Syllabus for CECS 528, Advanced Algorithms

Instructor: Dr. Todd Ebert

Fall 2025, Last Updated: 10/22/2025

General Course Information

Academic Unit Department of Computer Engineering and Computer Science, California State University, Long Beach

Prerequisites Open to Computer Science MS, Computer Engineering MS, or Engineering MS students only, or consent of instructor. Students are strongly encouraged to have completed an undergraduate course in data structures and algorithms similar to that of CECS 328.

Catalog Description Theoretical analysis of algorithms. Divide and conquer, dynamic programming and greedy algorithms; basic search and traversal techniques including search trees; sorting; matrix manipulations; NP-completeness.

Section Call Number 3912 (Section 1)

Instructor Dr. Todd Ebert (Todd.Ebert at csulb.edu)

Instructor Office Hours TuWTh 9:30 am - 10:30 am, ECS 548

Course Meeting Times MW 8:00-9:15 am (LA2 200)

Textbook S. Dasgupta, C. Papadimitriou, U. Vazirani, **Algorithms**, McGraw-Hill Education, 1st edition, 2006

Course Topics

- Review of Big-O notation
- Analysis Tools for Divide-and-Conquer Algorithms: Recurrences, Master Theorem, Substitution Method
- Divide-and-Conquer Algorithms: Mergesort, Quicksort, Finding Array Statistics, Finding the Median of an Array, Karatsuba's Integer Multiplication Algorithm, Strassen't Matrix Multiplication Algorithm, Maximum Subsequence Sum, Minimum Positive Subsequence Sum, Fast Fourier Transform
- Data Structures for Greedy Algorithms: Binary Heaps, Disjoint Set Data Structure
- Greedy Algorithms: Dijkstra's, Prim, and Kruskal's algorithms, Unit Task Scheduling, Task Selection, Fractional Knapsack, Fuel Reloading
- Replacement Method for proving correctness of greedy algorithms
- Dynamic Programming Algorithms: 0-1 Knapsack, Edit Distance, Optimal Binary Search Tree, Longest Common Subsequence, Minimum and Maximum Single Source Distances in DAGs, Floyd Warshall Algorithm, Runaway Traveling Salesperson.
- Turing Reducibility with Applications: 2SAT, Max Flow/Min Cut, polynomial-time Turing reducibility
- Mapping Reducibility: Even to Odd (and vice versa), Independent Set to Clique (and vice versa), Embeddings, Set Partition to Subset Sum, Hamilton Path to LPath, Contractions, Subset Sum to Set Partition, Vertex Cover to Half Cover, Clique to Half Clique, Max Matching to Max Flow
- Introduction to Computational Complexity Theory: complexity classes `P`, `NP`, and `co-NP`, `NP`-complete problems, Cook's Theorem, mapping reductions that establish NP-completeness, SAT to 3SAT, 3SAT to Clique, 3SAT to Subset Sum, 3SAT to Directed Hamilton Path (DHP), Independent Set to Vertex Cover, DHP to Hamilton Path, Hamilton Path to Hamilton Cycle, Hamilton Cycle to Traveling Salesperson
- Approximation algorithms: Vertex Cover, Traveling Salesperson, Data Clustering, Load Balancing, Max Cut
- Review of Probability Theory: random variables and events, expectation and variance of a random variable, linearity of expectation, Independence of random variables and events, Bernoulli, Geometric, and Binomial random variables, conditional probability, conditional expectation, conditional-expectation random variables, chain rule (including generalized version).
- Randomized algorithms: Min Cut, 3SAT, Randomized Quicksort, Randomized Finding Array Statistics, Max Cut, Hashing, Set Balancing

Learning Outcomes

This course has eleven **core learning outcomes (LO's)** that will be assessed on each exam, as well as on four quizzes. Your understanding of some outcome is assessed via a problem that is provided on the quiz or exam. In addition to earning points (on exams only) for solving these problems, you will also receive either a Pass (P) or No Pass (NP) grade. Receiving a pass grade means that you have successfully demonstrated competency with respect to that LO. You are allowed up to three attempts to pass each LO via three exams and four quizzes.

