# CS 381: Introduction to the Analysis of Algorithms

Last edited: August 6, 2018

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| **Course Web Page:** | Blackboard |
| **Lecture:** | Mon, Wed, and Fri 13:30-14:20 at Lilly Hall of Life Sciences G126 |
| **Instructor:** | Prof. Petros Drineas |
| **TAs and office hours:** | check Blackboard |
| **Instructor's e-mail:** | `pdrineas@purdue.edu` |
| **Required textbook:** | T. Cormen, C. Leiserson, R. Rivest, and C. Stein, *Introduction to Algorithms*, McGraw-Hill, latest edition. |
| **Optional textbook:** | J. Kleinberg and E. Tardos, *Algorithm Design*, Pearson Addison Wesley, latest edition. |

## 1 Course Outline

The course gives a broad introduction to the design and analysis of algorithms. The course plans to follow the topics outlined below; changes and adjustments may be made during the semester. See Blackboard for updates.

1. Mathematical Concepts for Algorithm Analysis
   - General introduction to algorithm design (CLRS Chapter 2), review of the analysis of sorting algorithms, review of mathematical induction and other analysis tools.
   - Asymptotic notation and complexity classes (CLRS Chapter 3).
   - Recurrences and the master theorem (CLRS Chapter 4).
2. Algorithm Design Techniques
   - Divide and conquer (CLRS Chapter 9.3, 4.1, KT Chapter 5), problems include skyline problem, maximum subarray problem, counting inversions, selection in linear time.
   - Dynamic programming (CLRS Chapter 15, KT Chapter 6), problems include weighted interval scheduling, matrix chain multiplication, longest common subsequence, sequence alignment, knapsack.
   - Greedy (CLRS Chapter 16, KT Chapter 4), problems include activity selection, scheduling.
   - Randomized (CLRS Chapter 5, 7.3, 9.2) and sublinear algorithms, problems include selection in expected linear time, polling, streaming algorithms.
3. Using data structures in algorithms
   - Review data structures including heaps as priority queues (CLRS Chapter 10-12), binary heaps (CLRS Chapter 6). Application: Prims algorithm (CLRS Chapter 23).
   - Balanced binary search trees (CLRS Chapter 13, 14.1-2). Overview of balanced tree structures and Red-Black Trees. Augmenting data structures.

- Disjoint set union-find. Union by rank and path compression techniques (CLRS Chapter 21, KT Chapter 4.6). Introduction to amortized analysis (CLSR Chapter 17). Kruskal's algorithm (CLRS Chapter 23).

4. Graph Algorithms

   - Fundamental graph explorations (CLRS Chapter 22). Review of breadth-first search, depth-first search. Topological sorting.
   - Graph connectivity (CLRS Chapter22). Connected and bi-connected components. Strongly connected components.
   - Shortest Paths (CLRS Chapter 24.1-3, 25.2), Bellman-Ford, Dijkstra, Floyd-Warshall.
   - Maximum Flow (CLRS Chapter 26, KT Chapter 7), Ford-Fulkerson, relationship between max-flow and min-cut, applications of max-flow.

5. NP-completeness: introduction to classes P and NP, NP-complete, polynomial time verification (CLRS Chapter 34.1-3, KT Chapter 8), reductions (CLRS Chapter 34.4).

6. Approximation algorithms (vertex cover, set cover, Traveling Salesman Problem (CLRS Chapter 35.1-3, KT Chapter 11).

## 2 Prerequisites and learning objectives

Prerequisites are: CS 182 and CS 251 or equivalent. Students who complete the course will have demonstrated the ability to do the following:

1. Perform basic algorithm analysis including: Use big O-notation formally to give asymptotic upper bounds on time and space complexity of algorithms. Explain the use of big-Omega, big-Theta, and little-o notations to describe the amount of work done by an algorithm. Use recurrence relations to determine the time complexity of recursive algorithms. Solve elementary recurrence relations, e.g., using some form of a Master Theorem. Give examples that illustrate time-space trade-offs of algorithms.

