CS 466/666: Algorithm Design and Analysis (Fall 2023)

Course Outline

1 Course Information

General information

Lectures: Mondays and Wednesdays, 4:00 PM - 5:20PM in PHY 313

Instructor: Sepehr Assadi – `sassadi@uwaterloo.ca` – https://sepehr.assadi.info

Prerequisites: CM 339/CS 341; Computer Science or Computational Mathematics students only.
Mathematical maturity, and a strong background in probability, data structures, and algorithm design.

Course webpage: https://sepehr.assadi.info/courses/cs466(6)-f23/

The course webpage will contain up-to-date course information, the schedule of lectures and assignments, and lecture notes and other resources.

There is a **LEARN website** for the course where you can submit your homework, and check your grades. We will use **Piazza** for online discussions.

Textbook: There is no official textbook and required materials will be posted on the course webpage.

Students with disabilities: You are encouraged to discuss with me any appropriate accommodations that we might make on your behalf following the guidelines of the AccessAbility Services[1].

Statement of inclusivity: I am committed to creating a learning environment in which all of my students feel safe and included, regardless of race, ethnicity, religion, gender or sexual orientation. Because we are individuals with varying needs, I rely on your feedback to achieve this goal. I invite you to let me know about what I can stop, start, or continue doing to make sure every one of my students feels valued and can engage actively in our learning community.

Academic integrity: All members of the UW community are expected to hold to the highest standard of academic integrity in their studies, teaching, and research. The Office of Academic Integrity's website[2] contains detailed information on UW policy for students and faculty.

Email policy: Please start the subject of your emails with '[CS466-F23]' for a timely reply. It may take up 24 hours (48 hours over the weekends) before you hear back.

Territorial Acknowledgement: The University of Waterloo acknowledges that much of our work takes place on the traditional territory of the Neutral, Anishinaabeg and Haudenosaunee peoples. Our main campus is situated on the Haldimand Tract, the land granted to the Six Nations that includes six miles on each side of the Grand River. Our active work toward reconciliation takes place across our campuses through research, learning, teaching, and community building, and is co-ordinated within the Office of Indigenous Relations[3].

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[1] https://uwaterloo.ca/disability-services/
[2] https://www.uwaterloo.ca/academicintegrity
[3] https://uwaterloo.ca/indigenous/

Course Staff and Office Hours

Instructor:	Sepehr Assadi	`sassadi@uwaterloo.ca`
	Office hours:	Mondays 2:30 to 3:30PM in DC 3117

TA:	Kam Chuen (Alex) Tung	`kctung@uwaterloo.ca`
	Office hours:	TBA

If you have something to discuss directly with me (e.g., a concern, a question, or a comment) that cannot be done as part of an office hour, send an email with the subject '[CS466-F23] ?' (replace ? with what you like to discuss) to me and we will set up a time for a meeting.

What should you expect to learn from this course?

This is an advanced algorithm design and analysis course, aimed at undergraduate students interested in a deep dive in theoretical computer science (TCS), as well as graduate students doing research in TCS. It is more specialized and in-depth than the undergraduate level Algorithms course (CS 341). We will cover advanced algorithmic ideas (some classical, some recent), and the theory behind them (theorems, proofs).

The following is a **tentative list** of the topics that we will cover in this course (not necessarily in order and definitely not all of them):