The following are some guidelines for success towards passing each of the learning outcomes.

1. When preparing for the learning-outcome problem, carefully read its official description in the syllabus so that you know what is expected for a passing mark.
2. Each LO has a set of exercises (with solutions) to help you prepare. These exercises are located at the end of the lecture that introduces the LO.
3. Re-solve each exercise until you are able to solve it on your own without using any notes. Note that the exam and quiz problems will be similar to the exercises but *not* the same problems.
4. The problem will seem similar to one of the lecture examples or assigned exercises. Therefore, it's important to review and solve these problems.
5. During exams and quizzes you are allowed to bring pens/pencils, eraser, and a non-programmable scientfic calculator **All other computing devices (cell phones, laptops, smart watches, etc.), notes, and books must be put away before starting. Failure to abide by these rules is grounds for receiving a final course grade of F without the possibility of having the grade forgiven**.
6. To help prevent cheating, when possible, please select a seat that leaves one or more empty seats between you and your nearest neighbor. **When there is sufficient evidence of exam plagiarism, all involved students are subject to receiving a final course grade of F without the possibility of having the grade forgiven**.
7. It's important to follow the directions for each problem and include all the pertinent steps of your solution.
8. During exams and quizzes, both a five and two-minute warning will be announced before solutions are to be turned in. Please have the courtesy to turn them in before the final call. A student who is still working after the final call will receive a warning and any subsequent infractions will result in a point reduction equivalent to the points earned from the highest scoring problem.
9. At the end of the semester each student will receive grade points in accordance with the following table and based on the number of different LO's passed.

Number Passed	Grade Points
1-3	0
4	0.5
5	1.0
6	1.25
7	1.5
8	2.0
9	3.0
10	3.5
11	4.0

The following are the LO's for which competency must be demonstrated.

LO1. The ability to use the Master Theorem to determine the growth of a function that satisfies a uniform divide-and-conquer recurrence, and the ability to use the Substitution Method to provide either a big-O upper bound or big-Omega lower bound for the growth of some function that satisfies a some divide-and-conquer recurrence.

LO2. An understanding of the concepts that establish the correctness or running time of a divide-and-conquer algorithm, and the ability to demonstrate the steps of the algorithm. The list of algorithms are Mergesort, Quicksort, Find-Statistic, Strassen's algorithm, Karatsuba's Integer Multiplication algorithm, Maximum Subsequence Sum, and Minimum Positive Subsequence Sum.

LO3. An understanding of the fundamental properties of complex numbers from which the FFT algorithm arises, and an understanding of how both the FFT and IFFT algorithms are used to efficiently compute the product of two polynomials. Finally, the ability to demonstrate both the FFT and IFFT algorithms.

LO4. The ability to demonstrate the steps of a greedy algorithm (see list in Course Topics section), and an understanding of how the binary heap and disjoint-set data structures are used for the sake of improving the running time of some greedy algorithms. The ability to demonstrate the use of one of these data structures within the context of Kruskal's, Prim's, Dijkstra's, or the `Unit Task Scheduling` algorithm.

LO5. The ability to provide a dynamic-programming recurrence and demonstrate the corresponding dynamic-programming algorithm for some problem studied either in lecture, or in the lecture exercises, including 0-1 Knapsack, Edit Distance, Longest Common Subsequence, Optimal Binary Search Tree, Matrix-Chain Multiplication, Shortest and Longest Paths in an Acyclic Graph, Runaway Traveling Salesperson, Floyd-Warshall,

LO6. The ability to understand the concept of Turing reducbility as a general algorithm strategy and how it is specifically used for solving the `2SAT` decision problem. Part 1: the ability to demonstrate the steps of the Improved `2SAT` Algorithm. Part 2: the ability to answer a question that arises from using the original `2SAT` algorithm that makes use of `Reachability`-oracle queries.

LO7. The ability to provide the definition of what it means to be a mapping reduction f from some problem A to another problem B, and demonstrate one of the following reductions, and verify that the solution to $x \in A$ the same as the solution to $f(x) \in B$.

