CSCI 445

Analysis of Algorithms

Fall 2020 MWF 12:55–2:05 pm MEY 063

http://cs.wheaton.edu/~tvandrun/cs445

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Contents

CATALOG DESCRIPTION. An introduction to algorithmic efficiency and to techniques for the design and analysis of efficient algorithms. General topics include review of asymptotics, algorithm design techniques (such as divide-and-conquer, dynamic programming, and greedy algorithms), graph algorithms, languages and automata, and NP-completeness.

TEXTBOOKS.

Cormen et al. *Introduction to Algorithms*, third edition, McGraw Hill / MIT Press, 2009. (See the course website for a link to solutions to some of the problems as found on the book's official website and a link to lectures by one of the book's authors from a class similar to ours.)

Lewis and Papadimitriou. *Elements of the Theory of Computation*, second edition, Prentice Hall, 1998. (The department owns copies for students to borrow.)

OBJECTIVES. The general goal of this course is for students to *improve their ability to devise, evaluate, and implement algorithms*. Specific goals are subdivided into five areas. At the end of the course, students should be able to

(1) devise new algorithms using

   a. the divide and conquer pattern
   b. dynamic programming
   c. the greedy approach

(2) prove the correctness of algorithms using loop invariants

(3) analyze the efficiency of algorithms using

   a. worse-case and expected-case analysis
   b. recurrences and the substitution method
   c. the master method
   d. amortized analysis

(4) articulate known algorithmic results

(5) prove the undecidability or intractability of a problem

In addition to these, together we have the general objective of seeing algorithmic work as a creative expression for God's glory and observing what the limitations of computation tell us about God's creation.

OUTLINE. This course is divided into three parts.

I. Core.

This course is mainly about building on earlier courses—especially CSCI 345—to advance your ability to devise algorithms, prove their correctness, analyze their efficiency, and implement them. The first segment of the course reviews and hones the skills you already have and introduces new techniques, tools of understanding, composing, and analyzing algorithms.

A. Correctness and efficiency of algorithms (CLRS ch 2 and 3)
   1. General introduction
   2. Review of analysis and loop invariants (CLRS ch 2)
   3. Asymptotics (CLRS ch 3)

B. Divide and conquer (CLRS ch 4 and 7)
   1. Recurrences (CLRS 4.(1–3))
   2. The master method (CLRS 4.(4 & 5))
   3. Quicksort (CLRS 7.(1, 2, & 4))

C. Advanced analysis techniques (CLRS ch 8 and 17)
   1. The limits of comparison-based sorting (CLRS 8.1)
   2. Amortized analysis (CLRS ch 17)

D. Dynamic programming and greedy algorithms
   1. Dynamic programming review (CLRS 15)
   2. Dynamic programming practice
   3. Greedy algorithms introduction (CLRS 16.(1 & 2))
   4. Greedy algorithms practice (CLRS 16.3)
   5. Matroid theory (CLRS 16.4)

II. Topics

Each semester I chose a handful of specific topics for study and for applying the ideas covered in the core unit. This year I have chosen

A. Linear programming (CLRS ch 29)

B. Fast Fourier transform (CLRS ch 30)
   1. Representing polynomials (CLRS 30.1)
   2. The discrete and fast Fourier transforms (CLRS 30.2)

C. Computational geometry (CLRS ch 33)
   1. Points and segments (CLRS 33.1)
   2. Convex hull (CLRS 33.3)

III. Computational complexity

We study the theory of computation with the goal that students learn the terminology and concepts of the field, the important results, and how to do reductions as used in proofs of undecidability and intractability.

A. Languages and automata (LP ch 2-4)
   1. Finite automata and regular expressions (LP ch 2)
   2. Context-free languages (LP ch 3)
   3. Turing machines (LP 4.(1-4))
   4. Non-deterministic Turing machines (LP 4.5)

B. Undecidablility (LP ch 5)

1. Definition of undecidablility (LP 5.(1-3))
2. Undecidability proofs (LP 5.(4-7))

C. $\mathcal{NP}$-completeness (LP ch 6 & 7 and CLRS ch 34)

1. The classes $\mathcal{P}$ and $\mathcal{NP}$ (LP ch 6)
2. $\mathcal{NP}$-completeness proofs (LP ch 7)
3. $\mathcal{NP}$-complete problems (CLRS ch 34)
4. Perspectives on $\mathcal{NP}$-completeness

For a schedule, see the course website.