2. Apply and modify algorithmic strategies and approaches: describe and use major algorithmic techniques (brute-force, greedy, divide-and-conquer, dynamic programming, and graph explorations). Use a greedy approach to solve an appropriate problem and determine if the greedy rule chosen leads to an optimal solution. Use a divide-and-conquer algorithm to solve an appropriate problem. Use recursive backtracking to solve a problem such as navigating a maze. Use dynamic programming to develop the recurrence relations and to solve an appropriate problem. Determine appropriate algorithmic approaches to apply to a given problem. Describe heuristic problem-solving methods. Understand the mapping of real-world problems to algorithmic solutions. Explain the major graph algorithms and their analysis and employ graphs to model application problems. Evaluate and compare different algorithms using worst-, average-, and best-case analysis. Demonstrate the ability to evaluate algorithms, to select from a range of possible options, to provide justification for that selection, and explain an implementation of the algorithm in a particular context.

3. Explain and apply foundational computational complexity concepts including: define the classes P and NP. Explain the significance of NP-completeness. Provide examples of NP-complete problems. Explain the impact pf NP-complete problems to different application domains. Explain the difference between NP-complete and NP-hard. Prove that a problem

is NP-complete. Use reduction techniques between problems. Demonstrate the use of approximation algorithms for NP-hard problems. Explain the halting problem and other undecidable problems.

## 3 Requirements, Grading, and Expectations

The course work consists of clicker participation, homeworks, two midterms, and the final. The course grade is based on:

- **Clicker participation (5%)**
  - You are expected to have your own clicker and have it registered on Blackboard by the first lecture.
  - Clickers will be used in class on a weekly basis. The two lowest clicker scores throughout the semester will be dropped.
  - **There are no makeup options for missed clicker questions.** It is your responsibility to attend every lecture and bring your registered clicker to class in order to get credit for clicker questions.
- **Homeworks (20%)**
  - There will be six homeworks. Homeworks must be submitted via Blackboard before the stated deadline (see also Section 3.1).
  - Students are expected to type their assignments, using Latex, MS Word, or any editor of comparable quality. Submitted files should be Acrobat (.pdf) files (no .docx, .rtf, .txt, .html, etc.[1]). Figures, diagrams, and more complex mathematical notations can be handwritten and included into the final .pdf as an image.
  - Students are allowed two uploads to Blackboard for each homework. We will only grade the latest upload. After submitting your homework, download the file and open it to ensure a valid .pdf file was uploaded.
  - **No late assignments will be accepted.**
- **Midterms (45%=22.5%+22.5%)**
  - There will be two evening midterms, each accounting for 22.5% of the overall course grade. Both midterms will be 60-minute evening exams and are closed book (no books, no laptops, no cell phones, no calculators, etc.).
  - You are allowed one double-sided A4 page of notes for each midterm. Each midterm will cover a subset of the course lectures, which will be announced at Blackboard.
  - Dates, times, and locations will be announced at Blackboard.
- **Final (30%)**
  - There will be a **cumulative** final exam (e.g., the final exam will cover material from the whole course). The date of the final exam is set by the university and it could be scheduled on the very last day of the finals week. *Do not* make travel plans before the final exam schedule is released.

[1] There are multiple online converters that can convert files of any type to .pdf files.

- The final is closed book (no books, no laptops, no cell phones, no calculators, etc.). You are allowed **two** double-sided A4 pages of notes for the final.
- Taking the final exam is a requirement for passing the course. Date, time, and location will be announced at Blackboard.

### 3.1 Details on homework submissions and grading

We expand on homework submission guidelines and grading:

- Use pseudocode to describe an algorithm. Do not describe your solution using code from a programming language.
- Start with a description of your main idea and the intuition of your solution.
- Describe your solution in steps.
- When appropriate, describe your algorithm with an example.
- When using algorithms and data structures presented in class, describe differences and any adjustments to be done. There is no need to reproduce material seen in class.
- When using material from other sources use your own words; DO NOT COPY AND PASTE; clearly cite every source you use.
- Describe the time complexity and space complexity of every major step/task.
- Describe the overall time and space complexities.
- Argue the correctness and optimality of your proposed algorithm.
- The description of an algorithm should typically not exceed two pages.
- Formatting guidelines: submit with a font size of at least 11 pt; 1.5 or double spaced; start every problem on a new page.

