EECS 690 Algorithms for HPC (Spring 2025)

Research Project

Project Goal:

The objective of this mini research project is to get students familiar with the process of conducting academic research, have students develop critical thinking, creativity, and problem-solving skills, and promote an understanding of research methodology among students.

Expectations:

The general expectation for students is to (re)produce theoretical/experimental results on a small-scale research topic related to high-performance computing (HPC) in 5-7 weeks. This will be done through a complete research cycle (as shown in the diagram below), with guidance and feedback from the instructor.

*You are also required to participate in the **Undergraduate Research Symposium** in Spring 2025 (curf.ku.edu/spring-undergraduate-research-symposium), and deliver a presentation at the symposium on the research findings (up to 10 minutes, online or in-person). More details about this event can be found on the event website.*

Research Topics:

Each project group should identify a research topic (possibly with the help of the instructor) that relates to an HPC problem with one or more of the following focuses. If you are actively conducting research in a related field, you are welcome to discuss that with the instructor to form a research topic.

- Propose a novel algorithm that solves a new or an existing HPC problem. If you are presenting a new research problem, clearly state the problem statement and formulation. If you are proposing a new algorithm for an existing problem, clearly present the problem with other existing approaches, and identify the uniqueness/advantage of your new solution (either theoretically or empirically).

- Theoretically analyze the performance of an existing or a newly proposed algorithm. This involves analyzing the runtime or space complexity (e.g., in terms of big-O notations), and/or any performance guarantee of the algorithm (e.g., optimality, approximation ratio, competitive ratio). If you are analyzing an existing algorithm, you should search in the literature on whether existing analysis already exists and show why your analysis is different from that of the literature (e.g., you provide an improved analysis result or a (slight) modification of an algorithm that can offer improved performance).

- Empirically evaluate the performance of a new or an existing algorithm based on experimentation or simulation. This involves implementing the algorithm and running experiments (either on real HPC systems or using simulations) to evaluate its performance (e.g., running time, performance bounds) under different parameter settings. You should also evaluate the impact of various parameters related to the algorithm and evaluate their impacts. A performance comparison should also be made with at least 2-3 other algorithms in the literature that solves the same problem.

The problems and/or algorithms you study can be related to the ones we discussed in the first half of the course or based on your own choice or research activity. However, the project must be related to HPC. You are encouraged to discuss your research topic with the instructor at any time during the course.

Assessment:

This mini research project constitutes 45% of your total grade and will take 7 weeks to complete (the entire second half of the semester). The deliverables include:

- For the first 5 weeks, a weekly meeting with the instructor in class to discuss the progress of your research based on the expectations of each week (see details below). Before the meeting, you should upload a 1-page progress report for the work you completed for that week.
- For the last 2 weeks, two rounds of presentations in front of the entire class. *Students will also give a presentation on the (partial) research results at the undergraduate research symposium during Week 5 (04/21-04/25).*
- A final project report detailing everything you have done for this research project, including problem statements, literature review, research methodology, results, and possible future work.

Please refer to the **project schedule** on Canvas for details of the weekly meeting/presentation schedule. For group-based projects, each group member is expected to make a significant contribution (~equally) to the research project.

Week 1 (03/24 – 03/28): Develop a research problem

Weight: 5 points.

Milestone: The goal for this first week is to successfully define a meaningful research problem. You are encouraged to start thinking about potential research topics early by following the guidelines provided previously in this document.

Things to note: The following are things you should note when defining your research problems, write your 1-page progress report, and discuss with the instructor for the week:

- What is the precise problem statement? Use mathematical symbols and notations, if necessary, to precisely capture the problem you are trying to solve, especially if it is a theoretical topic.
- Why is this problem important to the discipline, and what theoretical and/or practical applications can benefit from the solution to the problem?
- What is the outcome you expect to achieve at the end of this project? You should have realistic expectations based on the project duration and the number of students in your project group.
- What tools (theoretical and/or empirical) do you plan to use while conducting this research? What difficulties would you expect during the project?

Week 2 (03/31 – 04/04): Review the literature

Weight: 5 points.

Milestone: The goal for this week is to complete a literature review on existing solutions to the problem you are trying to solve, or if you are considering a new problem, a review of related problems. Discuss within the group, distribute the load of literature search evenly among the group members, and synthesize them in a coherent manner.

Things to note: The following are things you should note when conducting the literature review, write your 1-page progress report, and discuss with the instructor for the week:

- Use online tools such as Google Scholar, IEEE/ACM digital library or other scholarly portals, for searching the literature with keywords that define your problem. You should read at least 3-5 papers in-depth and review more papers broadly.
- You can also include textbooks as references if considering a classic problem that has been well documented in textbooks.
- What are the classical results for the problem (e.g., the results shown in textbooks) and what have been the latest developments in this field from recent years (e.g., the results in recent research papers)?
- What's new about your proposed research/methodology that is different from these existing works?

Week 3 (04/07 – 04/11): Conduct primary research

Weight: 6 points.

Milestone: Now, you should have a clear expectation of your research objectives and a good understanding of the literature. The goal for this week is to start conducting primary research on the proposed topic, and gain initial insights and lessons.

