Proposed Research Program

Nguyen Kim Thang

My interests primarily lie in Design and Analysis of Algorithms and Game Theory, especially in Algorithmic Game Theory, Approximation and Online Algorithms. Roughly speaking, Online Algorithms have limited access to information, Approximation Algorithms assume limited computational resources, while Algorithmic Game Theory deals with the competition and decentralization of self-interested agents.

The Internet, unlike traditional computing environments, provides a wealth of new arenas for strategic interaction. There is competition for the use of pipelines and routers, for the use of server and processor time, and in the increasingly popular online auctions for advertisements, goods, and services. Not surprisingly, computer scientists have been adopting concepts from game theory, the study of strategic behavior, to analyze computer networks and online markets, and the Internet as a whole. At the same time, computer scientists are also leaving their mark on economics, introducing new ways of understanding the effects of strategic behavior and efficient algorithms for finding equilibria.

In the following, I present my research projects, including short-term, long-term projects and concrete problems which represent small steps toward the goals of projects.

1 Equilibria and Inefficiency

The existence and inefficiency of pure Nash equilibria play important roles in many games. However, pure Nash equilibria do not necessarily exist in games and even they exist, equilibria may have a social objective far from the optimum outcome. The inefficiency [7, Part 3] characterizes the quality of equilibria and two well-known measures are considered: price of anarchy, denoted as PoA (the price of stability, denoted as PoS), which is the ratio between the worst (best) equilibrium and the optimum in term of the social objective. The measures illustrate the loss in efficiency when a system is operated through the competitive interaction of participants.

With the development of the Internet, large-scale autonomous systems have become more and more important. The systems consist of many independent and selfish agents who compete for the usage of shared resources. Every configuration has some social cost, as well as individual costs for every agent. Due to the lack of coordination, the equilibrium configurations may have high cost compared to the global social optimum. Since the behavior of the agents is influenced by the individual costs, it is natural to come up with a *mechanism* that both force the existence of Nash equilibria and reduce the inefficiency. The idea is to try to reflect the social cost in the individual costs, so that selfish agents' behaviors result in a socially desired solution. Designing mechanisms in games to guarantee pure equilibria with small inefficiency and algorithms to find such equilibria is one main branch of my research.

Network Games I am interested in games on networks, especially those that are motivated by real applications, for example Voronoi Games [3], Congestion Games, Connection Games [7, chapters 18, 19]. The first game models the competition between service providers who want to attract as many clients as possible and maximize their profit by strategically choosing a good place to open their facility. The Congestion Game represents daily situations in which people minimize the traffic time to go to work by choosing a route in order to avoid the congestion. The Connection Game models a situation in which players may cooperate to construct roads connecting certain cities and each one looks for different alternatives that minimize the own cost. This latter game attracts a lot of attention in Algorithmic Game Theory community and is one of my currently working project. Formally, given an undirected graphs with costs on the edges, there are n players. Player i wants to connect his source s_i to his sink t_i. An edge e can be used by player i if the edge is entirely bought, meaning that together with other players, player i need to contribute to buy the edge. Each player chooses the path satisfying his connectivity demand as well as minimizing his cost share. The social cost is the total cost of edges that are bought. In optimization, it is the well-known Steiner Forest problem. The most studied way of sharing the cost in the game is the Shapley cost-sharing protocol. Here, the cost of an edge is evenly shared between players using the edge.

The first issue of the game is to answer how powerful the Shapley cost-sharing protocol is. Even though of the simplicity, it is the best known protocol in both theoretical and practical aspects. However, the performance of the Shapley cost-sharing protocol is still unclear. More specifically, one interesting question is whether the PoS of the Connection Game under the Shapley cost-sharing protocol is constant. The second challenging issue would be answering whether there exists a cost-sharing method that induces a constant PoS and in the positive case, how we design such protocol. As the first step in the project, with my co-authors, we consider the Facility Location Games [6]. In Facility Location Games, there is a complete graph and n players. There are costs on the edges and opening costs on nodes. Each player is located on a node and wants to open a facility, possibly sharing with other players. A facility is opened on a node if the total contribution of players who want to use the facility is at least the opening cost of the node. In the game, we use the Shapley cost-sharing protocol, i.e., the cost of a facility is equally split to players using the facility. The cost of a player is the connecting cost (from his own node to his facility) plus his opening cost share (the cost share that he contributes to open the facility). The game can be considered as a simplified model of Connection Games combining with delay cost under the Shapley cost-sharing protocol. We extensively studied the game and get more or less a complete view about the picture. The next step would be understanding the general Connection Games.

