CSCI-561: Theory of Computation

Fall 2020

1 Overview and Outcomes

Are there "laws of physics" for computing? Are there fundamental limits to what computers can do—and thus things computers cannot do? If so, what makes computational problems harder or easier, solvable or unsolvable? And when faced with a new computational problem, how can we determine its difficulty and solvability?

In this course, we will address such questions about the fundamental capabilities and limits of computation. In particular, we will answer the following:

- *What is a computer?*
  We will study different models of computation.

- *What can we compute?*
  We will define problems that are solvable/unsolvable using different models of computation.

- *How well can we compute?*
  We will analyze the performance capabilities and limits for various computational models and problems.

At many universities, courses on the *Theory of Computation* are purely theoretical, in essence, math classes. Here at Mines, we aim to blend theoretical rigor and practical application. Thus, in this course, we will both study fundamental results of computational theory and reduce theory to practice though projects that implement and apply key algorithms of theoretical computer science. Through the activities in this course, you will learn the following (Figure 1):

Remember: Know definitions of conventional objects in language and automata theory.
      Example: Define a context-free grammar.

Understand: Describe computational problems using formal languages.
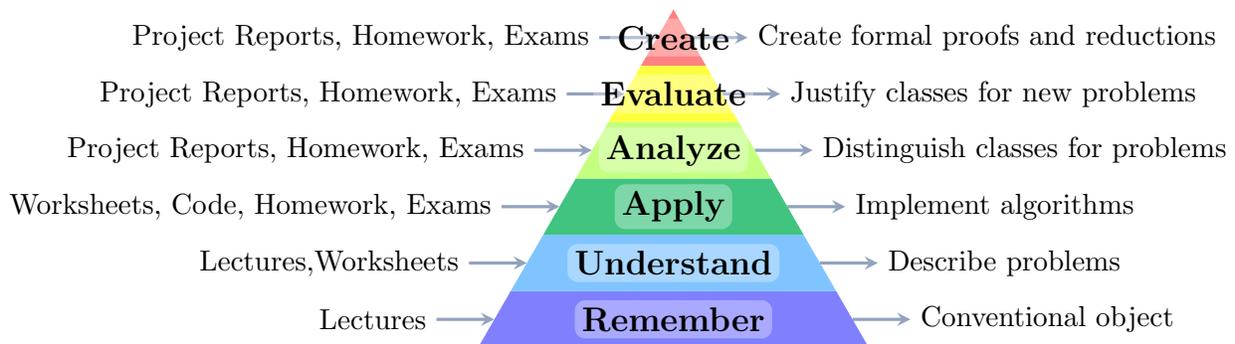   Example: Write a regular expression to find email addresses

Project Reports, Homework, Exams →	**Create**	→ Create formal proofs and reductions
Project Reports, Homework, Exams —	**Evaluate**	→ Justify classes for new problems
Project Reports, Homework, Exams —→	**Analyze**	→ Distinguish classes for problems
Worksheets, Code, Homework, Exams —→	**Apply**	→ Implement algorithms
Lectures,Worksheets —→	**Understand**	→ Describe problems
Lectures —→	**Remember**	→ Conventional object

Figure 1: Bloom's Taxonomy of Learning Activities and Outcomes

Apply: Implement existing language theory algorithms

Example: Write code to convert a regular expressions to a finite automaton.

Analyze: Distinguish suitable computational classes for new problems.

Example: Could we model some X as a regular language and/or solve via Boolean Satisfiability?

Evaluate: Justify the suitability of various computational classes for new problems.

Example: Why should we use context-free grammar vs. regular expressions to parse a particular file format?

Create: Develop proofs and reductions (algorithmic transformations) to characterize the required computation and/or solve a new problem.

Example: Create a formal proof that a file format cannot be parsed with regular expressions.

