Research Experience in Algorithmic Game Theory

Importance of Theoretical Studies in the Success of Google Ads

A Thesis Prospectus
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Computer Science is the most popular major in the UVA School of Engineering and Applied Sciences (UVA SEAS, 2022). Educating these many students with diverse interests and goals is an important sociotechnical challenge. Over the years, the UVA Department of Computer Science designs a curriculum that can be roughly separated into three categories: software development, computer system, and theory. Software development teaches students different coding languages and how to use them in practice. Computer system teaches the design of a computer and how programs run. Theory studies the inner workings of the algorithms and the formal analysis of what algorithms can or cannot do. Although there are courses in all three areas, theory courses are lacking in number and diversity. This lack of understanding will undermine the students' ability to learn and appreciate the essence of computer science and will lead to poor performance when students graduate.

As a computer science and math double major, I am interested in research in Theoretical Computer Science. Since the 2021 school year, I have been working with Prof. Haifeng Xu in a subfield called Algorithmic Game Theory. Algorithmic Game Theory studies Game Theory, a branch of Economics that studies how strategic agents interact, using a Computer Science perspective. During my research, I experience firsthand how the UVA undergraduate program is inadequate to introduce students to theoretical research. To address this, I will propose several changes to the curriculum, drawing on ideas from other departments and universities.

To better understand the importance of Theoretical Computer Science, I will also study a specific case of success in Algorithmic Game Theory: Google Ads. Google Ads is an online advertising platform developed by Google (Google, 2022). Advertisers place bids to display brief advertisements, while Google runs an auction mechanism to decide which ads to display for each

user. Google Ads is the main source of revenue for Alphabet Inc, contributing 168.6 billion US dollars in 2020 (Alphabet, 2020). The study of Algorithmic Game Theory contributes to the success of Google Ads. Auction Theory, together with scalable, fast algorithms, sets the foundation for the design of auction systems. I will apply Actor-Network Theory to study how theoretical studies influence the development of Google Ads.

To fully understand the importance of Theoretical Computer Science in undergraduate education, both technical and social aspects must be addressed. Below I describe my own research experience and offer ideas to improve the UVA curriculum. I will also use Actor-Network Theory to analyze the importance of theoretical studies in the success of Google Ads. With both projects, I address the problem of overlooking theory in the UVA undergraduate curriculum.

Technical Project Proposal

Since the start of the 2021 school year, I have been working with Prof. Haifeng Xu on research in Theoretical Computer Science. The research lies in the intersection of Computer Science and Game Theory, a branch of Economics that studies how strategic agents interact with each other using Mathematical reasoning. Computer Science provides an approach that previous Economics studies overlooked. For example, we study learning a defense strategy in a security game, something that Game Theory shows exists but does not study how to find (Yang et al., 2012). During the research, I need to manipulate Mathematical equations and find useful structures in the problem to come up with an algorithm. Then, I analyze the algorithm theoretically, understanding why it's correct and how fast it runs in terms of rigorous mathematical definitions. This requires

significant knowledge of Mathematics and Theoretical Computer Science, especially in fields such as Algorithms and Optimization.

Before my research, I had taken the CS 2102-3102-4102 sequence that introduces students to Theoretical Computer Science. Although the courses cover the basic ideas of the subject, they do not introduce students to current research or connect students with research interests with professors. The current offering of the Algorithm course, CS 3100, emphasizes the applications instead of the understanding of the taught algorithms (Floryan, 2022). If left unchanged, the theory sequence will be inadequate to teach UVA Computer Science undergraduates to understand and appreciate Theoretical Computer Science and hinder the goals of CS education set forth by the department (UVA SEAS, 2020). In addition, many courses that involve both developing and implementing algorithms should provide or even emphasize theoretical understanding. For example, in CS 4774 Machine Learning, the current course focuses on applying machine learning algorithms to solve problems (Nguyen, 2022). The derivations of various algorithms are either quickly summarized or skipped. Thus, many students lack knowledge of how the algorithms were developed and why they were better than the precedents. The students only get a superficial introduction to the ideas and this lack of understanding will ultimately hinder students' ability to implement the algorithms in practice.

