2
Homework	25%	30%
Exam 1	25%	20%
Exam 2	25%	20%
Final exam	25%	30%
Participation	±5%	±5%

There is no standard percentage that I associate with a particular letter grade (`A`, `B`, `C`, *etc.*). Instead, I decide on letter grade cutoffs by comparing each student's overall score to my understanding of the Platonic ideal of an x student (for $x \in \{\texttt{A}, \texttt{A-}, \texttt{B+}, \ldots\}$). To make the grades robust to small noise, I also look for large numerical gaps in the sorted list of scores when setting grade cutoffs.

Note that therefore *you should not care how difficult the exams (or homework assignments) are.* Indeed, the Platonic `A` student earns fewer points on a more difficult exam than she does on an easier exam. In fact, in many courses I intentionally make one exam harder than the others, which gives me information (in a mathematical sense) in separating an `A` performance from an `A-` performance.

There is also no preset curve of how many of each letter grade will be given. As such, *you are encouraged to help each other in the pursuit of perfection.* If you all do `A` work, you will each get an `A`. Feel free to talk to me if you are concerned about your standing in the class, with the understanding that given the nature of the aforementioned grading process, it is impossible to accurately predict your course grade before the final exam.

If you believe that there has been a mistake in the grading of a particular assignment or exam, please describe the error in an email or on a separate piece of paper and submit promptly to me. Be aware, I will look over the entire assignment/exam—not just the problem that you are questioning—so your regraded score may be higher or lower than your original score.

6. How to get help

If you need help there are are multitude of resources you can use:

(a) **Yourself.** If you're stuck on a problem or struggling with a concept from class, take a break and think about something else (*e.g.*, your Greek assignment, the economics of *Star Trek*) for a few hours and then try a fresh start.
(b) **The book.** Our text is *very* good; it's a great place to turn if you are having any trouble.
(c) **Your classmates.** You are each other's best resource: talking through the course material with someone else who is also trying to master it is a great way for you both to learn. (And don't discount the learning that you will do while trying to explain to a classmate an idea covered during class that you think you understand; I can't count the number of times that I've discovered that I didn't really understand something until I tried to teach it to someone.) The homework assignments are meant to challenge you, and figuring some of them out together is a great approach.
(d) **The instructor.** Come to my office hours or email to make an appointment. (Please include a list of a few times that you will be free to meet, and give me at least 24 hours of lead time.) I will consistently reserve Tuesdays for research, and I do not schedule office hours or make appointments for that day. I have this scheduled "research day" so that I can work on my research projects in an uninterrupted block of time. Without reserving a large block, I won't have time for any research. Thursdays 11:30–16:00 are usually good times for me.
(e) **College-wide resources.** The library, the Academic Skills Center, the Math Skills Center, the Writing Center (yes, writing proofs *is* writing), the CS lab assistants, *etc.*

7. Homework policy and tips

There will be regularly assigned problem sets throughout the term. Many assignments will be due in stages, bundling two or three due dates together. I will aim to make problems due at least two class meetings after they are posted, to give you scheduling flexibility as to when you work on them and to allow you more time for collaboration with your classmates or for visits to office hours. I will also try to make the assignments overlap: to have the next assignment out before the last part of the previous one is due. While I try to answer queries about homework within 24–48 hours, I cannot always make this timeline, and you should not rely on faster responses than this. Among other things, this means that you would be well advised to ask any questions of clarification earlier than the day before an assignment is due.

Collaboration. You are *strongly* encouraged to collaborate with your classmates on assignments in figuring out how to solve problems, as long as you:

(a) understand your solutions,
(b) write your solutions in your own words without copying, and
(c) indicate the names of your collaborators.

See the last section of the syllabus for the formal statement.

I strongly recommend keeping collaborative groups small (≤ 3); you will learn far more than in an enormous group. If you are working with a group, read over and attempt the problems on your own *before* you meet. You will get more out of it, and so will your group. You must list your collaborators on every problem, and you may not work from notes generated in a collaborative session.

Other resources. Besides the textbook, your classmates, and me, you should not be seeking help for the homework from any other sources. Searching for problems or key phrases on the Internet is not allowed. You may use the Internet for better understanding general concepts.

LaTeX. Homework must be typeset using LaTeX. LaTeX is *the* standard tool for communicating technical material, and so it is valuable to be familiar with it. Please see the course webpage for some references, tutorials, and a template you may use. If you have diagrams that you would like to submit as part of your homework solutions that are overly painful to typeset in LaTeX, hand-drawn supplements are acceptable (but they too must be submitted electronically). You may find it easiest to print your solution, draw in your diagrams, scan the printout, and submit the resulting PDF. Or you can scan or photograph just the diagram, include `\usepackage{graphicx}` and use `\includegraphics{image-file-name}` at the place where you want your image. Make sure your result is legible and clear.

Electronic submission. You will turn in one file for each homework problem. Name your PDF file exactly `psXX-YY.pdf` for problem set `XX` question `YY` (use two-digit numbers and lowercase letters). For example, if I was submitting question 3 on problem set 2, I would name my file `ps02-03.pdf`. The strict naming convention allows for processing the submissions by some software to aid in anonymous grading. Therefore, you must follow these requirements precisely and carefully; if you do not, you risk getting zero credit. Of course, your submission should **not** include your name anywhere.