2 General Course Information

Instructor:	Neil Dantam	ndantam@mines.edu
TAs:	Luke Drong	drong@mymail.mines.edu
	Levi Petty	lpetty@mymail.mines.edu
Class Representatives:	Evan Lim	
	Alex Pollock	
	Mona Wade	

Textbooks and References

- **Primary Textbook** (main reference for the course) Michael Sipser. *Introduction to the Theory of Computation.*

- **Alternate Textbooks** (reference some advanced topics)

  - John E. Hopcroft, Rajeev Motwani, and Jeffrey D. Ullman. *Introduction to Automata Theory, Languages, and Computation.*
  - Alfred V. Aho, Monica S. Lam, Ravi Sethi, Jeffrey D. Ullman. *Compilers: Principles, Techniques & Tools.*

- **Lisp References**

  - Peter Siebel. *Practical Common Lisp.* http://www.gigamonkeys.com/book/
  - *Common Lisp HyperSpec.* http://www.lispworks.com/documentation/HyperSpec/Front/
  - Paul Graham. *ANSI Common Lisp.* http://www.paulgraham.com/acl.html

Online Resources

- Course Web Page: Syllabus, lecture slides, worksheets

- Canvas: Announcements, lecture videos, grades, worksheet solutions

- Piazza: Questions, discussion, homework/project help

- Course Github Organization: Project code distribution and submission

- Isengard: ITS-managed Linux server with shell access

- Google Calendar

- Zoom: Remote office hours

Technology Requirements This course assumes you are able to access a GNU/Linux system (e.g., Debian, Ubuntu). If you do not run Linux on your personal workstation, you may use the ITS-managed Isengard server. The instructor and TAs can provide only very limited technical support if you attempt to use a non-Linux platform.

Who should I email/contact?

- **Miscellaneous basic policy questions** (when is the midterm? when is an assignment due?): Re-read the syllabus, check Canvas for announcements and assignments, check the course website, and ask any additional questions on Piazza.

- **Help with assignments or course topics:** Piazza, TA office hours, or instructor office hours. Private post on Piazza if the matter should be hidden from other students (e.g., something about your code or questions about your grade)

- **Solutions to in-class exercises:** Slides with completed exercises will be posted to Canvas after the lecture.

- **Anything sensitive or confidential** (e.g., a health issue) Email the instructor about the issue and/or to schedule a meeting to discuss the issue.

- **Concerns/suggestions about course procedures** Email the instructor, TAs or class representatives about the issue and/or to schedule a meeting to discuss the issue.

FAQ

- Q: Is the textbook "required?"
  A: Most students will need to study the textbook to learn the topics in this course. In fact, many would also benefit from studying the alternate textbooks as well.

- Q: When/where are office hours?
  A: The instructor will post office hours on Canvas the first or second week of the semester (it takes us some time to rearrange meeting schedules each semester). Instructor office hours are ~~in the instructor's office, BB249~~ on Zoom. TA office hours ~~will be posted~~ are on Zoom.

- Q: What's on the exam?
  A: Exam questions will be similar to the homework assignments and will focus on evaluating understanding, application, and synthesis of the course topics (i.e., the upper levels of Bloom's taxonomy), including specifically writing proofs. Questions will not focus on memorization,

but one must know the key definitions and concepts to apply them. For the midterm, all topics covered up to the exam may be included. The final will be cumulative but will focus on topics covered after the midterm. The instructor will post a specific list of topics after preparing each exam, typically about a week before the exam date (in past semesters, the topic list included 80-90% of the lecture material).

- Q: When is the midterm?
  A: Please see the tentative schedule in this document for an approximate time. The instructor will announce firm details about the midterm closer to the date and will post the details on Canvas.

- Q: When/where is the final exam?
  A: The registrar schedules all final exams. Please see the registrar's website.

- Q: What's my grade?
  A: The exact answer is unknowable until the end of the semester. For an approximate answer, see section 3 and compare your scores to the class distribution, which will typically be posted on Canvas for major assignments.

