

# CSC-341: Automata, Formal Languages, and Computational Complexity

## Spring 2022

### Instructor Information

- Nicole Eikmeier, Assistant Professor of Computer Science
- She/Her Pronouns
- Preferred name: Professor Eikmeier
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- Office Hours: Book online at [calendly.com/eikmeier](https://calendly.com/eikmeier)

### Mentoring Sessions

This course employs the use of a mentor to aid you in navigating the course. Our course mentor will assist us in class, and host 1 – 2 mentor sessions throughout the week. Mentor Sessions may review course content, provide practice problems, or provide help with problem sets or labs.

- Section 01 Mentor: Eamon Worden (he/him/his) [wordenea@grinnell.edu](mailto:wordenea@grinnell.edu)
- Section 02 Mentor: Sheldon Chen (he/him/his) [chenchum@grinnell.edu](mailto:chenchum@grinnell.edu)
- Mentor Session Times: TBD

### Course Overview, Topics, and Learning Outcomes

In your journey through computation, you likely have noticed that many problems can be solved with the same solution through a skill you have honed called abstraction. Through this process, you may have noticed more nuanced connections between problems. Some problems require some translation before being solved using the solution to another problem. Other problems are immune to this sort of transformation and feel fundamentally more difficult than others. Some problems feel downright impossible to solve—are they actually impossible?

In this course, we study the theory of computation where we use mathematics to model problems of increasing complexity and study their relationships with each other. By going through this modeling process, we can:

- Deeply understand a problem and its potential corner cases.
- Prove properties of a problem, e.g., the correctness of candidate solutions.
- Reduce a problem to another problem, i.e, formally solve one problem in terms of another.
- Categorize a problem as easier or harder than other problems in a precise way.

By the end of the course, we will explore the limits of computation. Are there problems that are intractable in practice? Are there problems that can provably never have a solution?

## **Course Topics**

*Mathematical literacy:* Reading and studying mathematical prose; Writing formal mathematical arguments

*Regular Languages:* Machine- and linguistic-based models; Nondeterminism; Equivalence of models; Closure operations, properties, and decision procedures; Irregularity (the pumping lemma)

*Context-free Languages:* Models and properties

*Decidable Languages:* Turing machines, low-level and high-level operations; Properties and variants

*Complexity Theory:* P vs. NP; Cook's theorem, NP-completeness, and reductions; Space complexity and Savitch's theorem

*Decidability Theory:* Decision procedures for Turing machines; Undecidability and reductions; The post-correspondence problem; Rice's theorem; The recursion theorem; Logical theories

*Special Topics in the Theory of Computation*

## **Learning Outcomes (LO)**

### **Group 1**

1. Represent a problem using a regular model of computation.
2. Prove closure and algorithmic properties of the regular languages.
3. Prove the irregularity of a problem.
4. Represent a problem using a context-free model of computation.
5. Represent a problem using a Turing machine.
6. Prove closure and algorithmic properties of Turing machines.

### **Group 2**

1. Prove that a problem is in a particular time complexity class.
2. Prove that a problem is NP-complete by way of a reduction.
- ~~3. Explain the practical ramifications of the P vs. NP problem.~~
4. Prove that a problem is in a particular space complexity class.
5. Describe the essential characteristics of problems belonging to each of the major complexity classes.
6. Describe the practical relationships between various time and space complexity classes.

### **Group 3**

1. Prove the decidability of a given machine analysis algorithm.
2. Prove the undecidability of a given problem by way of a reduction.
3. Prove the undecidability of a given problem through Rice's Theorem.
4. Describe the practical ramifications of computational undecidability.
5. Describe practical problem-solving strategies for dealing with intractable problems.