- **Probabilistic analysis:** Randomized algorithms, Concentration inequalities, Balls-and-bins
- **Minimum cuts:** Karger's algorithm, Vertex connectivity
- **Minimum spanning trees (MSTs):** Boruvka's algorithm, Linear-time randomized algorithm
- **Maximum matchings:** Hopcroft-Karp algorithm, Edmonds' algorithm, Auction algorithm
- **Shortest paths:** Low diameter decompositions, Tree embeddings
- **Graph compression:** Directed shortcuts, Spanners, Cut sparsifiers, Graph sketches
- **Linear programming:** Basics, Duality, Center-of-gravity algorithm, Rounding
- **Multiplicative weight update (MWU):** Expert problem, Fast packing/covering linear programs
- **Lovasz Local Lemma (LLL):** Basics, Algorithmic LLL
- **Random walks:** Connectivity in RL, Perfect matchings in regular bipartite graphs, Sampling
- **Sublinear time algorithms:** Connected components, Subgraph counting, Graph coloring
- **Streaming algorithms:** Distinct elements, Approximate matching
- **Distributed (LOCAL) algorithms:** Luby's MIS algorithm, Network decompositions
- **Dynamic graph algorithms:** Connectivity, Approximate matching
- **Online algorithms:** Ski rental, Karp-Vazirani-Vazirani (KVV) algorithm for bipartite matching
- **Approximation algorithms:** Vertex cover, Set cover, Graph coloring, LP rounding
- **Parallel algorithms:** Matching in RNC, Isolation lemma

Learning outcomes: I am hoping that by the end of the course, (1) you are able to design and analyze algorithms for a wide range of canonical problems studied in this course, and even more importantly, for new problems that you may have not encountered directly yet, (2) you know a wide range of algorithmic and mathematical tools commonly used in design and analysis of algorithms, and (3) you have a have a basic familiarity with various algorithmic models of computation studied in TCS.

2   Assignments and Grading

Grading

- 50% Homework assignments (4 assignments for 12.5% each)

- 50% Exams:

    - 25% Mid-term exam (take-home)
    - 25% Final exam (in-person)

Important note: In order to pass this course, you need to receive **50% of the class average grade** in the homework assignments and exams categories **separately**. This is both a necessary and sufficient condition unless there is an exceptional circumstance (at the discretion of the Instructor and TA).

> *Why this policy?*
>
> *Mostly to ensure fairness for students who have tried hard throughout the term versus the ones that may only show up for the exams or only did the assignments (potentially with the help of others). Also, the cutoff is defined based on the class average, not an absolute number – it is hard to justify passing a student whose grades are less than half of the average of everyone else.*

Participation in lectures is **not mandatory** but I strongly encourage it – this is a fast-moving course, so if you miss a lecture you may find it more difficult to keep up. Also, if you decide to participate in the class, I ask you to please be respectful of your fellow students and do not use any electronic devices (cellphones, laptops, tablets) during the lectures except for note-taking and other matters directly related to the lecture.

Homework assignments

The homework assignments are here to help you in developing and sharpening your algorithmic thinking skills. They will involve a small number of algorithmic questions for you to solve, as well as mathematical statements to prove. You should think of assignments as the main way of exercising your skills in this course beyond what is directly taught in the lectures.

- **Timing:** There will be four assignments (plus an *ungraded* "Homework 0" on backgrounds) and a tentative schedule of release and due dates are available on the course calendar (on the course webpage). Assignments will typically be released on a Monday and are due two weeks later by 11:59 pm of Monday. Occasionally, an assignment may be assigned/due on a different day so please follow the course calendar.

- **Format:** Assignments will be released on LEARN on the release dates specified in the course calendar. We will use Crowdmark to submit the solutions. The solutions should be turned in as a **single pdf** file containing the answers to the assignment questions in order. Moreover, you are strongly encouraged to typeset your solutions; if we cannot read your handwritten solutions, you may not receive *any* points on your assignment.

    The (strongly) preferred method for typesetting your assignments is to use **LaTeX**. Simple instructions on using LaTeX are available on the course webpage and a template will be released with each assignment. We are also available to help you with any question you may have in using LaTeX.

    > *This policy has a twofold purpose:*
    >
    > (i) *For students: LaTeX tremendously helps you in writing clean and well-structured proofs (a necessity for a rigorous proof) as well as editing an already written proof further. Moreover, learning LaTeX is an important life-long skill that will come handy sooner or later.*

(ii) *For graders: Grading assignments done in LaTeX is a considerably easier (and much more pleasant) task than handwritten assignments.*

- If you leave a question **completely blank** on your assignment, you will receive 25% of the grade for that question. However, you may and will receive zero credit for a completely wrong answer.