(a) `Even` $\leq_m$ `Odd` See Exercise 1 of the Mapping Reducibility lecture for the kind of problem to expect.

(b) `Max Independent Set` $\leq_m$ `Max Clique` and vice versa

(c) `Set Partition` $\leq_m^p$ `Subset Sum`

(d) `Hamilton Path` $\leq_m^p$ `LPath`

(e) `Subset Sum` $\leq_m^p$ `Set Partition`

(f) `Vertex Cover` $\leq_m^p$ `Half Vertex Cover`

(g) `Clique` $\leq_m^p$ `Half Clique`

(h) `Max Bipartite Matching` $\leq_m^p$ `Max Flow`

LO8. An understanding of the complexity classes `P`, `NP`, and `co-NP` and the kinds of problems that belong in each class. Also, the ability to identify an appropriate certificate for an instance of some NP problem, the ability to provide pseudocode for a verifier of some NP problem and to prove that the verifier requires a polynomial number of steps.

LO9. The ability to demonstrate and/or answer questions about one of the following polynomial-time mapping reductions that establishes the NP-completeness of some decision problem: 3SAT to Clique, 3SAT to Subset Sum, SAT to 3SAT, 3SAT to DHP, DHP to UHP, and Hamilton Cycle to Traveling Salesperson.

LO10. The ability to demonstrate the steps of an approximation algorithm on some problem instance and understand why a certain approximation algorithm achieves a certain approximation ratio. Algorithms include those for Min Vertex Cover, Clustering, Load Balancing, and Traveling Salesperson.

LO11. An understanding of the basic definitions, formulas, and techniques of probability theory and how they may be applied to the creation of novel and efficient algorithms for `Randomized Quicksort`, `Randomized Find Statistic`, `Matrix Multiplication Verification`, `Min Cut`, and `3SAT`.

Reading Assignments

A reading assignment will be provided on most weeks of the semester. Reading the textbook will offer a somewhat alternative and more comprehensive viewpoint of the subject matter. Please check the "Reading Assignments" link at the course website for the current and past assignments. The reading assignment topics pertain to those topics that will be covered in the class meetings for the following week.

Class Meetings

Our class meetings will be devoted to working through the course lecture notes. These notes have several examples. Some have provided solutions while the solutions to others will be demonstrated in class. The notes also contain all the needed definitions, formulas, theorems, exercises, and exercise solutions. Each Wednesday (except for exam days) I will devote the final 15 minutes of class to addressing any issues with the weekly homework and exercises. Although class attendance is not mandatory, at the end of the semester I look to improve the final grades of students who meet the following criteria: i) final course GPA is close to the borderline between two grades, ii) consistent class attendance, and iii) sustained improvement during the semester.

Weekly Exercises

Associated with each learning outcome presented in lecture will be a set of assigned practice exercises, as well as some additional exercises that pertain to a related peripheral learning outcome or represents a more advanced exercise that may form the basis for an advanced exam problem.

Homework

Homework will be assigned most weeks and consist of one or two problems that expand on ideas that were covered during a previous week. These problems are meant to either highlight interesting applications of the subject or represent a more advanced problem that requires more time to complete than the exercises.

The following are some rules and guidelines for solving the HW problems and submitting their solutions.

1. Problems will be made available at least one week before they are due.
2. Solutions should be submitted by uploading a single PDF file to the appropriate Canvas drop box.
3. Please make sure to write your full name at the top of each page.
4. Solutions should be presented in the same order that they appear on the problem sheet.
5. All solutions should be handwritten (including the use of an electronic writing tablet) **Typed solutions will not be graded**.

6. Plagiarizing the work of others shall not be tolerated. When plagiarism is first detected, the students involved will receive a warning. Detecting plagiarism a second time will result in a final homework grade of F. It is OK for students to collaborate on homework, but it's not OK for students to copy one another or copy from a source on the web. Each student has the responsibility to present each solution in a unique way.

Exams and Quizzes

There will be two midterm exams, four quizzes, and a final exam.