**Read carefully:** Every problem on an assignment must include a Collaborator and Resources (CR) statement: This means every problem on every assignment includes information on collaboration and use of on-line material. Help you get from a TA does not count as collaboration. You are expected to complete the following CR template for each problem:

- Names of students enrolled in class communicated/collaborated with: Name1, Name2, ...
- Names of students not enrolled in class who provided help: Name1, Name2, ...
- Name of tutor (if applicable):
- On-line resources consulted and made use of: URLs, one per line.
- State "none" if there is no one to mention or no resources to cite.
- An assignment problem that does NOT contain a CR statement will not be graded.

**Questions on a graded assignment problem:**

- Solution sketches will be posted for assignment problems. They typically are sketches, not complete solutions. They often contain a discussion of common mistakes students made.

- If the solution sketch does not answer your questions please contact the TAs.
- If you cannot make the TA office hours, e-mail the TA and set up a time to meet.

**Re-grading:**

- Assignments are graded for correctness, clarity, conciseness, rigor, and efficiency.
- Read the posted solution sketch before contacting the TA responsible for the question. You are expected to do so within 10 days from the date when the assignment was officially returned. No re-grading after this period.
- A re-grade means that the entire assignment undergoes a re-grade.

# 4 Course and University Policies

- **Channels of Communication:** Your first point of contact for questions related to the technical content of the lectures and homework problems should be the graduate TAs, everyone staffing 182 office hours, and the Head TA. For questions outside office hours, use email. While you should contact the instructor in case of an emergency (e.g., if you are unable to make the midterm and have a valid medical excuse by the appropriate campus authorities), questions on content and homework should not go to the instructor as responses will not be happen promptly. Effort will be made to respond to email questions promptly. However, responses can take longer than 48 hours. Keep this in mind as you are working on homework problems and preparing for exams. Take advantage of office hours as much as possible.
- **Regrading Requests:** If you request a **re-grade of a homework or midterm**, you must contact the TAs that graded the respective homework (will be announced in Blackboard) within **10 days** of receiving your homework or midterm back. There will be no re-grading after this time period has elapsed. You are expected to read and work through posted solutions before asking for a regrade.
- **Missed exam:** Missing an exam results in a score of zero unless you have a valid excuse covered under university policies. If you are unable to attend an exam due to an illness or an emergency, contact the instructor before the exam, if possible.
- **Announcements:** Announcements relevant to the course will be made in class and/or via the Blackboard course email list. You are expected to monitor Blackboard and your email for information related to the class.
- **Discussion forum:** There will be a discussion forum on Blackboard; instructions and guidelines will be posted in Blackboard. You are expected to be courteous, respectful, and professional when posting at the discussion forum.
- **Posting class material:** Posting materials associated to the class (e.g., homework and exams, slides, etc) without the written permission of the instructor is a violation of copyright. As a student in the class, you may make copies of course materials for your own use. You may not and may not allow others to reproduce or distribute lecture notes and course materials publicly, without the instructor's written permission. Violations will be dealt with as allowed by law under Section 512(c) of the Digital Millennium Copyright Act.

- **Missing or late work:** As discussed in the requirements and grading section, missing or late work will be counted as a zero.

- **Academic integrity:** Behavior consistent with cheating, copying, and academic dishonesty is not tolerated. Depending on the severity, this may result in a zero score on the assignment or exam, and could result in a failing grade for the class. Purdue prohibits "dishonesty in connection with any University activity. Cheating, plagiarism, or knowingly furnishing false information to the University are examples of dishonesty." (Part 5, Section III-B-2-a, University Regulations) Furthermore, the University Senate has stipulated that "the commitment of acts of cheating, lying, and deceit in any of their diverse forms (such as the use of substitutes for taking examinations, the use of illegal cribs, plagiarism, and copying during examinations) is dishonest and must not be tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest." (University Senate Document 72-18, December 15, 1972). You are expected to read both Purdue's guide to academic integrity (`http://www.purdue.edu/purdue/about/integrity_statement.html`) and Prof. Gene's Spafford's guide (`http://spaf.cerias.purdue.edu/integrity.html`) as well. You are responsible for understanding their content and how it applies to this class.

