CSCI 445

Analysis of Algorithms

Fall 2024 MWF 11:35am–12:45pm MEY 255

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. (There is a fourth edition, but I am sticking with the third.)

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

Purpose of the course. The objective 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.

  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) [Time permitting]

II. Topics

  A. Fast Fourier transform (CLRS ch 30)
    1. Representing polynomials (CLRS 30.1)
    2. The discrete and fast Fourier transforms (CLRS 30.2)
  B. Computational geometry (CLRS ch 33)
    1. Points and segments (CLRS 33.1)
    2. Convex hull (CLRS 33.3)
  C. Fibonacci heaps (CLRS 19)

III. Computational complexity

  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 Canvas. 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 through Canvas. 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.

Most problems are based on exercises or problems in the textbook but with additional instructions. In many cases, you are asked to solve a problem "completely", which means that your solution should include an implementation of an algorithm, unit tests demonstrating the correctness of your solution, a correctness proof for the critical part of your solution, and an analysis of your solution's efficiency.

Grading. There will be three mostly-noncumulative tests, currently scheduled for Monday Oct 7 (covering material up to dynamic programming), Friday Nov 1 (covering greedy algorithms through Fibonacci heaps), and Tuesday, Dec 17, 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 *homework 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.

To **pass** this course (to receive a grade of D or better), students must perform competently on each goal by completing at least 75% of the homework and having at least a 50% average on the tests. For students who have met the minimum requirements, etter grades are determined by clustering of semester scores. An estimation of semester grade will be given after each test (or more frequently on request).

I use the "Gradebook" feature on Canvas only to communicate scores on individual assigments and tests. I do **not** use the Canvas gardebook for my official record keeping for scores, for calculating semester scores, or determining letter grades. Please **ignore** any grade estimate that Canvas gives you for this course.

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 some daily work may include some problems with posted solutions. As suggested above, it's reasonable to check the solution found there *after* you've made your best attempt.

Students should not use ChatGPT, CodePilot, or similar machine-learning/AI powered tools for any daily work or problem sets. If you are curious how these tools would do on homework assigned in this course, wait until this course is over (Dec 19) to try it.

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 period. 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 Tuesday, Dec 17, 10:30am–12:30pm. 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).

Accomodations. 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. (See also the College's statement below.)

Office hours. My *drop-in* office hours this semester are MWF 3:30–4:30pm. You can make an appointment through Calendly; I'm available most of the day on Tuesday and sometimes on other days.

ELECTRONIC DEVICES. Electronic devices are allowed **only** for taking notes and referring to an electronic copy of the textbook. Please keep all other devices, especially phones, put away. If you need to check your phone for something, please discreetly step out into the hall. In particular, **NO TEXTING OR USING SOCIAL MEDIA DURING CLASS MEETINGS.**

All this, the Lord willing.

College syllabus statements

THE COLLEGE REQUIRES THAT THE FOLLOWING STATEMENTS BE INCLUDED IN ALL SYLLABI.

The "Academic Information" website referred to below is found and https://catalog.wheaton.edu/undergraduate/academic-policies-information/academic-information/

ACADEMIC INTEGRITY. (See "Integrity of Scholarship" on "Academic Information" website.)
The Wheaton College Community Covenant, which all members of our academic community affirm, states that, "According to the Scriptures, followers of Jesus Christ will. . . be people of integrity whose word can be fully trusted (Psalm 15:4; Matt. 5:33-37)." It is expected that Wheaton College students, faculty and staff understand and subscribe to the ideal of academic integrity and take full personal responsibility and accountability for their work. Wheaton College considers violations of academic integrity a serious offense against the basic meaning of an academic community and against the standards of excellence, integrity, and behavior expected of members of our academic community. Violations of academic integrity break the trust that exists among members of the learning community at Wheaton and degrade the College's educational and research mission.

ACCOMMODATIONS. (See "Learning and Accessibility Services" on the "Academic Information" website).
Wheaton College is committed to providing access and inclusion for all persons with disabilities, inside and outside the classroom. Students are encouraged to discuss with their professors if they foresee any disability-related barriers in a course. Students who need accommodations in order to fully access this course's content or any part of the learning experience should connect with Learning and Accessibility Services (LAS) as soon as possible to request accommodations http://wheaton.edu/las (Student Services Building -Suite209, las@wheaton.edu, phone 630.752.5615). The accommodations process is dynamic, interactive, and completely free and confidential. Do not hesitate to reach out or ask any questions.

BEHAVIOR POLICY. (See "Classroom Demeanor" on the "Academic Information" website).

GENDER-INCLUSIVE LANGUAGE. (See "Gender Inclusive Language" on the "Academic Information" website).
Please be aware of Wheaton College's policy on inclusive language, "For academic discourse, spoken and written, the faculty expects students to use gender inclusive language for human being."

TITLE IX AND MANDATORY REPORTING. Wheaton College instructors help create a safe learning environment on our campus. Each instructor in the college has a mandatory reporting responsibility related to their role as a faculty member. Faculty members are required to share information with the College when they learn of conduct that violates our Nondiscrimination Policy or information about a crime that may have occurred on Wheaton College's campus. Confidential resources available to students include Confidential Advisors, the Counseling Center, Student Health Services, and the Chaplain's Office. More information on these resources and College Policies is available at http://www.wheaton.edu/equityandtitleIX.

WRITING CENTER. The Writing Center is a free resource that equips undergraduate and graduate students across the disciplines to develop effective writing skills and processes. This academic year, the Writing Center is offering in-person consultations in our Center in Buswell Library, as well as synchronous video consultations onlin Make a one-on-one appointment with a writing consultant here [https://wheaton.mywconline.com/].