- Q: Can I have an extension on an assignment?
  A: In case of extenuating circumansances (medical issue, personal emergency, etc.) of course; please contact the instructor/TA. In other cases, sometimes it may be appropriate to extend a deadline for the entire class (see "Fairness" in section 3).

- Q: How can I improve my grade?
  A: Participate in lecture, come to office hours, study, ask questions, and start assignments early. (see "Fairness" and "Grading Corrections" in section 3)

3 Grading and Evaluation

The course score (percentage) will be computed as a weighted average of scores (points received over points possible) as follows:

Class Participation	5% (c)
Homeworks	10% (h)
Projects	35% (p)
Midterm Exam	20% (m)
Final Exam	30% (f)

$$\texttt{score} = .05 \left(\frac{c_{\text{recv.}}}{c_{\text{poss.}}} \right) + .1 \left(\frac{h_{\text{recv.}}}{h_{\text{poss.}}} \right) + .35 \left(\frac{p_{\text{recv.}}}{p_{\text{poss.}}} \right) + .2 \left(\frac{m_{\text{recv.}}}{m_{\text{poss.}}} \right) + .3 \left(\frac{f_{\text{recv.}}}{f_{\text{poss.}}} \right)$$

Class Participation During most lectures, you will have a worksheet to practice the material. After the lecture is complete (i.e., we finish the set of slides corresponding to the worksheet), scan or photograph the worksheet and submit it on Canvas. Your participation grade will be based on making an honest effort on the exercises.

Midterm Exam A midterm exam will take place around the middle of the semester.

Final Exam A cumulative exam will take place during finals week.

Homeworks There will be several homeworks and exercises.

Projects There will a warmup plus two projects on applications of CS theory. The amount of code you will need to write is fairly small (a few hundred lines at most). However, you will need to think carefully about the relevant theory, math, and algorithms. Thus, **it is critical that you start projects early** so you have sufficient time to think through the required implementation and application (and ask questions if you get stuck).

Project 0 Warm-up project on programming environment and mathematical preliminaries.

Project 1 Finite Automata and Regular expressions.

Project 2 Propositional Logic and Boolean Satisfiability.

Letter Grades Letter grades will be based on a curve. It is expected—but not guaranteed—that score distributions will be normally distributed and letter grades will correspond to university and department norms. Assuming consistent, normal distribution of scores, the A/B cutoff will be approximately at the median score, and scores more than one standard deviation below the average may receive less than a B. However, skewed student effort or score distributions may result in correspondingly skewed letter distributions.

Fairness It is import to evaluate all students as evenly as possible. While we will attempt to accommodate disabilities and extenuating circumstances (physical/mental health, school-related travel, and similar) to the greatest possible extend, it would be unfair to offer any further special treatment.

Grading Corrections Grading changes will only be made for grading errors. It is not possible to change grades in response to disagreements about point allocation, partial credit, letter grade cutoffs, etc., because such changes would be unfair to the rest of the class. Grading corrections will only be made for the following errors:

1. *Arithmetic:* The grader incorrectly summed your points.

2. *Code:* An error in the grading environment or scripts incorrectly tested your code.

3. *Written:* The grader incorrectly understood your answer.

Projects Expectations and Grading

- Projects will include a coding portion and a report portion.

- Code will be graded objectively. Code must produce the correct output to receive credit. Incorrect output, no output, compilation errors, or runtime errors will not receive credit. **Please double-check your submitted code to ensure that minor errors will not result in major test failures.**

- Code tests will include edge cases. Think through all possible conditions for your program.

- Report grading will evaluate your overall understanding for the project area.

Written Work Format and submit your written work as follows. Improper submission or formatting may result in a penalty on assignments.

- For FERPA compliance, include a cover sheet on all written work that contains only your name and no answers or other work.

- Write your name on *every page* of all written work. If the work cannot be matched to you, you cannot receive credit for it.

- Include page numbers and total page count in written reports to ensure pages are properly ordered and no pages are overlooked.

- Handwritten work must be *clearly legible* to receive credit.

