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Research Statement

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The last decade has seen a surprisingly rich interplay between economics, computer science, and game theory. From the economics side, the emergence of the Internet as a central platform to conduct trade has created new types of markets, mainly one-sided auction markets. These electronic markets share many properties with the more classical auction types, on the one hand, but also exhibit several important structural differences. These differences have motivated many studies, aiming to align classic economic theory with the new electronic environment. From the algorithmic side of computer science, the growth of the Internet has lead to new types of distributed agent systems that are characterized by interactions among computers with different ownership and incentives. Many new algorithmic questions are being asked as a result of this development. In contrast to the traditional assumption in computer science, that computers follow protocols and algorithm specifications, we now ask what happens when the input of the algorithm is kept by independent agents, acting selfishly to maximize their own utility. Game theory offers an elegant connection between these two different views, of classical economy vs. classical algorithmic theory. Using game-theoretic tools, a growing community has begun to study models that integrate these two view-points to enable a better understanding of the economic aspects of the Internet era. This community consists of researchers from both economics and computer science, demonstrating a fruitful cooperation between the two disciplines. As a researcher, I belong to this community of algorithmic game theorists. In recent years I have been interested in the following four main research directions, with new results as well as ongoing research and intriguing unsolved questions: Dynamic Mechanism Design, Auctions with Budget Limits, Ascending Auctions for Bidders with Complex Valuations, and Game Theoretic Aspects of Social Networks.

1 Dynamic Mechanism Design

In comparison to traditional markets, one particular key structural difference that the Internet setting posses is the more dynamic nature of the electronic environment, mainly the fact that players dynamically enter and leave the markets, in a highly irregular way. This is in sharp contrast to the assumptions in most of the classic economic theory, were the environment (buyers, sellers, goods) is stable, and the different participants hold correct prior beliefs about this environment. To capture this difference, new models must be constructed and analyzed. In an early work [15], we have studied a model of online auctions, where bidders arrive at different times, and the auction is required to make decisions about each bid as it is received. Such settings occur in computerized auctions of computational resources as well as in other settings. Our cleanest result in [15] is an incentive compatible ("truthful") on-line auction for a large number of identical items. This auction has an optimal competitive ratio, both in terms of sellers revenue and in terms of the total social efficiency obtained.

This work has seen a large volume of follow-ups, by economists (for example [5]) and by computer scientists (see the book chapter [20] on online auctions). However, the vast majority of these works,

including my own, yield direct mechanisms that are rarely seen in reality. Thus, a current research direction that interests me is to try to reconcile theory and practice in this context. In a work in progress [8], joint with Olivier Compte and Ella segev, we study the most simple and popular format in reality: a sequence of English auctions. This format is preferred probably due to a psychological preference for open mechanisms, but it also has several other advantages to such mechanisms. For example, it reduces information revelation of bidders' values, and it is more robust to changes in the utility model. We show that several small variants of this simple auction format are able to obtain the same approximation bounds that all previously suggested non-intuitive auctions obtain. In particular, first, under the assumption that bidders' arrival times are observable, and cannot be manipulated, we show how a simple activity rule drastically improves the guaranteed efficiency of the auction. Second, if arrival times are unobservable, we suggest as a second variant to stop the price ascent when several bidders are still active and choose the winner uniformly at random from this group of bidders. This yields larger competition for future items, that generates a good efficiency guarantee.

I believe that further understanding of this complex dynamic setting is crucially important to the more general understanding of e-commerce over the Internet, and will have more general implications on the theory of mechanism design. We need to introduce additional assumptions that will make the theoretical models even more realistic. One such assumption that I find extremely interesting is that players are boundedly rational and hence cannot fully plan for the future. This assumption is very natural because of the dynamic context, and renders all previously suggested auctions simply irrelevant. I am planning to pursue this research direction in the near future. I have recently received an award from the German Ministry of Education and Research to study this issue, jointly with Sophie Bade from the Max Planck Institute for Collective Goods.