Scheduling Games We studied coordination mechanisms for Scheduling Games in which each player is a job and players choose a machine which minimizes their costs, defined as the completion times of jobs. In the game, machines have policies that decide how to schedule jobs. Three models are considered: (i) *non-clairvoyant* means that a machine knows nothing about jobs; (ii) *strongly local policies* means that a machine looks only at the processing time of jobs on it; (iii) *local policies* means that a machine knows all information concerning jobs assigns to it, including the processing times of those jobs on all other machines.

In designing coordination mechanism for Scheduling Games, non-clairvoyant and strongly local policies are well studied, respectively in [4] and in [1]. Nevertheless, the model of local policies is far from well understood. In term of inefficiency, there exists policy that gives PoA as $O(\log^2 m)$. There are many attempts in improving the PoA by designing different policies. Nevertheless, the main difficulty in designing policies lies on the existence of equilibrium. The more sophisticated a policy is, the more complex the behaviors of jobs and consequently, no equilibrium is guaranteed. We are working on the problem, concentrating on the aspect of equilibrium existence. Inspired by the unusual dynamic discovered in [4], we are looking for a dynamic that guarantees the existence of equilibrium and the characterization of such dynamics in order to design policies with small PoA or prove impossibility results by improving the lower bound of the PoA.

2 Algorithmic Mechanism Design

The goal of algorithmic mechanism design [7, Part 2] is to design an *efficient* mechanism, in which the underlying data is unknown, that interacts with rational participants such that *self-interested behavior of participants yields a desirable outcome.* I will carry out research on mechanism design with the purpose of designing mechanism with desired properties (truthful, optimal, etc) depending on the settings.

Truthful mechanism without payment Truthfulness, also known as strategy-proofness in the social choice literature, is a central goal of mechanism design. A *truthful* mechanism is a mechanism in which participants have incentive to report their true private information. According to Gibbard-Satterthwaite impossibility result, in the general setting, payment is ubiquitous in designing truthful mechanisms. However, there are many important environments where money cannot be used as a medium of compensation, due to ethical considerations (for instance, in political decision making) or legal considerations (e.g., in the context of organ donations). It is therefore natural to ask whether it is possible to design truthful mechanisms without payments.

We consider the following specific problem. There is a set of agents on a given graph, each agent is located on a node. The central authority opens a facility (for example, a hospital, a library, etc in a city) based on the locations of agents. Agents may strategically report their locations so that they minimize the distance from their own nodes to the facility that will be opened. The objective of the authority is to design a truthful mechanism (without payment) such that it also minimizes an objective function, such as the total distances of agents to the facility, or the maximum distance among all agent. Without the truthfulness requirement, it is the well-known k-median (k-center) problem. With the truthfulness requirement, it is more complex. The approach to design truthful mechanism consist in sacrificing the optimality of the solution, meaning that we need to tradeoff the truthfulness with the approximation ratio. We are currently working on the problem and got promising results in truthful deterministic mechanisms as well as randomized mechanisms.

Non-dominant mechanism design The previous paragraph describes a concrete on-going work which is in my long-term project on mechanism design. In mechanism design literature, almost all work study dominant strategies, such as (group) strategy-proof. However, due to impossibility results of Arrow, Gibbard-Satterthwaite, Roberts, etc [7], the class of mechanisms with dominant strategies is limited, most of them are VCG-based (Vickrey-Clarke-Groves) mechanisms and computationally inefficient from the algorithmic point of view. The main issue, which is widely considered, is to overcome those impossibility results. The truthful mechanism without payment aims to bypass the negative result of Gibbard-Satterthwaite. One idea to circumvent the Roberts impossibility is to relax the dominant strategy, for example by relaxing truthful behaviors with approximate truthful behaviors – meaning mechanisms that do not require strictly true information from participants but only information close to the true one. Developing appropriate, meaningful solution concepts for non-dominant, computationally efficient mechanisms is my long-term project.