  This policy is <u>not</u> here to discourage you from attempting a problem if you think you know how to approach it as you will receive partial credit more than 25% if you are on the right track. But keep in mind that if you simply do not know the answer, it is best not to write something entirely meaningless as that may lead to 0 points.

- **Regrading:** If you believe your assignment is graded erroneously, you may submit a regrade request which clearly identifies the error. You can make your request **within <u>at most one week</u> after you received your grades for that assignment**. To do so, send a **private post on Piazza** to the instructors and TAs using the title " Regrade Request: Assignment #?" (replace ? with the actual number). If you request a regrade for a particular question, <u>**all** parts of that question will be regraded</u> and it is possible (although unlikely) that you lose further points on your grade.

- **Groups:** You are allowed to form groups of size two or three students for solving each assignment (you can also opt to do it alone if you prefer). The policy regarding groups is as follows:

  - You can pick different partners for different assignments (e.g., from HW1 to HW2) but for any single assignment (e.g., HW1), you have to use the same partners for all questions.
  - The members of each group only need to write down and submit **a single solution file** between them, and all of them will receive the same grade.
  - For submissions, only one member of the group submits the full solutions on Crowdmark and lists the name of their partners in the group. The other members of the group also need to submit a PDF on Crowdmark that contains only a single line, stating the name of their partner who has submitted the full solution on Crowdmark (Example: Say A, B, and C are in one group; A submits the whole solution and writes down the names A, B, and C. B and C only submit a one-page PDF with a single line that says "See the solution of A").

    To be perfectly honest, this does <u>not</u> look like the right way of handling group submissions; but, I am not sure if Crowdmark or LEARN support better ways of doing so. We will explore other options in the next few days and update this part if there is a better alternative.

  - You are allowed to discuss the questions with any of your classmates even if they are not in your group. But, **each group must write their solutions independently** and should specifically mention the name of other students outside the group that they have collaborated with.

- **Late submissions:** You are allowed to **submit <u>two</u> assignments late, each <u>up to two days</u>** (for instance, if the deadline is on Monday 11:59pm, you can submit your solutions until Wednesday 11:59 pm). These are intended to cover events such as unexpected illness, an out-of-town events, etc. (although you are free to use them for any reason you like without justification). You do <u>not</u> need to ask for permission to use your extensions.

  You will receive <u>zero credit</u> for any assignment submitted after two days passed the deadline or after you have used both your extensions. Exceptions will be made only for exceptional circumstances and you will need to provide a university-issued written verification.

  Use your extensions wisely! It helps to save an extension for the end of the term. Avoid taking an extension on the first homework.

  Extensions for groups: All the students in a group can decide to use an extension and submit their solutions up to two days after the original deadline. In this case, all members of the group lose one of their extensions. Since the group members can change during the term, to ensure fairness, as long as there is even one member of the group who has used less than two extensions, the entire group is allowed to use an extension.[4]

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[4]This means that some students may end up using more than two extensions throughout the term, and that is okay.

- **Extra Questions:** Some of the assignments may contain extra credit questions. These questions are for students who like to familiarize themselves with the topics taught in the course on a more advanced level and will be significantly more challenging than typical questions or may be rather out of scope of the materials taught in this course. Generally, you should do extra credits because you enjoy the material, not because it will help your grade (although high success on the extra credits may improve your final grade)

- **External resources:** You are **allowed** to use external resources that were not discussed in the class (say, related research papers) when writing your solutions to homework assignments (the course webpage also contains links to many useful resources). But, you should clearly acknowledge and cite your sources in your solutions – failing to cite a source is considered plagiarism. Moreover, the solutions you hand in should be entirely your own; for instance, if you got a hint about a question by searching online, internalize the hint, then close it, and only then write your own solution, and at the end, cite your source.