2 Auctions with Budget Limits

The starting point of almost all of auction theory is the set of players' valuations: how much value (measured in some currency unit) does each player assigns to each possible outcome of the auction. When attempting actual implementations of auctions, a mismatch between theory and practice emerges immediately: *budgets*. Players often have a maximum upper bound on their possible payment to the auction – their budget. This budget limit is not adequately expressible in most existing auction theory.

Several of my recent papers address this issue and reveal an interesting state of affairs regarding the possibilities and impossibilities of truthful auction design in the presence of budgets. In [2] we design a Generalized Position Auction for players with private values and private budget constraints. Our mechanism is a careful modification of the Generalized English Auction of [10]. By enabling multiple price trajectories that ascent concurrently, we are able to retrieve all the desired properties of the Generalized English Auction, an auction that was not originally designed for players with budgets. In particular, the ex-post equilibrium outcome of our auction is Pareto-efficient and envy-free. Moreover, we show that any other position auction that satisfies these properties and does not make positive transfers must obtain in ex-post equilibrium the same outcome of our mechanism, for every tuple of distinct types. This uniqueness result holds even if the players' values are fixed and known to the seller, and only the budgets are private.

The setup in the previous paper assumes that bidders have unit-demand. In [9], we study *multi-unit* auctions where the bidders have a budget constraint. Our main result is an impossibility:

there is no truthful auction that always allocates the items in a Pareto-optimal way. To prove the impossibility, we first consider the case of publicly-known budgets. For this case, we identify the *unique* incentive-compatible auction that is Pareto-optimal. In the paper we show how this uniqueness result paves the way to prove the impossibility for the private-budgets case.

Thus, when the bidders' demands expand from unit-demand to multi-unit demand, the Pareto optimal and truthful auctions are possible only if budgets are public knowledge. In a joint work [13] with my student Marina May we show that if demands take even a more general structure, so that items may be complements, the impossibility result (unfortunately) further expands: any deterministic mechanism, for allocating identical items that are complements to budget-constrained bidders, cannot simultaneously satisfy individual-rationality, strategy-proofness, Pareto-efficiency, and no-positive-transfers. This holds even for two bidders, two items, and commonly known budgets; this also generalizes to richer settings.

Despite these impossibilities, it seems extremely important to identify the possibilities that rests with budgets. I plan to advance this aim in three ways. First, I intend to direct attention to randomized mechanisms. It seems possible that randomization can significantly improve the range of possible auctions and, up to now, this methodology was barely examined. Second, I would like to deepen the understanding of the constrained efficiency problem of maximizing efficiency subject to Bayesian incentive-compatibility constraints, as initiated in [19]. Third, I plan to examine what happens if the Pareto optimality assumption is relaxed, and only approximate optimality is required. How far do we need to move from Pareto optimality in order to retrieve the other desired properties?

3 Ascending Auctions for Bidders with Complex Valuations

Auction formats can be categorized as either (1) "sealed-bid auctions", where players submit bids that determine the allocation of goods and the payments, or (2) "open-cry auctions", where players report their demands assuming a given set of item prices, the auctioneer then raises the prices of over-demanded items, and this iterates until an equilibrium outcome is reached. While the classic theory tends to analyze the first type, the second type gains high popularity over the Internet. Electronic auction houses seem to prefer it, perhaps because bidders can "actually feel" the price creation mechanism. However, the theoretical foundations of this type of auctions are less developed, especially for the case where there are many different items, and players value *bundles* of items. I am studying various questions regarding this ascending auction process.

A myopic approach. A Walrasian equilibrium with non-identical indivisible items exists only for small classes of players' valuations (mostly "gross substitutes"), and may not generally exist even with decreasing marginal values. In a work in progress [11] we study a relaxed notion, "conditional equilibrium" (CE), requiring only individual rationality and "outward stability": at given prices additional items will not increase player's utility.