3 Online Algorithms

Online problems are optimization problems dealing with dynamic setting, in which the input is received in an online manner — the input is in form of sequence of requests that are revealed little by little — and in which the output must be made irrevocably with partial or without knowledge about the future. For example, problems such as paging, telephone circuit switching, investment planning and so on are intrinsically online. The issue in online algorithms is that each online output — decisions made with limited information — influences the cost of the overall solution.

Online primal-dual in scheduling Online primal-dual technique is a breakthrough discovered by Buchbinder and Naor [2]. Using that elegant and powerful technique, they solved many longstanding open questions and revealed the nature of online problems of type covering/packing. However, it is not known how to use this technique in scheduling problems. The main difficulty is that we need to deal with the released times and deadlines of jobs. Together with Christoph Durr (from Ecole Polytechnique) and Nikhil Bansal (from IBM Research), we are trying to apply the technique to Scheduling.

Online Auctions Inspired by Internet, online auctions, as the phenomenally-fast growing markets, are the most obvious and interesting motivations for this subject. Maximizing the profit is the most important issue of an company in which decisions must be made without knowledge of future information in the sense of online algorithms. For example, in Adwords market (of Google or Yahoo!), bidders submit values they would pay per click if their advertising contents appear and their limited budgets for a day. A search company needs to choose winning bidders and match the contents of those bidders to advertising slots in such a way that its gain is maximized without exceeding bidders' budgets and without full knowledge about future potential bidders. In a bank, one has to decide how to sell a variety types of stocks at right moments to different clients in order to maximize the profit under the uncertainty of the environment. One of my interests consists in working on specific problems in auctions which is fascinating as it is inspired by real applications and needs mathematical tools and ideas. We have preliminary work [5, 8] that encourage us to continue in this direction.

Random order arrival In many setting, worst-case analysis does not provide useful insights on the performance of algorithms or heuristics. Developing means for predicting the performance of algorithms and heuristics on real inputs is a challenge. I would like to explore the online algorithms in the model where the input is given in random order, in contrast to the traditional worst-case adversary model. In my point of view, random order adversary is a promising next step towards that goal.

References

[1] Yossi Azar, Kamal Jain, and Vahab S. Mirrokni. (almost) optimal coordination mechanisms for unrelated machine scheduling. In *Proc. of the 19th Annual ACM-SIAM Symposium on Discrete Algorithms*, pages 323–332, 2008.

[2] Niv Buchbinder and Joseph Naor. The design of competitive online algorithms via a primal-dual approach. *Foundations and Trends in Theoretical Computer Science*, 3(2-3):93–263, 2009.

[3] Christoph Dürr and Nguyen Kim Thang. Nash Equilibria in Voronoi Games on Graphs. In *Proc. of the 15th Annual European Symposium on Algorithms*, 2007.

[4] Christoph Dürr and Nguyen Kim Thang. Non-clairvoyant Scheduling Games. In *Proc. of the 2nd International Symposium on Algorithmic Game Theory*, 2009.

[5] Christoph Dürr, Łukasz Jeż, and Nguyen Kim Thang. Online scheduling of bounded length jobs to maximize throughput. In *Proc. of the 7th Workshop on Approximation and Online Algorithms*, 2009.

[6] Thomas Dueholm Hansen, Nguyen Kim Thang, and Orestis A. Telelis. Facility location games with fair cost allocation. Submitted, 2009.

[7] Noam Nisan, Tim Roughgarden, Eva Tardos, and Vijay V. Vazirani. *Algorithmic Game Theory.* Cambridge University Press, New York, NY, USA, 2007.

[8] Nguyen Kim Thang. Improved online scheduling in maximing throughput of equal length jobs. Submitted, 2009.