Announcements

- **June 27:** Solutions to hw4 are now available on courseworks.
- **June 25:** Solutions to hw3 are now available on courseworks. Solutions to hw4 will be posted around 11am on Wednesday.
- **June 22:** Solutions to the midterm exam are posted on courseworks under Files.
- **June 22:** Final exam information
  - Date: Thursday, June 28
  - Time: 1-2:30 (tentative)
  - Location: 524 Mudd
  - Material: all lectures from 6/7 (Belman-Ford and Floyd-Warshall) up to and including all NP-complete problems from 6/26; makeup lecture on 6/1 is also part of the final.
    - True/false questions
    - Multiple choice questions
    - Past final exam questions:
      - Homework 3: problems 1, 4, 5; recommended exercise 3.
      - Homework 4: problems 2, 3b, 4, 5; recommended exercises 1, 3.
  - Algorithm design questions: you must argue correctness (even if you do so briefly) and analyze the running time of all algorithms you give; you must clearly described your algorithm in English; only give pseudocode if time permits. Think carefully which algorithm design technique (recursion, greedy, DP, reduction) is appropriate for each problem.
  - If you give a reduction:
    1. describe the inputs to the two problems
    2. clearly give the reduction transformation and argue that it takes polynomial time
    3. prove equivalence of instances
  - Final is **closed books, no calculators, no cheat sheet**
- **June 17:** Reminder: there will be no class this Tuesday. The instructor's OH are moved to Thursday June 21 4:15-6pm.
- **June 16:** hw4 is now available. It is due by 10pm on Tuesday June 26 (hard deadline: 10am on Wednesday June 27).
- **June 11:** Solutions to hw1 were posted this morning on courseworks under Files. Solutions to hw2 will be posted around 11am on Wednesday.
- **June 9:** hw3 is now available. It is due by **10pm on Tuesday June 19**.
- **June 7:** Makeup class **TOMORROW (Friday)** 1-4:10pm in 524 Mudd followed by instructor's OH 4:15-6. The instructor's OH on 6/12 are canceled.
- **June 5:** Reminder: makeup class this Friday (June 8) 1-4:10pm in 524 Mudd (please note the slight change in time). The class will be recorded.
- **June 4:** Midterm exam information
  - Date: Thursday, June 14
  - Time: 1-2:30
  - Location: 524 Mudd
  - Material: all lectures up to and including 6/7, without the Belman-Ford and Floyd-Warshall algorithms; also, makeup lecture on 6/1 is not part of the midterm.
  - Total #problems: ~7, potentially with multiple parts
- True/false questions
- Multiple choice questions
- Past midterm questions:
  - HW1: problems 3, 4, 5a and 5b, 6a and 6b; recommended exercise 1.
  - HW2: problems 1, 2, 3, 4; recommended exercises 2, 3, 4.

  - **Algorithm design questions**: you must argue correctness (even if you do so briefly) and analyze the running time of all algorithms you give; you must clearly described your algorithm in English; only give pseudocode if time permits.
  - If you give a **dynamic programming** algorithm:
    1. clearly describe the **subproblems**
    2. state the **recurrence**
    3. give **boundary conditions**
    4. analyze the running **time** of your algorithm
    5. analyze the **space**
    6. explain **how to fill in** the DP table, if applicable

- Midterm is **closed books, no calculators, no cheat sheet**

  - **June 2**: hw2 is now available. It is due by **10pm on Tuesday June 12**. **HARD deadline: 10 am on Wednesday June 13**.
  - **May 31**: Reminder: makeup class TOMORROW (Friday) 12-1:30pm in 1127 Mudd. The class will be recorded.
  - **May 28**: Few announcements about this week follow.
    - Office hours start this week (May 29).
    - Short makeup class this Friday (June 1) 12-1:30pm in 1127 Mudd. The class will be recorded. There will be no class on Thursday, June 14 after the midterm exam.
    - Thursday's regular class will also take place in 1127 Mudd.
  - **May 26**: hw1 is now available. It is due by **10pm on Tuesday June 5**. For a description of the SAT problem in question 4, please review slides 23-32 from slide set SAT. We will also go over this in Thursday's class.
  - **May 25**: As discussed in class today, the release dates and deadlines for submitting homework assignments have been moved by one day (see homework section below).
  - **May 24**: Next Thursday's (5/31) and Friday's (6/1) classes will take place in 1127 Mudd due to construction work next to our regular classroom.
  - **May 24**: Reminder: makeup class TOMORROW 11:30-2:40pm in 524 Mudd. The class will be recorded.
  - **May 20**: Several important announcements follow:
    - Please enroll in piazza using the following link: piazza.com/columbia/summer2018/summer2018analysisonalgorithms. We look forward to questions and discussions!
    - Makeup class this Friday (May 25, tentative time: 11:30-2:40pm) in 524 Mudd. The class will be recorded. There will be no class on Tuesday, June 12.
    - Homework 1 will be out end of this week. Please note that you must submit your assignment as a pdf file on courseworks.
    - Lecture videos will be available to every student. Please be patient while I work this out with CVN.
    - Office hours will start next week (May 29).
General course information