  You are **allowed** to use Generative Artificial Intelligence (GenAI) tools such as Chat GPT, Google Bard, etc., as a way of helping you to come up with your solutions to homework assignments in this course. But note that you are entirely responsible for the accuracy of your submitted solutions and again, any solution you hand in should be your own.

  > *A word of advice: GenAI tools seem quite confident in generating absurdly false answers to algorithmic questions; always question the answers you get from them and treat them as an opinion (possibly biased) or a suggestion (possibly invalid) not a fact – this is based on my experience with ChatGPT in particular but I suspect it carries over to other ones as well.*

  See the policies and statements sections for our formal statement about using GenAI.

Mid-Term Exam

There will be one mid-term exam in this course.

- The mid-term exam is **take-home** and is tentatively scheduled to be on Thursday, October 26. It will be released on 9am on the Thursday and will be due 24 hours later on 9am on Friday, October 27.

- The mid-term exam covers the topics of Lectures 1 to 11 (and leaves out Lectures 12 and 13 that are in the same week as the exam).

- Similar to homework assignments, if you leave a question **completely blank** on your mid-term, you will receive 25% of the grade for that question. However, you may and will receive zero credit for a completely wrong answer.

- Similar to homework assignments, you can use external resources and GenAI tools for answering your mid-term exam. Nevertheless, and in contrast to homework assignments, I actually discourage you from doing so, given the limited time you have on the mid-term exam, and in preparation for your final exam.

- **The mid-term exam should be done individually** and you are not allowed to discuss these questions with anyone else in or out of the class. This includes asking any questions or clarifications regarding the exam from other students or posting them publicly on Piazza – during the exam, you can ask your clarification questions as **private posts** on Piazza. You can consult all the materials used in this course (in particular, lecture notes and listed references on the course webpage) while writing your solution.

- **A missed exam draws zero credit.** However, emergencies will be considered upon submitting a university-issued written verification to the Instructor.

Final Exam

– The final exam will be held at the end of the term according to the University schedule.

– Similar to the mid-term exam, leaving a question **completely blank** on an exam also will result in 25% of the grade for that question.

– The final exam is **in-person** and no textbooks or electronic devices are allowed. However, you can bring in a one-page cheat sheet with you to the exam. Moreover, unlike homework assignments and mid-term exam, you are not allowed to use any outside sources at all when working on your final exam.

– Further details on the timing and format of the final exam will be released later in the term.

3   Policies and Statements

Territorial Acknowledgement

The University of Waterloo acknowledges that much of our work takes place on the traditional territory of the Neutral, Anishinaabeg and Haudenosaunee peoples. Our main campus is situated on the Haldimand Tract, the land granted to the Six Nations that includes six miles on each side of the Grand River. Our active work toward reconciliation takes place across our campuses through research, learning, teaching, and community building, and is co-ordinated within the Office of Indigenous Relations[5].

Email Policy

Email is fast and tends to give the illusion of constant and immediate access. But that cannot realistically happen. I am available to you in general during this course via email but it may take up 24 hours (48 hours over the weekends) before you hear back from me[6]. Also, please use email only to communicate specific concerns, questions, or comments regarding your experience in the course, or setting up appointments for in-person meetings outside office hours in case necessary. Questions directly related to the materials of the course and clarifications about lectures should be posted on Piazza or discussed during office hours instead.

Important note: Please start the subject of all your emails in this course with '[CS466-F23]'[7] (like "[CS466-F23] discuss my final grade") – there is no guarantee on response time for emails not adhering to this format.

> *I am using bunch of different email filters to manage my (unmanageable) inbox and I may not get to see emails without this format at all...*

Students with Disabilities

You are encouraged to discuss with me any appropriate accommodations that we might make on your behalf following the guidelines of the AccessAbility Services[8].

AccessAbility Services, located in Needles Hall, Room 1401, collaborates with all academic departments/schools to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with AccessAbility Services at the beginning of each academic term.

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[5]https://uwaterloo.ca/indigenous/

[6]And probably even more if you send me an email at midnight...

