Research statement and proposal

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1 Research statement

Over the past fifty years, computer science was based on theoretical models which originated from Von Neumann (or alternatively Turing) and computer science theory was built mainly on the foundations of logic and combinatorics. In recent years we are witnessing a fascinating phenomenon which requires a radically different way of thinking, namely, the emergence of applications and environments that involve strong socio-economic aspects. The examples are numerous, including electronic commerce and economics in general, the design of wide area networks, multi-agent systems and a large number of Internet applications. Problems that stem from such applications are very different from traditional algorithmic problems as the behavior of the participants in these applications is determined by their *own* goals and not by the instructions of the designer. From a technical point of view, these problems require the fusion of methods from both computer science and game theory (and micro-economics) and above all, a novel set of tools and ideas. Currently, very little is known about such problems and their understanding is a fascinating and deep challenge.

2 Past and future research

My Ph.D. dissertation focuses on optimization problems that arise among self interested participants. The work contains two major parts and was done in collaboration with professor Noam Nisan. The first part develops a general framework for presenting and analyzing such problems. This framework is based on a sub-field of game theory and micro economics called mechanism design, as well as on basic notions of theoretical computer science such as approximation. It shows that many problems, natural to computer science, cannot even be approximated by the standard tools of mechanism design. It then develops a novel way to solve a large class of such problems *optimally*, demonstrates the power of randomized mechanisms and more.

The second part of my dissertation, focuses on the computational side of such problems. It shows that *all* known general techniques for solving such problems are either intractable or degenerate (arbitrary far from optimal). It then shows a novel generic way of turning every polynomial time algorithm of the corresponding optimization problem into a polynomial time protocol. The results of the protocol are guaranteed to be *at least as good as* the algorithm's. Another fundamental problem of most protocols that emerge from mechanism design theory is that they require the agents *fully describe* their utility functions to the mechanism. For complex problems these functions require exponential time and space. In a later paper I proposed a general solution for this problem. By this I completed the "project" of turning mechanism design protocols into tractable.

Economic environments and games in general are essentially complex. Thus, methods and ideas which were developed within the computer science community, have a good chance of contributing to both game theory and micro-economics. A major problem in economics is the design of selling (buying) protocols that produce high revenue. In particular the design of optimal protocols in the case of a single object is a long standing problem. In a recent paper I studied the problem using a computer science based approach. Among the results are a generic two approximation and a protocol that guarantees almost all optimal revenue under reasonable assumptions. My ongoing projects include further analysis of this so called optimal auction problem, the introduction of failures to mechanism design and the study of structure effects.

The research of problems on the border of computer science and game theory (or economics) is still in its infancy. It will take years until a deeper understanding of these issues will emerge and the theoretical and conceptual challenges are deep and exciting. In the future I would like to keep exploring this field. I conclude this section by a brief description of some concrete issues which I would like to focus on:

Complex mechanism design problems Mechanism design and game theory in general study "well behaved" solution concepts such as dominant strategies and Bayesian equliberia. However, real life problems, in particular those which emerge from computer science, are complex, dynamic and involve a lot of uncertainty. Thus, it is not reasonable to expect that such problems could be solved under the above solution concepts. Currently, in the absence of clean solutions, even a methodology for *comparing* between potential protocols does not exist, all the more so tools for the design of protocols for such problems.

In the future, I would like to keep bridging the gap between classical mechanism design and the design of protocols for complex, real life problems.

Algorithmic problems that stem from game theoretic environments Game theoretic environments give rise to many challenging algorithmic problems. For example how to design a network topology that will function well with selfish users, how to test and design robust organizational structures, etc. I would like to exploit my background in both theoretical computer science and game theory to identify and explore such problems.

Bounded rationality Game theory implicitly assumes that agents are capable of optimal behaviour. Most games however are very complex and such optimal behaviour demands an infeasible amount of resources. Many problems in bounded rationality require methodologies of both computer science and game theory. Most of the research that has been conducted in the past, was focused on repeated games between finite automata. Very little is currently understood about more general models and I see it as a major challenge.

Collaboration with researchers from other sub-fields Problems on the border of computer science and game theory are tangent to many other fields of computer science. Among the examples are distributed algorithms, artificial intelligence, network design, computational learning and theoretical computer science. I would be happy to collaborate with researchers from these sub-fields.

3 Research highlights

Algorithmic Mechanism Design The paper studies optimization problems that involve self-interested participants from the point of view of theoretical computer science. It introduces a framework for the description and analysis of such problems and presents a representative task allocation problem for which the standard tools of mechanism design do not suffice. The paper contains several inapproximability results, approximation algorithms under various models and a novel way of constructing optimal solutions under an additional assumption natural to many problems. (W. Noam Nisan, In Proceedings of the 31st Annual ACM Symposium on Theory of Computing (STOC99), and Journal of Games and Economic Behaviour.)

Computationally Feasible VCG Mechanisms shows that for large classes of complex mechanism design problems, all the known general protocols are either intractable or degenerate (arbitrary far from optimal). It then shows a novel generic way of constructing polynomial time solutions. (W. Noam Nisan, The second annual ACM Conference on Electronic Commerce (EC-00).)

Mechanism Design with Incomplete Languages Most of the protocols that emerge from mechanism design theory require the agents to fully describe their utility functions to the mechanism. For complex problems these functions require exponential time and space. As a result, these mechanisms lose their good game theoretical properties. The paper proposes a general solution for this problem. (The third annual ACM Conference on Electronic Commerce (EC'01).)

On Approximating Optimal Auctions The paper studies a fundamental problem in micro-economics called optimal auction design. Results include a 2-approximation for the general case and an almost-optimal auction for reasonable cases. (The third annual ACM Conference on Electronic Commerce (EC'01).)

4 Motivation for future research

Research on the border of computer science and game theory attracts a growing number of scholars from various communities (conferences like a recent Dimacs workshop, the ACM conferences on Electronic Commerce and the importance of game theory within the Artificial Intelligence community demonstrate that). The interest in this field results from both intellectual and practical motives. I conclude this statement with a number of issues which in my opinion will motivate future research in this area.

The need for unified theories Complexity issues are inherent to game theory and economics and are currently absent from these disciplines. Similarly, the "human" ingredient is inherent to many computer science applications. Unifying these (very different) fields is a deep and fascinating challenge and will be the source for many intriguing problems.

Internet protocols and applications The Internet brings together an enormous mass of resources - people, information and computational power. However, despite the great potential, very little cooperation among these entities has emerged. Socio economic approaches foster such cooperation. Future applications of the Internet will presumably exploit this approach. Moreover, the design of protocols for the Internet (e.g. routing with high quality of service) differ significantly from traditional protocol design as the protocols' participants are likely to follow their own personal goals instead of acting as instructed by the designer. Problems that stem from the protocols and applications mentioned above give rise to many algorithmic mechanism design problems. These problems differ from traditional mechanism design problems by their computational ingredients, type of environment, and design objectives. They thus require new ways of thinking.

Economics and electronic commerce In recent years the world economy is changing dramatically as many major economic processes are being automated or semi automated. This gives rise to many problems that involve both computational and economic or game theoretic aspects. Example applications include complex auctions like the Billion $20 FCC auctions, and privatization efforts like the California market for electricity.

Wide area networks Users of wide area networks want their own traffic to be optimized and behave accordingly. This raises many interesting questions that involve both computational and game theoretic ingredients.