## **Class Requirements/Components**

### **Attendance & Participation**

Your attendance and participation in class is an integral part of your learning. On each day of class, you will either be marked as *satisfactory (S)* or *not-satisfactory (NS)*. You may obtain an *S* each day by meeting the following requirements:

- Arrive on time for class, do not leave early
- Arrive prepared for class activities by having completed the required reading
- Actively engage and participate in all lab work
- Engaged in full group discussion/lecture (not on phone, etc)

You may be excused for a class under certain situations. Excusable reasons to miss class include college sponsored sports absences, religious holidays, family emergencies, and illness. Please email me at least a week in advance in the event of a planned absence. In the case of illness, I may request documentation from a doctor's office or SHAW. Please do not attend class if you suspect you may have a respiratory infection such as COVID-19. If you are excused from class, then you will receive an *S* for the day.

### **Labs** (Assessment of all LO)

Most class days will consist of a lab component. Lab exercises give you a chance to engage with our class material in a low-stakes way, with the benefit of collaboration from your peers. All labs will be graded on the scale of *satisfactory (S)* or *not-satisfactory (NS)*. A lab will receive an *S* by meeting the following requirements:

- The lab is completed
- The submission shows a good faith effort, and engagement with the material  
*Because labs are a low-stakes assessment, if you do the work you should expect to get an S, therefore you may not resubmit lab exercises.*

### **Quizzes** (Assessment of all LO)

Quizzes will test individual LO's, where one problem will correspond to exactly one LO. The quizzes will be online through gradescope and will have a 24-hour time window in which you may complete them. Each problem on the quiz will be graded on a scale of *satisfactory (S)* or *not-satisfactory (NS)*, where *S* indicates that your answer is completely correct. Any Learning Outcome for which you do not receive *S* you will have the opportunity to attempt again the next time we take a quiz.

### **Problem Sets** (Assessment of all LO)

Problem Sets are opportunities for you to demonstrate mastery of the course learning goals by applying these concepts and skills to problems larger in scope and complexity than the labs. As often as possible, problems are drawn from "real-world" domains to also help you begin drawing connections between the course and other areas of computer science. Problem sets will be graded on a scale of *satisfactory (S)* or *not-satisfactory (NS)*. If you receive a grade of *NS*, you may resubmit the assignment one time without penalty. You may receive an *S* on each problem set by meeting the following criteria:

- The problem set must be complete, by providing answers to all questions, and/or following all instructions.

- It must show a good faith effort on every problem.
- Key understanding is shown for each concept (this will vary by problem set)
- Mistakes are minimal - mistakes which do not reflect understanding may still result in an S

**A note on revised work:** In the case of problem sets, you must first submit an assignment in order to re-do it.

**A note on feedback:** I urge you to read all feedback given through gradescope, especially on *labs* and *problem sets*. Even if you receive full credit, it does not mean I would give full credit on a Quiz, and the feedback there is essential for you to understand how to improve. In gradescope, viewing feedback means clicking through a few buttons beyond your grade.

**A note on instructor/grader workload:** In order for your instructor to maintain sanity this semester, no more than three of your problem sets or revised problem sets will be graded in a single week. While revised work is not officially due until the last day of finals, this means you cannot submit more than 2 revisions in a single week.

## Letter Grades

This course will rely on ideas of [specifications grading](#). One of the fundamental principles behind this grading scheme is that you will have opportunities to re-try assignments if they do not originally obtain a satisfactory grade. My goal in using this schema is to reduce the stress that accompanies typical grading rubrics and give you permission to make mistakes and learn as much as possible. Ultimately, my goal is for each student to learn as much as possible, and I would be very happy to give every student an A.

Letter grades for the entire course will be assigned according to the bundles in the table below. You will receive the grade corresponding to the bundle for which you meet all the requirements. All bundles list minimum amounts, you may exceed the requirements for a bundle and still qualify for it.

Grade	Attendance & Participation (out of 27)	Readings (out of 24)	Problem Sets (out of 8)	Labs (out of 27)	Quizzes (out of 17)
C	20xS	15xS	5xS	19xS	11xS
B	23xS	19xS	6xS	22xS	13xS
A	25xS	21xS	7xS	25xS	15xS

D: 3-4 requirements of a C are met  
 F: 0-2 requirements of a C are met

To move from a *B* to a *B+* or a *C* to a *C+*: you must have completed the requirements of the lower tier (*B/C*) and meet the requirements of at least 3 components of in the higher tier (*A/B*).