[7]I do know that for some of you this is the course CS666 and not CS466 – but just for consistency and to avoid any confusion, let us all use [CS466-F23] tag for this purpose.

[8]https://uwaterloo.ca/disability-services/

Statement of Inclusivity

I am committed to creating a learning environment in which all of my students feel safe and included, regardless of race, ethnicity, religion, gender or sexual orientation. Because we are individuals with varying needs, I rely on your feedback to achieve this goal. I invite you to let me know about what I can stop, start, or continue doing to make sure every one of my students feels valued and can engage actively in our learning community.

Faculty of Math Statement on Diversity: It is our intent that students from all diverse backgrounds and perspectives be well served by this course, and that students' learning needs be addressed both in and out of class. We recognize the immense value of the diversity in identities, perspectives, and contributions that students bring, and the benefit it has on our educational environment. Your suggestions are encouraged and appreciated. Please let us know ways to improve the effectiveness of the course for you personally or for other students or student groups. In particular:

- We will gladly honour your request to address you by an alternate/preferred name or gender pronoun. Please advise us of this preference early in the term so we may make appropriate changes to our records.

- We will honour your religious holidays and celebrations. Please inform us of these at the start of the course.

- We will follow AccessAbility Services guidelines and protocols on how to best support students with different learning needs.

Your Health & Well-Being

This is a challenging course with various advanced topics and not-so-easy assignments and exams. All of these are going to be time and energy consuming. But, this is also an elective course so one of my main goals is for you to enjoy taking this course and learning these cool materials as much as I enjoy teaching them. Part of making sure you have fun involves taking care of yourself. Do your best to maintain a healthy lifestyle and work-life balance this term by eating well, exercising, getting enough sleep, and taking some time to relax – all of these will tremendously help you to achieve your goals in the course and to enjoy the process in the meantime.

You can find more resources to help you with your health and well-being with the Campus Wellness and Student Success Office – they have tons of resources on helping you to succeed, including very good tips on time management techniques.

Faculty of Math Statement on Mental Health: The Faculty of Math encourages students to seek out mental health support if needed:

- **On-campus Resources:**
  - Campus Wellness: here to help enhance and support your wellness in a safe, respectful, and inclusive environment.
  - Counselling Services: email counselling.services@uwaterloo.ca or phone 519-888-4567 ext. 32655
  - MATES: one-to-one peer support program offered by Waterloo Undergraduate Student Association (WUSA) and Counselling Services: mates@wusa.ca
  - Health Services: located across the creek from the Student Life Centre; phone: 519-888-4096.

- **Off-campus Resources:**
  - Good2Talk (24/7): Free confidential help line for post-secondary students. Phone: 1-866-925-5454 (Ontario and Nova Scotia only)

- Here 24/7: Mental Health and Crisis Service Team. Phone: 1-844-437-3247 (Waterloo Region only)
- OK2BME: set of support services for lesbian, gay, bisexual, transgender, or questioning teens. Phone: 519-884-0000 extension 213 (Waterloo Region only)
- EMPOWER ME: Phone 1-833-628-5589 for Cdn./USA; for other countries see here
- EMPOWER ME in China: China North 108007142831 and China South 108001402851

Rights and Responsibilities

Every member of this class—instructor, TA, and students—has rights and responsibilities toward having a pleasant, fair, supportive, and free of discrimination and micro-aggression environment in this course, and we are all answerable to the University policies governing ethical behaviour (Policy 33).

In addition, academic dishonesty and plagiarism is considered a serious offense in this course. I expect that any assignment or exam you submit in this course will be your own product and follows the collaboration and external resources policies specified earlier in this course outline.

> *If an assignment is too hard, start earlier, ask for help, or simply do not answer the question — academic dishonesty is never the right answer. If you have any concerns or questions about these policies, please discuss them with me.*

Finally, a reminder that all the course content including lecture notes, presentations, and other materials prepared for the course, are the intellectual property (IP) of the instructor. These course materials are available to you to enhance your educational experience, and sharing them without permission and proper citation is a violation of intellectual property rights.