- **Time:** TTR, 1-4:10pm
- **Location:** 524 Mudd Building
- **Instructor:** Eleni Drinea, eleni@cs.columbia.edu
- **Office Hours:** Tuesdays, 4:15-6pm (or by appointment), Mudd 414
- **Teaching Assistants and Office Hours:**
  - Daniel Gomez, daniel.gomez@columbia.edu, Office Hours: Saturdays, 2-4pm, Mudd 122A (CS TA room)
  - Midhun Gundapuneni, g.midhun@columbia.edu, Office Hours: Sundays, 2-4pm, Mudd 122A (CS TA room)
- **Textbook:** Introduction to Algorithms, by Cormen, Leiserson, Rivest and Stein (3rd edition) will be the main text for this course. Other recommended reading: Algorithm Design, by Kleinberg and Tardos; Algorithms, by Dasgupta, Papadimitriou and Vazirani
- **Grading:** Homeworks 40%, Midterm 30%, Final 30%. The midterm and final exams will be in-class. The percentage contributions above are approximate and subject to change.

Prerequisites

- Familiarity with mathematical proofs and how to write one, as well as basic knowledge of probability and linear algebra is required.
- You might want to refresh your memory on some of the required math background for this class by going over the following sections in our textbook:
  - Appendix A: pp. 1145-1147, a basic understanding of 1150-1153
  - Appendix B: B.1, B.3, B.4 (parts of B4 and B5 will be covered in class)
  - Appendix C: pp. 1183-1186, C.2, C.3, C.4
  - Appendix D: D.1, D.2

Course description

This course focuses on the design and analysis of efficient algorithms. We will discuss general design paradigms as well as specific problems.
A preliminary list of topics follows.

- Fundamentals: induction, asymptotics, recurrences
- Sorting and searching: insertion sort, merge-sort, quicksort, binary search
- Graph algorithms: depth-first search, breadth-first search, shortest paths
- Greedy algorithms: huffman coding, minimum spanning trees
- Network flows
- Dynamic programming: data segmentation, sequence alignment
- Linear programming
- Reductions and NP-completeness
- Hashing: Bloom filters, document similarity
• Approximation algorithms

Homeworks

• **General:** There will be four homework assignments to help you better assimilate the course material.
  1. Homework assignments will be out on Saturdays (late in the evening). They will be due 10 days later by 10pm. For a tentative schedule of homework assignments and/or to download a homework, please go to the end of this section.
  2. You should submit your homework assignment online (on canvas) as a pdf file. If needed, scan your handwritten assignment and submit the resulting pdf---make sure the quality of your scanned document is good and your handwriting very neat!

• **Late homework policy:** No homework extensions will be granted. However you have 5 late days for all assignments: for example, you may submit Homework 1 at 9:59pm on Thu, 6/7, thus using 2 of your 5 late days. Note the following **hard deadlines** for Homework 2 and Homework 4:
  - Homework 2: 10am on Wed, 6/13 (if you do so, you will use 0.5 late days)
  - Homework 4: 10am on Wed, 6/27 (if you do so, you will use 0.5 late days)

• **Collaboration policy:** You are allowed to brainstorm and think through solutions with a small number (2-3) of your classmates. However you must write up your solutions entirely on your own. If you have used collaborators, you must state their names clearly next to your name on your write-up. Finally, copying solutions from the Internet or other textbooks is strictly prohibited. You should adhere to the [department's academic honesty policy](#).

1. **Homework 1:** Out: Saturday, May 26, Due: 10pm on Tuesday, June 5
2. **Homework 2:** Out: Saturday, June 2, Due: 10pm on Tuesday, June 12 (**HARD deadline: 10am on Wednesday, June 13**)
3. **Homework 3:** Out: Saturday, June 9, Due: 10pm on Tuesday, June 19
4. **Homework 4:** Out: Saturday, June 16, Due: 10pm on Tuesday, June 26 (**HARD deadline: 10am on Wednesday, June 27**)

Preliminary schedule of lectures

• **Tue, 5/22:** Insertion sort, induction, worst-case running time analysis, efficient algorithms, asymptotic notation, divide and conquer principle, mergesort, solving recurrences: recursion trees [insertionsort, Sections 1.1, 2.1, 2.2, mergesort, mastertheorem, Sections 3.1, 2.3, 4.0]

• **Thu, 5/24:** Master theorem; more divide & conquer algorithms: binary search, fast integer multiplication, fast matrix multiplication (Strassen's algorithm); quicksort, randomized algorithms, randomized Quicksort, balls-in-bins problems [moredivideandconquer, quicksort, balls in bins, Sections 4.2, 4.3, 4.4, 4.5, 7.1, 7.2]

