COMP3821/9801: Extended Algorithm Design and Analysis

Project Specification

COMP3821/9801 is offering a term-long project designed to explore more about the field and fields adjacent to algorithms. Students have the freedom to do something motivated by their own interests with guidance and advice from a mentor, extending the material explored in the course.

There will be weekly drop-in sessions for students to talk to other students in the course about their project idea(s), as well as to talk to a mentor about their progress. Our aim with this project is to help spark an interest in students and to develop their own understanding of the course as a whole.

Format of the project

The format of the project is open-ended, allowing you to be as creative or as theoretical as you want it to be. A few possibilities are listed below, but you are not limited to these options.

- **Theoretical**: Students can attempt to solve an interesting and (preferably) open problem related to algorithm design and analysis. For students interested in this option, topics of interest may also include areas not taught in this course such as:
  - *Randomised and Approximation algorithms*.
  - *Parameterised and Quantum algorithms*.
  - *Exact and exponential algorithms*.
  - *Computational Geometry and Combinatorial Optimisation*.

  Because of the time constraints of the project, it is expected that students will not make any groundbreaking new results. Therefore, the presentation of the project should describe partial progress towards a solution. Progress can include *complete* solutions to special cases of interest, counterexamples to demonstrate that possible approaches to a problem will not work, coherent ramblings of half-baked ideas, interesting approaches that didn't quite work, and approaches that seemed likely to succeed but turn out to fail. These are all common themes when doing proper research and each part plays a pivotal role in the success (or failure) of a resolution.
- **Scholarly**: Students can also choose to write a comprehensive survey on some problem from the course. Surveys include the history of the problem and some motivating applications of the problem, a summary of known results, a sketch of known algorithms to solve the problem and any proof related to the algorithms, motivating open research problems, and concluding remarks, if any. For students interested in this option, topics of interest may include:
  - *Knapsack and its related variants*.
  - *Knight's tour and its variants*.
  - *A History of Flow Networks and its Combinatorial Applications*.
  - *Dynamic Programming and Genetic Algorithms*.

  Again, because of the time constraints of the project, groups choosing this option should decide early on what kind of problem they want to survey. For most well-defined problems, there are comprehensive surveys in the literature already. Therefore, your aim is not to copy these surveys but use these surveys as inspiration to write your own survey of the problem.

- **Experimental**: Students can also attempt to implement one or more of the algorithms for a problem(s) discussed in the course and to discuss their empirical results. Discussion of efficiency should take into account the data structure(s) used to evaluate the trade-offs between time and space complexity. For students interested in this option, some topics that may be of interest include:
  - Assessing the trade-offs between an exact (but slow) and an approximate (but efficient) solution. For example, the *travelling salesman problem* has an exact exponential-time solution and an approximation polynomial-time solution.
  - Implement new algorithms that might be hard to analyse but are efficient in practice. New (or novel) algorithms can be developed around topics discussed in this course.
- **Educational**: Students can also develop educational resources for any of the topics explored in class. For students interested in this option, topics can include:
  - Real-world applications of the topics in the course.
  - Working implementations of the algorithms explored in this course; there should be some level of complexity.
- **Creative**: Students can also develop something cool based on the topics in this course. Topics of interest include the four major topics of the course: *divide and conquer*, *greedy algorithms*, *flow networks*, *dynamic programming*. Students can also choose to explore any other topic that have an algorithmic flavour. Such topics may include:
  - *Universal Search and Hutter Search*.
  - *A Sudoku or Chess Engine*.
  - *Simulating fractal generation algorithms*.

Students are encouraged to work on topic(s) driven by their own curiosity and desire, and to collaborate with students both within the course and outside of the course. Students are also encouraged to work on the project during lab times, if necessary.

Structure of the project

The project is designed to last the entire term, which should give students time to research about topics of their interest related to the course. Because slides are uploaded per week, we understand that the topics that students may be interested in might require a deeper understanding of the later topics. As such, we have provided full course notes with additional information at the end of the course notes for students to read. These cover the foundations of the topics that may be relevant for the project.

- The project can be done in groups of two to four students. Individual projects are *strongly* discouraged since research is collaborative rather than individual. However, if you are determined to do a solo project, then please consult us in advance. You'll be surprised at how much you can learn from talking to other students.
- Submissions will be uploaded onto `formatif`. We will also provide weekly submission boxes for students to submit their progress. Apart from the project deadlines, these submissions are completely optional. Mentors will grade and provide feedback on the progress, and to ensure that the scope of the project is appropriate for the timeline of the course.

Project Deadlines

- **[15%] Proposal**: Week 3.
  - Each group submits a project proposal by Friday of Week 3. Proposals should be roughly 2 to 3 pages in length and should include a self-contained statement of the proposed topic, a *brief* survey of the topic (including any currently known results and conjectures left unresolved), a potential approach to the problem (or more), and one or two ideas that might not work.

For students opting for the creative option, your proposal should include a brief background discussion of the project (including discussions of the related topic from the course) and your motivations for the project. Where possible, include a discussion on any real-world applications.