- Submit electronic reports, homeworks, etc. in PDF format. Do not submit word processor files because these are inconsistently formatted by different software.

- Work must be readable when printed in black and white.

4 Tentative Schedule

(updated 2020-10-20)

Week	Date	Topic(s)
Week 1	Aug 25	L00: Course Introduction and L01: Math Review
Week 2	Sept 1	L02 and L03: Common Lisp
Week 3	Sept 8	L04 and L05: Finite Automata
Week 4	Sept 15	Career Day and L06: Regular Expressions
Week 5	Sept 22	L07: MYT and L08: Regular Decision Properties
Week 6	Sept 29	L09: Pumping Lemma and L10: Regular Closure Properties
Week 7	Oct 6	L11: FA Minimization and Review
Week 8	Oct 13	Midterm and L12: Discrete Event Systems
Week 9	Oct 20	Fall Break and L12: Discrete Event Systems
Week 10	Oct 27	L13: SAT and L14: SATPlan
Week 11	Nov 3	L15: Grammars and L16: Pushdown Automata
Week 12	Nov 10	L17: Context-Free Languages and L18: Context-Free Pumping Lemma
Week 13	Nov 17	L19: Parsing and L20: Turing Machines
Week 14	Nov 24	L21: Decidability and Thanksgiving Break
Week 15	Dec 1	L22: Complexity
Week 16	Dec 8	Review
Week 17	Dec 15	Finals Week

5 Policies

5.1 Mines Policies and Resources

Mines Policies and Resources

5.2 CS Collaboration Policies

CS Collaboration Policies

5.3 Course Policies

5.3.1 Laptop and Smartphone Policy

- Lecture slides are posted in advance. You are strongly encouraged to use your laptop or phone to follow along during lecture and to review slides during exercises.

- Note-taking on laptops, tablets, etc. is welcome if you find it useful.

- Please refrain from using laptops, phones, etc. for non-class activities, e.g., email, web browsing, games, during classtime, as it is distracting to other students.

5.3.2 Netiquette

DO

- Ask questions and engage in conversations as often as possible—feel free to contact the instructor and TAs via the discussion forum for questions.

- Be patient and respectful of others and their ideas and opinions they post online.

- Remember to be thoughtful and use professional language. Keep in mind that things often come across differently in written text, so review your writing before posting.

- Be prepared for some delays in response time, as "virtual" communication tends to be slower than "face-to-face" communication. Ask questions well in advance to deadlines to ensure sufficient time for a response.

- If the instructor does not respond to an important email for a few days, please send a reminder. Faculty receive a large number of emails and sometimes messages get lost or overlooked.

- Contact the instructor if you feel that inappropriate content or behavior has occurred as part of the course.

DON'T

- Use inappropriate language—this includes, but is not limited to, the use of curse words, swearing, or language that is derogatory.

- Post inappropriate materials—for example, accidentally posting/showing a picture that is not appropriate for the course content.

- Post in ALL CAPS, as this is perceived as shouting and avoid abbreviations and informal language ("I'll C U L8R").

- Vent, rant, or send heated messages, even if you feel frustrated or provoked. Please instead communicate any specific concerns privately to the instructor, TAs, or class representatives; we want to improve the course and to accommodate any extenuating circumstances. Similarly, if you should happen to receive a heated message, do not respond to it.

- Except for course content questions on Piazza, send an email or post to the entire class, unless you feel that everyone must read it.

6 COVID Addendum

6.1 Hybrid Course Procedures

This section describes the planned procedures for a "hybrid" course. The department and instructor have discussed extensively over the summer how to best support your education and safety. While these procedures require additional effort from both students and the instructor, they are our best response to the current situation.

Be ready for change We cannot fully predict the course of the virus, but we can prepare. As of late August, case numbers in Colorado having been declining; however, the situation may change. These hybrid course procedures and the instructor's course revisions anticipate the possibility that it may become necessary to switch to remote learning. We will follow the data and guidance of medical experts to prioritize both your safety and education.