• **Fri, 5/25, 11:30am-2:40pm (makeup class 1, full):** Graphs, graph representation, Breadth-First Search and applications: connected components, testing bipartiteness; Depth-First Search and applications: cycle detection, topological sort [graphs and BFS, optional reading: Appendix B, Sections B.4, B.5, pp. 1168-1179, Sections 22.1, 22.2, dfs-toposort, optional reading: Sections
22.3, 22.4]
  ○ Sat, 5/26: hw1 out
  ○ Tue, 5/29: Analysis of randomized Quicksort; balls-in-bins problems, the coupon collector problem; hashing: hash table, universal hash functions, analysis of chain hashing using balls-and-bins; hashing for saving space: fingerprints, Bloom filters [randQS-ballsinbins, hashing, Sections 7.3, 7.4, 5.1, 5.2 without the hiring problem]
  ○ Thu, 5/31: Greedy algorithms: Huffman coding for data compression; cache maintenance, online algorithms [huffman, 16.3, cache, if you need more context on this problem, read Section 4.3 from Tardos-Kleinberg; optional reading: Chapter 6 from your textbook (binary min heap)]
  ○ Fri, 6/1, 12-1:30pm (makeup class 2, short): strongly connected components in directed graphs [stronglyconnectedcomponents, optional reading: Section 22.5]; single-source shortest paths in weighted graphs (non-negative edge weights): Dijkstra's algorithm [optional reading: Sections 24.0-24.3]
  ○ Sat, 6/2: hw2 out
  ○ Tue, 6/5: Dynamic programming principle: segmented least squares, sequence alignment, matrix-chain multiplication [datasegmentation, sequencealignment, recommended reading: Chapter 15, Section 15.4; matrixchainmultiplication, Sections 15.0, 15.2, 15.3 without the discussion on shortest/longest simple path]
  ○ Tue, 6/5: hw1 due by 10pm
  ○ Thu, 6/7: Single-source shortest paths in weighted graphs (negative edge weights): Bellman-Ford; all-pairs shortest paths: Floyd-Warshall [shortestpaths-negativeweights, optional reading: Sections 24.0-24.3, Section 25.2]; the knapsack problem
  ○ Fri, 6/8, 1-4:10pm (makeup class 3, full): Network flows, the Ford-Fulkerson algorithm for max flow; correctness of Ford-Fulkerson, applications of max flow: maximum bipartite matching [flows, pp. 708-720, 724-726, pp. 720-724, Section 26.3]
  ○ Sat, 6/9: hw3 out
  ○ Tue, 6/12: no class (makeup class on 5/25)
    ○ Tue, 6/12: hw2 due by 10pm (HARD deadline: 10am on Wed 6/13)
  ○ Thu, 6/14: midterm exam
    ○ Midterm exam information
      ▪ Time: 1-2:30pm (regular time) (no class after the exam, makeup class on 6/1)
      ▪ Location: 52 Mudd (regular classroom)
      ▪ Material: all lectures up to and including lecture 6/7, except for the following:
        ▪ makeup lecture 6/1;
        ▪ Bellman-Ford & Floyd-Warshall from lecture 6/7
    ○ Midterm is closed books, no calculators, no cheat sheet, no external aids
    ○ Sat, 6/16: hw4 out
  ○ Tue, 6/19: no class (makeup class on Friday, 6/8)
    ○ Tue, 6/19: hw3 due by 10pm
  ○ Thu, 6/21: Reductions; complexity classes P, NP, Satisfiability of boolean functions (formulas, circuits); proving NP-completeness, TSP and more NP-complete problems [reductions, Sections 34.0, 34.1 up to and including p. 1056, 34.3 up to p. 1073, SAT, optional reading: Section 34.4, 34.5.2, more NP-complete problems, optional reading: 34.2 up to and not including Verification Algorithms, 34.5.4, p. 1118]
  ○ Tue, 6/26: Linear programs, weak and strong duality, dualization; interpreting the dual LP; [LP_part1, optional reading: Sections 29.0, 29.1 (without the slack form), Theorem 29.13 on p.
892 (just the statement, no proof), duality, optional reading: Section 29.4 up to and including Corollary 29.9, Section 29.2 (without min-cost flow/multi-commodity flow)]
  • Tue, 6/26: hw4 due by 10pm (HARD deadline: 10am on Wed 6/27)
  • Thu, 6/28: Final exam
    • Final exam information:
      • **Day/Time:** Thursday, June 28, 1-3pm
      • **Location:** 524 Mudd Building
      • **Material:** all lectures from 6/8 (Belman-Ford & Floyd-Warshall) up to and including 6/26, WITHOUT linear programming
      • Final exam is closed books, no calculators, no cheat sheet, no external aids.