Course procedures

How we do this course. This course's pedagogical style is collaborative practice guided by the textbooks. For most class periods, students will have a textbook reading and practice problems (referred to as *daily work*). In class we will clarify points in the readings, review solutions to practice problems, and work together on new problems.

Students will have more serious *problem sets* for turn-in and grading about every week-and-a-half. There will be three mostly-noncumulative tests, two held during class time, the last during the exam block.

Daily work. For almost every class period students will be assigned a reading and set of exercises. These exercises will be inspected for completeness. Much of our class time will be spent discussing the reading and going over solutions to the assigned exercises.

Turn in your daily work as a pdf through Schoology. I will check them for best-effort completeness. I may give feedback as time permits, but don't expect it. I recommend having a notebook for this class and using for taking notes from the readings and from class, as well as writing solutions for daily work and scratch space for the homework.

Problem sets. The bulk of the work in this course will be pencil-and-paper(-and-computer) problem sets, usually from the textbook. You are permitted to work together to a reasonable extent. If you work with another person or two, be your own judge that you are making a grade-worthy contribution and receiving the full benefit of the exercise.

Assignments should be turned in electronically. Code portions of a problem should be turned in as source code files to a turn-in folder on the lab file system; everything else should be turned in as a PDF. I strongly encourage you to write up your solutions using LaTeX. I will provide some help (such as LaTeX source for some of my notes and solutions) to get you started learning LaTeX.

A problem marked as **complete** indicates your solution must include

- a code solution
- unit tests demonstrating the correctness of your solution
- a correctness proof for the algorithm
- a formal analysis of the algorithm's efficiency

See the course website for further details.

Turnin in assignments. As noted above, code portions of problem sets are to be copied to a turn-in folder on the lab file system. All other work should be turned in **as PDFs** through Schoology. If you use Word or a similar program, convert to PDF before turing in; do not turn in docx files. If you take a picture of hand-written work for an assignment, please use Adobe Scan or a similar tool to capture it as a PDF; do not turn in jpg files.

Grading. There will be three mostly-noncumulative tests, currently scheduled for Monday Oct 5, Friday Wed Oct 28, and Wednesday Dec 16 (10:30am–12:30pm), which is our final exam block.

Your *participation score* consists mainly in doing the daily work, with additional points for contributions to class discussion.

Your *problem set score* is the sum of your scores on the individual problem sets plus your participation score (so, your participation score essentially counts as one problem-set assignment).

Your *semester score* is the geometric mean of your homework score and your scores on the three tests, with homework score counted twice. That is, your semester score is

$$\sqrt[5]{HW^2 \cdot Test1 \cdot Test2 \cdot Test3}$$

The geometric mean is used because it is self-normalizing: the individual tests have different numbers of total points but affect the semester score equally. Note in particular that test 3 is not worth more than the other tests, even though it is held during the exam block.

Letter grades are determined by score clustering. An estimation of semester grade will be given after each test (or more frequently on request).

Electronic course organization. I am using Schoology much more this semester than previously. As noted above, Schoology is used for the turning-in of most of your work. Schoology is also where I post assignments, slides, videos, etc. I still have a "course website" like I have traditionally used, but it contains only a schedule, without assignments or links to other course material.

Students can join class though Zoom on Schoology. However, I might not start a Zoom session on days when we are likely to have 100% in-person attendance. Please notify me if expect to join remotely when I wouldn't expect it (such as, because of going into quarantine).

Videos. To free up classtime for discussion and answering students questions, I plan to post videos containing material that otherwise would have been done in class. We will make more use of videos during remote instruction after Thanksgiving (or earlier, in the event of an emergency pivot).

COVID transition plan. This course as designed should require minimal adjustment when transitioning to all-remote instruction after Thanksgiving break (or earlier, if necessary). The main difference will be that class sessions will be held completely through Zoom (and, as noted above, greater use will be made of asynchronous videos).

Policies etc

Academic Integrity. Collaboration among students in the class is permitted on most assignments.