Midterm 1 four problems worth 25 points each and pertaining to LO's 1-4, and additional problems worth a total of 50 points.

Quiz 1 two problems pertaining to LO's 5 and 6

Midterm 2 four problems worth 25 points each and pertaining to LO's 5-8, additional problems worth a total of 50 points, and four problems worth 0 points each and pertaining to LO's 1-4.

Quiz 2 two problems pertaining to LO's 7 and 8

Quiz 3 two problems pertaining to LO's 9 and 10

Quiz 4 two problems pertaining to LO's 9 and 10

Final Exam four problems worth 25 points each and pertaining to LO's 9-11, additional problems worth a total of 75 points, and eight problems worth 0 points each and pertaining to LO's 1-8

The purpose of the quizzes is to provide each student with multiple opportunities to pass each of the learning outcomes. All problems are graded as Pass/No Pass (P/NP). To provide more incentive for students to prepare for quizzes, extra credit is awarded for passing any part of a learning outcome that first appears on a quiz (as opposed to first appearing on an exam). For example, LO's 5 and 6 first appear on Quiz 1. Therefore, passing either of those (or a part thereof) earns extra credit in the amount of one credit per passing an entire LO, and 0.5 for passing part of an LO (if applicable). Note that, although an LO may have multiple parts, it may nevertheless be considered as an "all or nothing" LO, meaning that attempting the LO results in either a full pass, or a no pass. Finally, each quiz will have additional make up problems from previous LO's and students may solve either one of these LO's or one part each of two different LO's that offer partial passes.

Final Grade Determination

At the end of the semester, grades will be assigned based on the six categories shown in the table below.

Categories	Percentage Weight
Learning Outcomes	30%
Midterm 1	20%
Midterm 2	20%
Final	20%
Homework	10%

Exam and Quiz Dates

Midterm 1 September 24th

Quiz 1 October 15th

Midterm 2 October 29th

Quiz 2 November 5th

Quiz 3 November 19th

Quiz 4 December 3rd

Final Exam Monday December 15th, 8:00-10:00 am

Exam and Quiz Makeups

Exam and Quiz Makeups will only be permitted in case of a documented accident, emergency, or illness. Acceptable documentation includes a doctor's notes, police report, photographs, etc.. Documentation must be provided in advance before taking the makeup assessment.

Registration Deadlines

September 8th Last day to add or drop classes without approval

September 15th Deadline to add a course

November 19th Withdrawal deadline

Study Suggestions

About 80% percent of your success in this course will depend on your ability to demonstrate competency in each the course learning outcomes. Here are some suggestions that should help you accelerate towards competency. The following steps should be applied to each learning outcome.

1. Prepare to solve the assigned exercises by reviewing the part of the lecture notes that pertains to the outcome, including definitions, results, general discussion, and examples.
2. Perform a first pass of solving the exercises with the help of the lecture notes. For each exercise, give yourself up to 20-30 minutes to solve it with the help of reviewing the solution(s) to the pertinent lecture example(s). If after that time you still cannot solve it, then review the exercise's solution and make sure you understand it. If not, then seek help from other students or the instructor.
3. Based on your understanding and skill that were attained from the previous step, develop 3×5 note cards that cover all the essential definitions, results, and steps that are needed to solve the different kinds of problems that are related to the learning outcome. These note cards should be general so that they apply to all future problems that pertain to the outcome.
4. Perform a daily review of the note cards with the goal of memorization, together with re-solving a few of the assigned exercises to see if your performance has improved. Continue to do this until you feel comfortable with your level of understanding and performance.
5. Repeat the previous step, but now focus on solving new exercises (without the help of your notecards) taken from assessments given in previous semesters.

Steps 1-3 should occur within 24 hours after lecture, while step 4 should be ongoing until you feel comfortable with your understanding and performance. Finally, step 5 should occur soon before the next class assessment of the outcome.

The above steps should comprise about 80% of your studying for the subject outside of attending class. The other 20% should involve completing homework assignments, solving the assigned additional problems which can help prepare you for the additional problems on each exam, and reading the course textbook.