Mount the `COURSES` drive (use `map-network-drives` on lab machines; see `https://wiki.carleton.edu/display/itskb/Network+drives` for instructions to mount on your own machines). Turn in your file for each question by placing it in the directory `cs254-00-s17/Hand-in/username/` where `username` is your username. Leave your submitted files on `COURSES` for the entire term.

Additionally, submit or update a file called `collaborations.txt` in the same directory. This file should have two lines for each question on each problem set, one listing the problem set and question number and usernames of your collaborators and the other listing the details of these collaborations. The collaboration statement is mandatory even if you worked alone. Here are two examples:

```
ps02-03: none
I worked alone.
ps02-04: sipserm, austenj
I brainstormed general approaches with austenj and I helped sipserm see how to
apply the pumping lemma.
```

Occasionally, I will ask you to write some code for a question. Your code should use good style. Any programming questions will have specific instructions on how to name the file and how to turn it in.

Grading. Most homework problems will be graded. Sometimes, there may be insufficient time to grade and only a subset of problems will be graded. Do all of the homework problems to ensure you get credit.

Questions will be graded on a four-point scale: quality deserving of being a solution set (4); correct with minor errors or flaws of presentation (3); essentially correct idea but with significant technical or presentation errors (2); some good ideas but fundamentally flawed solution (1); no genuine attempt (0). I will ask the grader to be sparing in giving out 4's.

Late work policy. Homework is typically due at 22:00 on the day it is due. You are allowed up to eight (8) late question-days throughout the term for homework. (A **day** starts at 22:00 and ends at 22:00 after the next class, usually 2 or 3 calendar days later.) This allotment is to cover for legitimate reasons for tardiness that may arise. No explanation for the tardiness is necessary or desired, but please do inform me (in person in class is fine) that you are submitting an assignment late. Obviously, you must refrain from looking at posted solutions until you have submitted the work. After the freebies, work handed in late will receive zero credit. You may not use more than one late day for a single question. Late days may not be used for extensions beyond the final day of classes. To be fair to everyone in the class, I will generally not grant additional extensions without the intervention of a doctor or class dean. But if a genuine emergency situation arises, please talk to me.

Some tips for problem sets in this class.

- Start assignments early. At the least, *read the entire assignment the day that it is handed out.* Doing so will let your brain work on the questions even while you are not actively working on the assignment.
- Do not limit yourself to solving the homework questions in order! I may order questions on a problem set for any of a number of reasons, including where the page breaks nicely, so do not use the order of the questions as a guide to difficulty.
- Unless indicated to the contrary, you must formally prove the correctness of your solution to every homework and exam problem.
- Treat your problem set as you would an essay for an English class. Draft. Edit. Rewrite. Think about clarity as you write your answers; you are trying to communicate a solution.
- On any question in which you give a complicated proof or construction, please also give an English description of your ideas. This will help the reader understand what you have written, and will help you get the partial credit you deserve.
- Answers to homework questions are not always supposed to be obvious to you—you *should* have to think and struggle to answer some of the questions. To calibrate your personal expectations: do not worry if you cannot solve every problem! (Getting an `A` does not require solving all the questions.) Write up whatever progress you have made on each question. You will receive partial credit, especially for an answer like "Here's where I got stuck. I can't see how to finish the argument because x." (On the other hand, getting an `A` *does* require solving *most* of the problems; just do not panic if there is a question once every two or three weeks that stumps you.)
- If you are totally stuck on a question, find someone (me or a classmate) with whom to chat about it.
- Do not write down anything that you do not believe. Avoid making yourself believe a false proof—it damages your brain.

8. Academic honesty and collaboration policy

Collaborative work is an integral part of many successful ventures. As such, I expect that you should collaborate with your classmates a lot during your time in this course. However, it is important to understand that there is a big difference between thinking about and solving a problem as part of a group (which is good, both educationally and morally) and copying an answer or letting someone else copy your answer (which is bad, educationally and morally, and has punitive consequences).

In short, ***I trust you to maintain the utmost level of academic integrity in this course.*** Please do not break this trust; if you do, there will be repercussions. The formal policy below lays this out explicitly, and supplements the College's academic integrity policy and the Dean of the College's detailed guide to academic integrity.

Collaboration policy: You may collaborate on the homework assignments to the extent of formulating ideas as a group, but you may not collaborate in the actual writing of solutions (unless explicitly allowed in the instructions). In particular, you may not work from notes taken during collaborative sessions. You *must* cite all sources, including classmates from whom you obtained ideas. You may not consult any materials from any previous offerings of this course or from any other similar course offered elsewhere.

You are required to completely understand any solution that you submit and, in case of any doubt, you must be prepared to orally explain your solution to me. If you have submitted a solution that you cannot verbally explain to me, then you have violated this policy.

Of course, there is to be no collaboration whatsoever on any exams. Policies for what constitutes acceptable reference material, if any, will be specified in detail when the exam is distributed.