Things to note: The following are things you should note when conducting the research, write your 1-page progress report, and discuss with the instructor for the week:

- Get together as a group and discuss/brainstorm a research plan that involves everyone in the group to equally contribute to the problem solutions.
- What tools (theoretical and/or empirical) are you using for conducting the research? If theoretical, what analysis techniques are you using, and if empirical, what experimental platforms (e.g., programming languages, datasets) are you using?
- Conducting research is not an easy task. Which aspects of the research are going well, and what difficulties do you encounter? How do you plan to get around the difficulties?
- What can you learn from existing solutions in the literature? How can you leverage those solutions (e.g., analysis techniques, existing code base) to shape your own solutions.
- *You should also have registered for the undergraduate research symposium (registration deadline: 04/13).*

Week 4 (04/14 – 04/18): Continue primary research

Weight: 6 points.

Milestone: This week continues the primary research tasks you started last week. You are expected to make substantial progress towards your research goal. You should start getting preliminary findings (theoretical and/or empirical) and performing a comparison study with existing solutions.

Things to note: The following are things you should note when conducting the research, write your 1-page progress report, and discuss with the instructor for the week:

- Again, gather as a group and re-iterate on the role each group member should play for successful completion of the research project. Be specific on each member's subtasks and coordinate to combine them for the final solution.
- Are the current tools you are using sufficient for achieving the end goal? What additional tools (theoretical and/or empirical) can you utilize to further your research progress? What have you done to resolve the previous difficulties?
- Start evaluating the impact of different parameters on the performance of your solutions. Also, start comparing your solution to existing solutions in the literature.
- What preliminary results have you obtained so far? How do you plan to conclude the research? You might need to think about adjusting the original expectations based on this week's progress.

Week 5 (04/21 – 04/25): Collect data, gather results

Weight: 6 points.

Milestone: This will be the last week of conducting the primary research for your project. The goal of this week is to wrap up your work, collect data and gather all the results. You are expected to organize your findings and start putting together a narrative for presentation.

Things to note: The following are things you should note when gathering the results, write your 1-page progress report, and discuss with the instructor for the week:

- What are your main research findings? Have you accomplished the goals that were initially planned at the start of the project? What additional findings (e.g., unexpected results) have you got?
- If you obtained good results, you should perform a basic sanity check to verify that the results make sense. The performance of your solution should also be evaluated (theoretically or empirically) and compared against the existing solutions.
- If your initial goals were not met, what partial results have you got? What has gone wrong and what could you have done differently to meet the goals?
- If given more time, what future work could you explore to further this research?
- *You need to participate in the undergraduate research symposium this week and present your (partial) research findings there. You don't need to submit the 1-page progress report, and instead you should submit your presentation slides and get feedback from the instructor.*

Week 6 (04/28 – 05/02): 1st round of presentation & Week 7 (05/05 – 05/09): 2nd round of presentation

Weight: 5 points (1st round) + 5 points (2nd round)

Milestone: The last two weeks are dedicated to presenting your research problem and findings to the class. Please refer to the **project schedule** on Canvas for when you are expected to present. No progress report is needed for these two weeks, but attendance is required for all.

Things to note: The following are things you should note when delivering the presentations:

- The 1st round should present the project overview (i.e., problem, importance) and the research methodology (e.g., analysis techniques, experimental environment, dataset).
- The 2nd round should present the research findings (e.g., analysis/experimental results), lessons you learned, and future work.
- Each round should be 10-15 minutes, including Q&A from the audience.
- Have your audience in mind: not everyone is familiar with the research topic you have worked on; make sure to introduce the necessary background.
- Use sufficient visuals (e.g., figures, tables, diagrams) during your presentation. Remember: a picture is worth a thousand words.
- Avoid putting a lot of words/texts/maths in your slides. Use them concisely and always use bullet points for better organization.
- You can use notes but avoid reading off a script during your presentation.
- Engage with the audience, maintain eye contact, and be prepared to answer questions.

Project Conclusion: Submit final report

Weight: 7 points

Milestone: To conclude this research project, you are expected to submit a final report, in which you should document everything you have done for the project. This report, along with the presentation slides (for both rounds), should be submitted on Canvas. Please refer to the **project schedule** for the submission deadline.

Things to note: The following are things you should note when preparing your final report:

- There is **no required format or page limit**. You are free to choose the report format and you should include all the relevant background and research results in the report.
- The final report shouldn't be a simple compilation of your 1-page progress report for each week (although you can draw content from your progress reports). Instead, it should be a cohesive document that maintains a logical flow between different sections, which are typically organized as follows:
    - **Title**: A clear and concise title that reflects the research topic.
    - **Abstract**: A brief summary of the research, including objectives, methods, key findings, and conclusions.
    - **Introduction**: Background information, research questions, and objectives.
    - **Literature Review**: A review of relevant existing research to provide context.
    - **Methodology**: A detailed description of how the research was conducted.
    - **Results**: Presentation of findings using text, tables, and figures. You should also include interpretation of results, connections to previous research, and possible limitations.
    - **Conclusion**: Summary of findings and their significance, along with recommendations or future directions.
    - **References**: Proper citations of all sources (e.g., papers, books, urls) used.
- Please make sure your final report is well presented. Specifically, you should:
    - Use clear and precise language.
    - Avoid unnecessary jargon unless it's necessary and well-defined.
    - Clearly label all figures and tables with captions and proper reference in the text.
    - Avoid plagiarism: instead of copying text word-for-word, rewrite the ideas in your own words and always provide a proper citation for a reference.
    - Proofread for any grammar, spelling, and typographical errors.
- Lastly, include the contributions made by each member of your group. Be specific on the role each member plays in the research. Avoiding generic statements, such as "All members contributed equally to the project".