In case of illness If you or a family member become ill or face specific COVID-related challenges, please contact the instructor. We will make whatever accommodations are appropriate to deal with these extenuating circumstances. If the instructor becomes ill, there is another designated faculty member to substitute for this course (and for every course in the department).

Class Representatives The instructor has organized a few students in the course to collect and communicate concerns relating to the unusual challenges that we are facing. These class representatives will regularly meet with the instructor and TAs to identify responses, changes, and improvements to course procedures. Please do communicate any concerns or suggestions regarding class procedures to the instructor, TAs, or the class representatives.

Required Technology
- Microphone

- Headphones

- Webcam

- Zoom

- Media player supporting H.264 and AAC

Prerecorded lectures The instructor will prerecord lectures to the greatest possible extent to support both remote students and the reduced face-to-face time of the hybrid course. Please understand that recording lectures requires a significant time commitment from the instructor.

Study Groups Social and peer learning is a vital aspect of the university experience. To support peer learning in our current, distanced environment, the instructor will facilitate organized study groups of around 4 students. The study groups may, but need not, be the same as project groups. Study groups should work together to discuss lectures and exercises, e.g., sharing and reviewing each other's proofs.

Alternating In-Class Attendance Half the class will attend on alternating days, so that we reduce in-person contact. The instructor will post the groups and attendance schedule the first or second week of class so that study groups members can attend on the same day. Students should watch any posted lecture videos prior to attendance, so that in-class time can focus on questions and exercises.

Exams

   Midterm The midterm will be in class and will be taken over two days to support alternating attendance. Each attendance group may receive a different exam. If there is a significant difference in scores between attendance groups, the instructor may normalize the scores.

   Remote Exam If any students must take exams remotely, it may be necessary to use proctoring software or to use a webcam to record the student taking the exam to ensure fair assessment of all students. We are still determining the appropriate process, and will be mindful of privacy concerns regarding proctoring software.

   Final Exam Currently, we expect the final exam to follow the typical procedure: in-person during finals week at a time and place scheduled by the registrar.

Project Collaboration Please use the full array of software collaboration tools to support collaboration on group projects: git, github, email, text chat, video chat, etc.

Remote Office Hours All instructor and TA office hours will be remote, via Zoom.

6.2 Oredigger Promise: We Climb Together

Orediggers climb together. Orediggers look out for each other. It will take a shared commitment from each and every one of us to stop the spread of COVID-19, open campus and be together at Mines this year. We take great pride in being a top engineering and applied sciences university and we will strive to be the exemplar in preventing the spread of COVID-19 in a university setting.

   Therefore, as a member of the Oredigger community, I promise to protect classmates and colleagues, our families and neighbors, and myself by adopting the practices and attitudes summarized below; I will:

- Complete training sessions to learn required safety practices and expectations for learning, working, and living on campus.

- Monitor my health daily. I will report to a medical professional if I experience any of the COVID-19 symptoms: fever of 100.4F or higher, dry cough, difficulty breathing or shortness of breath, chills, unusual muscle aches, sore throat, or new loss of taste or smell.

- Stay home if I have COVID-19-related symptoms, even if I feel well enough to come to campus.

- Isolate and self-quarantine for the prescribed period of time after exposure to someone who is ill or has tested positive for COVID-19.

- Maintain appropriate social distancing in all settings, both on- and off-campus.

- Wear an appropriate face covering over my mouth and nose when indoors and in any other setting where it is difficult to maintain social distancing, and use any other protective gear prescribed by the university.

- Wash my hands frequently using soap and water or hand sanitizer. Contribute to the cleaning of classroom surfaces as requested.

- Carefully observe and follow campus and building instructional signs and directions.

- Participate in COVID-19 testing and contact tracing to preserve the wellness of the community.

- Be positive and gracious when others provide safety reminders and suggestions.

- Be attentive and helpful to anyone around who may be in need of support.