University Policies: It is your job to know the university policies that govern your behaviour in this course. Some pointers are:

- **Academic Integrity:** In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. All members of the UW community are expected to hold to the highest standard of academic integrity in their studies, teaching, and research. The Office of Academic Integrity's website contains detailed information on UW policy for students and faculty. This site explains why academic integrity is important and how students can avoid academic misconduct. It also identifies resources available on campus for students and faculty to help achieve academic integrity in—and out—of the classroom.

- **Grievance:** A student who believes that a decision affecting some aspect of their university life has been unfair or unreasonable may have grounds for initiating a grievance (Policy 70). When in doubt please be certain to contact the department/school's administrative assistant who will provide further assistance.

- **Discipline:** A student is expected to know what constitutes academic integrity to avoid committing academic offences and to take responsibility for their actions. A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course professor, academic advisor, or the undergraduate associate dean. For information on categories of offences and types of penalties, students should refer to Policy 71. For typical penalties check Guidelines for the Assessment of Penalties.

- **Appeals:** A decision made or penalty imposed under Policy 70, Student Petitions and Grievances (other than a petition) or Policy 71, Student Discipline may be appealed if there is a ground. A student who believes they have a ground for an appeal should refer to Policy 72, Student Appeals.

Intellectual Property. Students should be aware that this course contains the intellectual property of their instructor, TA, and/or the University of Waterloo. Intellectual property includes items such as:

- Lecture content, spoken and written (and any audio/video recording thereof);

- Lecture handouts, presentations, and other materials prepared for the course (e.g., PowerPoint slides);

- Questions or solution sets from various types of assessments (e.g., assignments, quizzes, tests, final exams); and

- Work protected by copyright (e.g., any work authored by the instructor or TA or used by the instructor or TA with permission of the copyright owner).

Course materials and the intellectual property contained therein, are used to enhance a student's educational experience. However, sharing this intellectual property without the intellectual property owner's permission is a violation of intellectual property rights. For this reason, it is necessary to ask the instructor, TA and/or the University of Waterloo for permission before uploading and sharing the intellectual property of others online (e.g., to an online repository).

Permission from an instructor, TA or the University is also necessary before sharing the intellectual property of others from completed courses with students taking the same/similar courses in subsequent terms/years. In many cases, instructors might be happy to allow distribution of certain materials. However, doing so without expressed permission is considered a violation of intellectual property rights.

Please alert the instructor if you become aware of intellectual property belonging to others (past or present) circulating, either through the student body or online. The intellectual property rights owner deserves to know (and may have already given their consent).

Use of Generative Artificial Intelligence. The following statement is prepared by the Office of Academic Integrity with input from the Centre for Teaching Excellence, Library, and consultations with Associate Deans and members of the Standing Committee on New Technologies, Pedagogy, and Academic Integrity (Last Updated: August 2023):

Generative artificial intelligence (GenAI) trained using large language models (LLM) or other methods to produce text, images, music, or code, like Chat GPT, DALL-E, or GitHub CoPilot, may be used for assignments in this class with proper documentation, citation, and acknowledgement. Recommendations for how to cite GenAI in student work at the University of Waterloo may be found through the Library:

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https://subjectguides.uwaterloo.ca/chatgpt_generative_ai

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Please be aware that generative AI is known to falsify references to other work and may fabricate facts and inaccurately express ideas. GenAI generates content based on the input of other human authors and may therefore contain inaccuracies or reflect biases.

In addition, you should be aware that the legal/copyright status of generative AI inputs and outputs is unclear. Exercise caution when using large portions of content from AI sources, especially images. More information is available from the Copyright Advisory Committee:

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https://uwaterloo.ca/copyright-at-waterloo/teaching/generative-artificial-intelligence

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You are accountable for the content and accuracy of all work you submit in this class, including any supported by generative AI.

A Final Word

> *Finally, welcome to the course! I am hoping you enjoy taking this course as much I enjoy teaching it, and looking forward to having a great term together!*