To move from a *B* to an *A-* or a *C* to a *B-*: you must have completed the requirements of the lower tier (*B/C*) and meet the requirements of at least 4 components of in the higher tier (*A/B*).

## **Course Materials**

### **Required Textbooks & Materials**

- *Introduction to the Theory of Computation*, by Michael Sipser

### **Resources**

- Course webpage: <https://eikmeier.sites.grinnell.edu/csc-341-spring-2022/>
- Submit your assignments on [gradescope](https://gradescope.com) (<https://gradescope.com>) Entry code: given via email
- Databases, journal articles, and more: [Grinnell Library](https://www.grinnell.edu/academics/libraries) (<https://www.grinnell.edu/academics/libraries>)
- Health and Wellness: [SHAW](https://www.grinnell.edu/about/offices-services/student-health) (<https://www.grinnell.edu/about/offices-services/student-health>)

## **Course & College Policies**

### **Attendance**

I highly encourage you to attend all class sessions. Attendance affects your learning in this course, and thus affects your grade. If you know in advance that you will miss class due to a college-sponsored sport or a religious holiday, please let me know in the first two weeks of the semester. If you have another emergency come up please let me (or the college) know when safe for you.

### **Late Policy**

All assignments are to be turned in electronically by 10:30PM Central Time on the day they are due. Due to the exceptional nature of this year I will attempt to be as flexible as possible in accepting late work. I am aware that there are a number of things outside of your control that may affect your ability to complete work on time. If possible, please let me know if you plan to turn in work late. Assignments turned in more than two days late, without prior approval (before the original due date) of the instructor will not be accepted. Please refer to the Student Workload statement below, to emphasize that you should attempt to follow the posted deadlines. Please keep in mind that if you turn in work late, I may not be able to grade it as quickly as you or I hope.

## **Incomplete Grade Policy**

All work for the course is due by 5:00 pm on the last day of finals (5/20/2022). In exceptional circumstances, incomplete grades can be granted. Talk with me if you think you might need an incomplete to complete all the requirements of the course.

## **Student Workload**

You can expect to spend 12 hours per week on this course, including all in-class and out of class time. This number is based off of the Grinnell Guidelines for credit-hours. Since our class meets for approximately 3 hours each week, you can expect to work 9 additional hours outside of class time. This includes: reading the textbook, mentor sessions, office hours, problem sets, quizzes, and studying.

## **Academic Honesty Statement**

[Grinnell College's Academic Honesty policy](#) is located in the online Student Handbook. It is the College's expectation that students be aware of and meet the expectations expressed in this policy. In addition, in this course, it is my expectation that students may collaborate on the Problem Sets, Labs, and Readings, however your collaboration must be attributed.

In this course, you are not allowed to use solutions you find on the internet, and further, you are **not allowed to search for problem solutions on the internet**. Further, **you are required to work individually during quizzes**. I know that there is great temptation to look for solutions online when things get difficult. I will provide you with numerous resources to get help which include office hours, group class work, and mentor sessions. It is my hope that allowing you to resubmit problem sets without penalty eases some of the pressure that you might feel. If you have questions about how a particular assignment relates to the College's policy, or how to attribute your collaboration, I will gladly consult with you in advance of the assignment's due date.

## **Religious Observance**

I encourage students who plan to observe holy days that coincide with class meetings or assignment due dates to consult with me in the first two weeks of classes so that we may reach a mutual understanding of how you can meet the terms of your religious observance and also the requirements for this course.

## **Students with Disabilities**

I encourage students with documented disabilities, including invisible disabilities such as chronic illness, learning disabilities, and psychiatric disabilities, to discuss appropriate accommodations with me. You will also need to have a conversation about and provide documentation of your disability to the Coordinator for Disability Resources, located on the ground level of Steiner Hall (641-269-3124).