I also encourage the Computer Science departments to facilitate the interaction between students seeking research opportunities and professors. The department has a website for professors needing research help, but the information on the website is often outdated and not many professors use the website (UVA SEAS, 2022). Undergraduate students should be encouraged to join research presentations by PhDs. For those already in research groups, weekly gatherings and discussions should be held. For example, during the first few months of my research

experience, I was often recommended books to read, and discussion with other students with similar backgrounds would have helped. Other important research skills, such as reading conference papers and writing, should be taught in a newly designed course that introduces students to research techniques.

In my technical report, I will describe specific ways in which the teaching of theoretical Computer Science can be improved to better prepare students for research in this area. Due to the similarities Theoretical Computer Science shares with Mathematics, I will draw ideas from the design of Mathematical courses to improve upon the Computer Science courses. I will also consult scholarly frameworks that study how to make Theoretical Computer Science education more accessible to students with little or no Mathematical background (Lowenstein, 2020). In addition, I will compare the UVA curriculum with other universities that are known to have good undergraduate CS education, such as Carnegie Mellon University and Massachusetts Institute of Technology.

STS Project Proposal

Google Ads is an online advertisement platform launched by google in 2000 where advertisers place bids to have their advertisements displayed on either search engines like Google Search or on other websites, mobile apps, and videos. After the bids are submitted, Google runs an auction mechanism to determine which ads to display for each user, whether during a search or a visit to a website. The advertisers are charged under a pay-per-click pricing model. That is, Google charges companies whenever a user clicks on the ads displayed, with the amount of money paid related to the company's bid and the auction mechanism. There are several challenges to this auction system. First, it should be fair and transparent enough that the advertisers trust Google

with their money. Second, it should generate as high a revenue as possible for Google, while both short-term revenue and long-term relations with the advertisers matter. In addition, the algorithm should show relevant ads to different users to maximize the probability that the user clicks on the ad. Ever since its launch, Google Ads has been the main source of revenue for Google (Alphabet, 2020). Throughout the years, Google has provided new features and used newer auction mechanisms.

Currently, professionals attribute the success of Google Ads to the implementation and experiments with different auction formats (Weaver, 2022). However, they overlook the importance of the theoretical studies of the auction mechanisms by the theoreticians. Auction Theory is tightly related to Game Theory because the bidders can be considered strategic agents that have different incentives as the platform. Therefore, theoreticians need to rigorously analyze the behaviors of auction mechanisms, so advertisers bid truthfully, and high revenue is generated. In addition, the multitude of searches happening requires the auction mechanism to be automated and fast to run. This means that researchers need to make the algorithms scalable with a large user base. If one overlooks the theoretical challenges of designing a successful online auction system, one cannot fully understand the success of Google Ads.

Drawing on actor-network theory, I claim that the theorists should be considered an important actor in the technological network of Google Ads. Actor-Network Theory views technology as a network, where a network builder must recruit human or non-human actors to construct (Cressman, 2009). The theorists in Academia and research group in Google and other companies have their own interests, like publishing new papers or simply pursuing knowledge. Therefore, they form an actor that must be recruited to stabilize the network of Google Ads. During Translation, which is the process of network formation and maintenance, theorists play a crucial role in determining

which auction formats to use and consequently affect how the Ads are chosen and displayed for each user. Then, when new features are to be added, theorists are needed to analyze what changes will be brought to the system. The theoretical understanding can change the decisions of which features can or should be added. For example, Google updated the budget cap in 2017 that upset paid search professionals (Marvin, 2021). This decision could be because an analysis of different budget caps yields that a higher budget cap would mean higher revenue. Applying the framework, I will show that theoretical studies have a real-world impact. To find evidence for my arguments, I will find historical accounts by Google through website archives, as well as scholarly studies of auction systems as published in Computer Science journals.

Conclusion

In the technical project, I will describe the challenges I faced in my research experience, give concrete arguments for why the UVA undergraduate CS education is failing in teaching Theoretical Computer Science, and provide suggestions to improve the current curriculum. In the STS project, I will apply actor-network theory to argue that the theorists and the theoretical studies of the auction mechanisms have a significant impact on the creation and maintenance of the Google Ads system. By studying how theory can influence the application in the case of Google Ads, I will illustrate why theoretical studies should be emphasized if not prioritized in an undergraduate Computer Science education.

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