With decreasing marginal values, CE exhibits: (1) Approximate first welfare theorem: the welfare in CE is at least half of the maximal welfare; (2) A natural ascending auction that obtains it; (3) Second welfare theorem: any welfare maximizing allocation has a supporting CE. Thus, CE always exists with decreasing marginal values (whereas Walrasian equilibrium generally does not exist for such common valuations). Additional strategic foundation is provided via a strong connection to Nash equilibria of combinatorial auctions with item bidding. Via this connection we strengthen previous results of [6] for this auction game.

Given these appealing properties we seek a maximal valuation class that ensures CE existence and includes unit-demand valuations. Our main technical results provide upper and lower bounds on such classes. One such class is significantly larger than gross-substitutes, with a limited mixture of substitutes and complements. For three items our bounds are tight, implying uniqueness of this class for this case. Our proofs are constructive, using a "flexible-ascent" auction based on algorithms previously suggested for "fractionally subadditive" valuations. This auction is rather non-standard as players may decrease prices of obtained items as long as their overall price strictly increases.

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A strategic approach. In a joint work with my previous student Sigal Oren [16] we analyze a simultaneous ascending auction with anonymous item prices for two items that are substitutes. This popular format entails increased opportunities for coordination among bidders, since bids are observable and can be used as signaling. This has happened in real auctions, e.g., in the Netherlands 3G Telecom Auction and in the FCC auctions. While it may seem that such bidding harms economic efficiency, we show that side communication may actually improve efficiency: We describe an ex-post sub-game perfect equilibrium with limited communication that is ex-post efficient. In contrast, without communication, we show that there is no ex-post equilibrium which is ex-post efficient in this auction. In this equilibrium, bidders initially report true demands, and then perform a single demand reduction at a certain point, determined using a single message exchanged between the bidders. This limited signaling opportunity resolves the strategic problems of myopic bidding and may improve the social welfare.

Additional future plans: Robustness to inaccuracies in the utility model. Statements of Pareto or welfare optimality of mechanisms always need to be based on some model of the agent-preferences. I conjecture that dynamic mechanisms, like ascending auctions, allow for more freedom in the specification of such models of agents preferences. Thus, statements of optimality of dynamic mechanisms might be less vulnerable to errors in the specification of utilities relative to the case of direct mechanisms. This is a second issue that will be studied with Dr. Bade from MPI.

4 Game Theoretic Aspects of Social Networks

I have been involved in two other research initiatives in the past year, that may advance the study of algorithmic game theory in two additional directions.

In a work with Shay Kutten and our joint post-doc Amitabh Trehan [12], we study composition games for distributed systems. A traditional distributed system is often designed by a central manufacturer and by some central owner. However, increasingly, the components of modern distributed systems have different owners. Moreover, such systems are formed rather distributively, by people teaming up to pool their resources together. For example, many Peer to Peer (P2P) networks are composed of nodes belonging to different persons, who would like to gain resources or knowledge by cooperating. In this work, we consider ways by which people make distributed decisions regarding composition of such systems in an attempt to realize high values. We initiate the evaluation of those ways by analyzing the quality of resulting systems. We concentrate on settings in which a node can increase its utility by connecting to other nodes. However, the node must also pay a cost

that increases with the size of the system. The right balance is achieved by the right size group of nodes. We study the price of anarchy of three intuitive games and show how simple changes in the protocol can improve the price of anarchy drastically. In particular, we identify two important properties for a low price of anarchy: agreement in joining the system, and the possibility of appealing a rejection from a system. We show that the latter property is especially important if there are some pre-existing constraints regarding who may collaborate (or communicate) with whom.

This research project is carried in the newly founded Technion-Microsoft research center. This center aims to encourage new synergies between various disciplines that are broadly related electronic commerce (here, we study game theoretic aspects of distributed systems; Kutten and Trehan brought expertise in distributed computing, while I bring the game-theoretic aspect). In addition to the advantages of collaborating with other scholars, joining the center enabled me to receive funding for students and post-docs. I plan to continue my research activity within the center.

