Academic Statement

Ray Tsai

I am applying to the Master's program in Computer Science at University of Illinois Urbana-Champaign (UIUC) to deepen my understanding of theoretical computer science, particularly in coding theory and combinatorial optimization. My goal is to become a researcher working at the intersection of computer science and mathematics, finding ways to bridge the two fields. I intend to pursue a Ph.D. after the master's program to further this objective.

As a mathematics-computer science major at UC San Diego, I placed most of my attention to mathematics in my undergraduate studies, primarily through honors and graduate-level coursework. While I appreciate the beauty of pure mathematics, I wasn't satisfied pursuing abstract mathematics for its own sake. I instead looked for a field in mathematics with a closer connection to the real world and turned to graph theory, the study of relationships that can model a wide range of practical problems effectively.

During my sophomore year, I began my research journey by directly reading under Professor Jacques Verstraete, exploring the vast literature on extremal graph theory. Through the readings, I was exposed to a variety of powerful techniques for tackling extremal graph problems, from probabilistic methods to algebraic constructions, which laid the groundwork for my honors thesis centered on the Double Turán problem. The problem asks for the maximum possible number of edges across n subgraphs of a complete graph K_n such that no pairwise intersection of these subgraphs contains a specified forbidden structure. After dedicating my summer to studying the case where the forbidden graph is non-bipartite, I established a tight upper bound on the number of edges under the stricter condition that each subgraph is induced. Specifically, I showed that the extremal condition is uniquely achieved when all subgraphs extremal graphs for the forbidden graph, by recursively expanding the intersection of all subgraphs. This case serves as a stepping stone for the project, and I am currently working on the general case.

As I progressed in my research, I also developed an interest in the computational aspects of combinatorial problems. I had the opportunity to learn about computational complexity theory directly from Professor Russell Impagliazzo, studying Arora and Barak's text, Computational Complexity: A Modern Approach [1]. With this foundation, I then joined Professor Impagliazzo's research group, studying Multicalibration to mitigate unintended biases to certain subpopulations in learning models from the perspective of complexity theory. We are trying to connect notions in smooth boosting to multicalibration. By modeling the fairness of algorithms with random-like structures yielded by Szemeredi's Regularity Lemma, this research brought the application of extremal combinatorics and complexity theory to a new level and further strengthened my commitment to utilize my mathematical foundation to solve practical problems.

With my mathematics-heavy background, I aim to build a deeper understanding of computer science concepts to support my future research endeavor. UIUC's Master's program offers an ideal path for this. I plan to learn more about the combinatorial side of the study, and taking courses like Approximation Algorithms (CS 583), Combinatorial Optimization (CS 586), Coding Theory (ECE 556), and, if offered, Expansion, Codes, and Optimization both Classical and Quantum (CS 598) would be a great start.

Moreover, I am drawn to the opportunities to work with the UIUC faculty and aim to write a master's thesis, particularly under Professor Fernando Granha Jeronimo. His work on coding theory and expanders has intersects significantly with combinatorics, which aligns well with my intended research direction. If possible, I would also like to join Professor Olgica Milenkovic's Interdisciplinary Data Processing Group under the Electrical & Computer Engineering department. Their research focus on constructing and analyzing codes on graphs seems very interesting, and I believe I can contribute to their research with my background in graph theory.

Another faculty member I would like to work with is Professor Ruta Mehta on envy-freen item allocations. Her paper on EFX orientations shows a surprising connection between the envy-freeness up to any good (EFX) property and chromatic number of a graph [3]. This topic is closely related to back background in both extremal graph theory and complexity theory, and I believe my specialized knowledge can be applied to this area. I also want to work with Professor Karthekeyan Chandrasekaran under the Department of Industrial and Enterprise Systems Engineering. I find his old research topic on deterministic algorithms for the Lovász Local Lemma [2] especially interesting, as it develops a deterministic algorithm to construct solutions that satisfy a probabilistic statement. I am looking forward to study more about this topic under his mentorship.

I have only begun to scratch the surface of theoretical computer science, and there are still a lot of topics to explore. Research at UIUC has significant intersections with both my academic background and my research interests, which will build me a solid foundation while I shift my focus from mathematics to computer science. I am confident in my ability to excel in the program and evolve into a capable researcher, and I look forward to contributing to the vibrant academic community at UIUC and bridging the worlds of mathematics and computer science.

References

[1] Sanjeev Arora and Boaz Barak. *Computational complexity: a modern approach*. Cambridge University Press, 2009.

[2] Karthekeyan Chandrasekaran, Navin Goyal, and Bernhard Haeupler. Deterministic algorithms for the lovasz local lemma, 2019.

[3] Jinghan A Zeng and Ruta Mehta. On the structure of efx orientations on graphs, 2024.