## **Technology Usage Policy**

Materials you have obtained from this course including problem sets should not be distributed outside of the members of our class. Live synchronous sessions should not be recorded by students.

## **Inclusion Statement**

It is my intention that students from all backgrounds and perspectives will be well served by this course, and that the diversity that students bring to this class will be viewed as an asset. I welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, socioeconomic background, family education level, ability – and other visible and nonvisible differences. All members of this class are expected to contribute to a respectful, welcoming, and inclusive environment for every other member of the class. Your suggestions are encouraged and appreciated.

## **Take care of yourself**

Do your best to maintain a healthy lifestyle this term by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available through campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, I strongly encourage you to seek support. Student Health and Wellness (SHAW) is here to help: call [641-269-3230](tel:641-269-3230) and visit their website at <https://www.grinnell.edu/about/offices-services/student-health>. Consider reaching out to a friend, faculty, or family member you trust for help getting connected to the support that can help.

If you or someone you know is feeling suicidal or in danger of self-harm, call someone immediately, day or night:

- Need to Talk Line: 641-269-4404 (available 24/7 for counseling needs)
- 24/7 Suicidal Hotline: 1-800-273-8255
- **If the situation is life threatening, call 911**

## **Syllabus Acknowledgements**

- The inclusion statement has been taken verbatim from <https://lgbtq.asee.org/resources/ally-resources/>
- The Take Care of Yourself Section has been taken verbatim from <https://www.cmu.edu/teaching/designteach/design/syllabus/syllabussupport.html>
- Ideas for specifications grading were developed by Peter-Michael Osera and adapted to meet the needs of this course.

# Course Schedule

	Date	Topics/Activities	Readings and Deadlines
1	1/25	Introduction to the Course, Review of Proofs	See webpage
	1/27	Mathematical Literacy	Sipser: Chapter 0
2	2/1	Finite Automata	Sipser: 1.1
	2/3	Nondeterminism	Sipser: 1.2
3	2/8	Regular Expressions	Sipser: 1.3 <b>Problem Set 1 due</b>
	2/10	Decision Procedures	Reading posted on website
4	2/15	Nonregular languages	Sipser 1.4
	2/17	Context-Free Grammars	Sipser: 2.1 <b>Problem Set 2 due</b>
5	2/22	Turing Machines	Sipser: 3.1
	2/24	Variants of Turing Machines	Sipser: 3.2 <b>Quiz opens today</b>
6	3/1	Working Differently Day - no class	<b>Problem Set 3 due</b>
	3/3	Complexity	Sipser: 7.1 and 7.2
7	3/8	NP-completeness	Sipser: pg 292-304 (7.3 and part of 7.4)
	3/10	The Cook-Levine Theorem	Sipser: pg 304-311 (7.4)
8	3/15	P vs. NP	Sipser: 7.5 <b>Problem Set 4 due</b>
	3/17	Savitch's Theorem	Sipser: 8.1, 8.2
	3/22 - 3/31	Spring Break - no class	
9	4/5	PSPACE	Sipser: 8.3
	4/7	PSPACE continued	<b>Quiz opens today</b>

10	4/12	L and NL	Sipser: 8.4 <b>Problem Set 5 due</b>
	4/14	Intractability	Sipser: 9.1, 9.2
11	4/19	Decidability	Sipser: 4.1 <b>Problem Set 6 due</b>
	4/21	Undecidability	Sipser 4.2
12	4/26	Reducibility	Sipser: 5.1, 5.3 <b>Problem Set 7 due</b>
	4/28	A simple, undecidable problem	Sipser: 5.2
13	5/3	Rice's Theorem	Reading posted on webpage
	5/5	The Recursion Theorem	Sipser: 6.1, 6.2 <b>Quiz opens today</b>
14	5/9	Approximation Algorithms	Sipser: 10.1 <b>Problem Set 8 due</b>
	5/11	SAT, Wrap-up Course Evaluations	
15	5/16	Exam Week	<b>Quiz makeups (optional)</b>