A different aspect of the Internet platform that gradually influences the economic reality is the emergence of electronic social networks. In [1] we study sequential voting in a social network, assuming that each voter has a private preference over the alternatives, but also dislikes to vote against the chosen winner. This model is different than classic sequential voting in two ways: First, there are no informational uncertainties as the quality of the outcome is completely objective. Second, there are new strategic considerations that result from the desire to vote for the winner. We study the game-theoretic properties of this game, and show two main results: (1) In the unique symmetric subgame-perfect equilibrium of this game, herding occurs despite the complete absence of informational uncertainties, and (2) Nevertheless, there are cases in which sequential voting is strictly better than simultaneous voting, in the sense that it chooses the most preferred alternative with higher probability.

This research project was conducted while I was a part-time visiting researcher at Microsoft Research Israel, collaborating with a highly active group of visiting researchers there. This group studies the broader research area of electronic commerce and social networks, and I have been part of that group for the last several months.

5 Summary and Additional Remarks

A grand challenge facing the community of algorithmic game theory today, in my view, is to achieve a better adjustment of theoretical models to the Internet reality. In this research statement I have identified and discussed three different facets of this issue: the dynamic nature of Internet markets, the realistic need to properly insert budgets to the theory of auctions, and the question of how to properly analyze indirect iterative auctions with the goal of developing a complete understanding of their de-facto advantages.

The past several years were successful also for my past research projects, and I wish to give three main examples.

Characterizations of truthful mechanism design for multi-dimensional domains: In his Nobel-winning work, Myerson demonstrated the large possibility space of mechanism-design with single-dimensional types, characterizing truthfulness via simple monotonicity. However, many settings are multi-dimensional and players have different values for various attributes. What kinds of multi-dimensional mechanisms are truthful? In [14] we study this problem in the context of the

computational complexity of mechanisms, and give several characterizations. Parts of this paper were later published in Econometrica [7].

Computationally-efficient Combinatorial Auctions: The multi-dimensionality of combinatorial auctions, where bidders have different values for different bundles of items, raises serious computational problems. In a JACM publication [18] we describe a truthful-in-expectation and computationally-efficient combinatorial auctions with the best possible welfare approximation. This was the first work to completely solve the computational aspect with proper incentives. Following this work, our constructions had applications to several other problem domains. In a second JACM publication [4] we design combinatorial auctions that exemplify how to utilize the interesting solution concept of undominated strategies to obtain computationally-efficient auctions.

Truthful scheduling: In the game-theoretic version of this fundamental problem, a designer assigns tasks to workers, but does not know the time each worker needs for each task. The designer's goal here, of minimizing the makespan, is unusual to mechanism design as it is different from welfare or revenue maximization. In [17] we design various truthful mechanisms with close-to-optimal schedules for a certain challenging special case, showing how to utilize a condition called cycle-monotonicity to construct truthful mechanisms with good approximation guarantees. In [3], we show that *anonymous* mechanisms for the general problem domain must obtain far-from-optimal outcomes. A preliminary version of this work won an outstanding paper award at EC'09.

These projects receive continuous recognition, many citations and follow-ups, and are being taught in many advanced courses on algorithmic mechanism design given at top universities, e.g. at Harvard (by Parkes), Stanford (by Roughgarden), and Berkeley (by Papadimitriou). The new synergies between computer science and economics, developed by the community of algorithmic game theory, also affect fundamental research questions being pursued by mainstream theoretical economic research. Two examples for such topics, which are directly related to my own research, are robust mechanism design and dynamic mechanism design. My publication list well demonstrates this interplay between the economics and computer science communities, with papers in the top economics and game theory journals, as well as papers in the top computer science journals and conferences.

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