- **Attendance:** Students are expected to be present for every meeting of the classes in which they are enrolled.

- **Grief Absence Policy:** Purdue University recognizes that a time of bereavement is very difficult for a student. The University therefore provides the following rights to students facing the loss of a family member through the Grief Absence Policy for Students (GAPS). According to GAPS Policy, students will be excused for funeral leave and given the opportunity to earn equivalent credit and to demonstrate evidence of meeting the learning outcomes for missed assignments or assessments in the event of the death of a member of the student's family.

- **Conduct and Courtesy:** Students are expected to maintain a professional and respectful classroom environment. In particular, this includes: silencing personal electronics; arriving on time and remaining throughout the class; do not insult or deride others for any reason (even in jest); leave class promptly and wait to ask the instructor questions in the hall. You may use non-disruptive personal electronics during class.

- **Violent Behavior Policy:** Purdue University is committed to providing a safe and secure campus environment for members of the university community. Purdue strives to create an educational environment for students and a work environment for employees that promote educational and career goals. Violent Behavior impedes such goals. Therefore, Violent Behavior is prohibited in or on any University Facility or while participating in any university activity.

- **Students with Disabilities:** Purdue University is required to respond to the needs of the students with disabilities as outlined in both the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1990 through the provision of auxiliary aids and services that allow a student with a disability to fully access and participate in the programs, services, and activities at Purdue University. If you have a disability that requires special academic accommodation, please make an appointment to speak with the Head TA or instructor within the first three (3) weeks of the semester in order to discuss any adjustments. It is important to talk about this at the beginning of the semester. It is the student's

responsibility to notify the Disability Resource Center (`http://www.purdue.edu/drc`) of an impairment/condition that may require accommodations and/or classroom modifications.

- **Emergencies:** In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructors control. Relevant changes to this course will be posted onto the course website and/or announced via email. You are expected to read your `purdue.edu` email on a frequent basis.

- **Emergency Preparedness:** Emergency notification procedures are based on a simple concept: *If you hear a alarm inside, proceed outside. If you hear a siren outside, proceed inside.* Indoor Fire Alarms are meant to stop class and immediately evacuate the building. Proceed to your Emergency Assembly Area away from building doors. Remain outside until police, fire, or other emergency response personnel provide additional guidance or tell you it is safe to leave. All Hazards Outdoor Emergency Warning sirens mean to immediately seek shelter (Shelter in Place) in a safe location within the closest building. "Shelter in place" means seeking immediate shelter inside a building or University residence. This course of action may need to be taken during a tornado, a civil disturbance including a shooting or release of hazardous materials in the outside air. Once safely inside, find out more details about the emergency. Remain in place until police, fire, or other emergency response personnel provide additional guidance or tell you it is safe to leave. In both cases, you should seek additional clarifying information by all means possible: Purdue Home page, email alert, TV, radio, etc. Review the Purdue Emergency Warning Notification System multi-communication layers at `http://www.purdue.edu/ehps/emergency_preparedness/warning-system.html`. Please review the Emergency Response Procedures at `https://www.purdue.edu/emergency_preparedness/flipchart/index.html`. Please review the evacuation routes, exit points, emergency assembly area and shelter in place procedures and locations for our building. Video resources include a 20-minute active shooter awareness video that illustrates what to look for and how to prepare and react to this type of incident. See `http://www.purdue.edu/securePurdue/news/2010/emergency-preparedness-shots-firedon-campus-video.cfm`

- **Nondiscrimination:** Purdue University is committed to maintaining a community which recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Purdue University prohibits discrimination against any member of the University community on the basis of race, religion, color, sex, age, national origin or ancestry, marital status, parental status, sexual orientation, disability, or status as a veteran. The University will conduct its programs, services and activities consistent with applicable federal, state and local laws, regulations and orders and in conformance with the procedures and limitations as set forth in Executive Memorandum No. D-1, which provides specific contractual rights and remedies.

- **Instructors' absence:** Video lectures may be used to supplement missing class periods.

- **Changes to the course syllabus:** This syllabus is subject to change. Updates will be posted at the course website.