- **[15%] Progression check**: Week 7.
  - Each group submits a small report by Friday of Week 7. The report should be no more than 3 pages in length and should include a self-contained discussion of the problem statement as described in the proposal. Additionally, the report should contain some discussions about how their overall project is tracking.
    - For students doing the *theoretical* option, the report should include current results and any new results that have been discovered since the proposal, and where possible, proofs of the results. The report should also include progress regarding their plan of attack as outlined in the proposal and where appropriate, whether one or more of the ideas from the proposal has seen any success.
    - For students doing the *scholarly* option, the report should include a brief outline of the historical results from the proposal and any new results that have been discovered since the proposal.
    - For students doing the *experimental* option, the report should include implementation of one or more algorithms and any empirical results that have been developed. Where possible, discussions of some of the empirical results are also welcome.
    - For students doing the *creative* option, the report should include some discussions of the state of the project.
- **[70%] Final presentations or report**: Week 10.
  - Students have two options when it comes to submitting their project.

    Option 1: *Poster and presentation*.

    There will be a dedicated lecture (or two...) for students to present their work to the rest of the cohort, which may also include industry mentors and academics. Students are required to design a poster and prepare a talk that outlines their work, including any demonstrations that would highlight the project. A schedule of presentations will be released in week 9.

    Option 2: *Report*.

    If students do not wish to do a presentation, students can alternatively write a report detailing the entire project, including any new results that have been discovered since the start of the project.

  More information will be released closer to Week 10.

Advice for finding good problems

Now that you have some ideas of what the project is aiming towards, it's time to start thinking about good potential problems to think about. But where do you start? Good question! We have compiled a list of points for you to think about as you progress through the project.

- **Start with a paper chase.** Oftentimes, the first step to defining the objectives and goals of your project is to understand the problems that you want to solve and read any relevant literature surveys on the topic. Keep reading and reading until you eventually get lost. The moment you get lost is the first point of research – this is good!
- **Talk to other students.** If there was one piece of advice I want to give to a research student, it's to talk with your peers. Other students have all sorts of background and intuition that you won't have and conversely, you will have insightful background and intuition that other students won't have. Research is the ultimate collaborative industry, so share your ideas, however ambitious or half-baked they may be! You never know if that one insane idea can turn into something fruitful with the right perspective! Listen to other students' ideas and build on those conversations. Give your problems

to someone else and see if they have any new insights into the problem that might get you unstuck on the problem you've been having for a few days. Ask for suggestions for any papers or expositions that you should read upon, and offer some suggestions in exchange.

- **Talk to your mentor.** Your mentor is also your peer, even if it doesn't seem so. One of our jobs is to guide and help facilitate interested students to explore their own interests and motivations. It drives us to see budding students be invested in their work, so yes – bug us with all of your ideas, however absurd they may be! We also have insane and absurd ideas of our own – we just hide them amongst the other less insane and absurd ideas that are floating around in our minds.
- **Solve a lot of problems.** Part of the journey to picking the right problem is, well, solving problems on your own. There is, unfortunately, no way around it. You will spend lots of time solving problems of varying difficulties. Take a look at some of the current problems from the `formatif` tasks and practice problems. Pick a problem and try to solve it on your own. If you can solve it, what sort of information does your solution tell you? Is the problem that you just solved a special case of a more general problem? What other problems can you solve with the same (or similar) techniques? If you can't solve the problem, maybe try a less restrictive variation of the problem. Or try a special case of the problem by fixing some of the constraints. What sort of useful pieces of information can you extrapolate from looking at these cases? Can you generalise these techniques to solve the original problem? Understanding what works and doesn't work, and being able to tweak existing problems is a crucial step to being a successful problem solver and researcher.
- **Read a lot.** Similar to the previous point, part of picking out good problems to tackle is to read a lot. Many textbooks and research papers conclude with a list of open results. Read some of the results that are published by the research papers and see if you can find ways to improve upon the results, either empirically through some menial testing or by finding a new way to approach the same problem. Look at some of the problems that current researchers *aren't* asking as well! Could there be an avenue for you to make a contribution by providing insight into an area that rarely anyone has looked into? But of course, don't just read papers! Invest in books, talks (whether that be conference talks or just local research/student talks), and podcasts! There is an endless sea of resources for you dive head-first into; you just need to grab the wheel and start navigating.
- **Embrace the difficulty.** Research is difficult. It is tiring. Oftentimes, you'll come across a problem that seems easy on the surface but when you dive deeper into the material, it resists and resists and resists from being solved. That is okay. That is completely normal. You'll often feel more and more confused as you read on. Embrace it, because that can be a sign that you're moving in the right direction – it is a sign that you're making progress on the problem, even if it does not feel like it.
- **Take breaks.** Work on a problem. Take a break. Come back to the problem. Take a break. Working in a rut is never good for anyone – you still need to let your mind wander elsewhere, because those are often the most illuminating moments in your research. Do something creative and off-topic, come back to your problem. Rinse and repeat.
- **Write everything down.** When you hear something remotely relevant to your research, record it somewhere. It could be inside of a physical notebook, or digitally in a personal blog – just as long as you have it recorded. Even if it is an absurd idea. Once you look back on these scribbles, you'll begin to realise how much you've grown as an aspiring researcher. As you progress further into your research career, your notes will slowly culminate into a sea of discoveries. It will accentuate the way you approach problems, and this extends beyond just your academic career.

Finally, here are some relevant comics to help you through the journey.

- PHDComics #961 – an experimental mess...
- PHDComics #1193 – for when your endeavours didn't quite pan out.
- xkcd #2239 – for when you find a counter example to an approach you've been working on for weeks.