Many problems you will be assigned are discussed or solved in the computer science literature or on the Internet. Here are the policies for these resources:

- *Using any resource that specifically serves as a solution to exercises in Cormen et al is not permitted on homework.* Students will receive a 0 on the entire assignment for a first violation of this policy.
- Using any outside resource for homework is discouraged. If a student gets ideas, partial solutions, or other help from an outside resource, that resource should be cited as it would be in a research paper. Students will receive a 0 on the assigned problem for a first violation of this policy
- Students are discouraged from using outside resources for help on daily work until after the student has made a fair, independent attempt.

Repeated offenses will be handled through the college's disciplinary procedures and may result in failing the course.

The official website for the textbook includes solutions to selected exercises. The homework sets won't include any problems that have posted solutions there, but the daily work is. As suggested above, it's reasonable to check the solution found there *after* you've made your best attempt.

LATE HOMEWORK. Homework normally will not be accepted late. If an assignment is not complete by the deadline, turn in what you have at that time for partial credit. I am commited, however, to making special arrangements for students with extended illness or similar emergency situations. The minimum completion threshold for students in special circumstances is all of the problem sets.

ATTENDANCE. Students are expected to attend all class periods—in person, for students on campus; virtually for students off campus. It is courtesy to inform the instructor when a class must be missed.

EXAMINATIONS. Students are expected to take all tests, quizzes, and exams as scheduled. In the case where a test must be missed because of legitimate travel or other activities, a student should notify the instructor no later than one week ahead of time and request an alternate time to take the test. In the case of illness or other emergency preventing a student from taking a test as scheduled, the student should notify the instructor as soon as possible, and the instructor will make a reasonable accommodation for the student. The instructor is under no obligation to give any credit to students for tests to which they fail to show up without prior arrangement or notification in non-emergency situations. The final exam block is Wednesday, Dec 16, at 10:30 AM. Students are not allowed to take the final exam at a different time (except for urgent reasons, approved by the department chair, as per the college's policy).

FACE COVERINGS. In accordance with the Wheaton College Face Covering Policy and COVID-Safe, Thunder-Strong Commitment, signed by each student and faculty member, CDC-approved face coverings and social distancing are required while attending class. Failure to comply with wearing a face covering or social distancing will result in dismissal from the class session and an unexcused absence. Multiple violations can lead to dismissal from the class.

SPECIAL NEEDS. *Institutional statement:* Wheaton College is committed to providing reasonable accommodations for students with disabilities. Any student with a documented disability needing academic adjustments is requested to contact the Academic and Disability Services Office as early in the semester as possible. Please call 630.752.5941 or send an e-mail to `jennifer.nicodem@wheaton.edu` for further information.

My own statement: If you have a documented need for accommodations, I will have received a letter on your behalf from the Disability Services Office. But *please talk to me* about what accommodations are most useful to you. In particular, if you desire accommodations for test-taking, talk to me a reasonable amount time in advance (say, at least two class periods) so arrangements can be made.

GENDER-INCLUSIVE LANGUAGE. For academic discourse, spoken and written, the faculty expects students to use gender inclusive language for human being.

CONFIDENTIALITY AND MANDATORY REPORTING. As an instructor, one of my responsibilities is to help create a safe learning environment on our campus. I also have a mandatory reporting responsibility related to my role as a faculty member. I am required to share information regarding sexual misconduct about a crime that may have occurred on Wheaton College's campus with the College. Confidential resources available to students include Confidential Advisors, the Counseling Center, Student Health Services, and the Chaplain's Office. More information onthese resources and College Policies is available at `www.wheaton.edu/sexualassaultresponse`.

OFFICE HOURS. Please schedule office hours through Calendly. I am trying to make myself available as much of the time as possible, but times may vary from week to week.

ELECTRONIC DEVICES. Under normal circumstances my intent is for my courses to be electroinic-device-free zones. But these aren't normal circumstances. So instead I ask of you, whether you are joining class in-person or remotely, *please do not use your laptop, table, phone, etc, for anything other than class activities*. "Class activities" means looking at an electronic version of the textbook, looking at your solutions to daily work, taking notes, and using Zoom (if joining class remotely). Please refrain from from all other uses of electronic devices. In particular, **NO TEXTING OR USING SOCIAL MEDIA DURING CLASS MEETINGS.**

All this, the Lord willing.