ELECTRONIC MARKET DESIGN

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Introduction

During the week of June 9—14 the Dagstuhl Seminar on Electronic Market Design was held. The aim of the seminar was to provide researchers and practitioners in economics, mathematics and computer science working on topics in electronic trading, auction design, mechanism design and artificial intelligence with a platform where they could interchange results and ideas and profit from the achievements of each other's field of expertise.

Electronic market design is a new field of research that builds on theories from various established fields. The challenges of market design are to create rules for trading interaction, in particular for auctions, that lead to economically desired allocations of items and payments, and that are immune against manipulation by strategic behavior of the participants. When market design is implemented electronically, in principle more complex market designs are realizable because of computerized transactions. However, computational complexity increases rapidly and excludes therefore certain designs. These problems have led to plenty of research in computational issues of market design, which was widely presented at the seminar. At the same time, most electronic markets will still have human participants interacting with them. The impact of design on their behavior cannot completely be captured by theoretical models, but requires an empirical or experimental investigation. Finally, every (electronic) market design has to be embedded into a broader set of issues, for example the industrial environment in which it takes place, asking for careful economic considerations of the impact of design on market outcome in the short and the long term.

The Dagstuhl seminar on electronic market design has successfully provided a forum, in which world-wide leading researchers from these fields could exchange their ideas. The working atmosphere was excellent, in particular thanks to the perfect local organization in Dagstuhl. In the following we will give a short overview of the main topics addressed during the seminar and the impact the workshop has on the development of the field.

Scientific Overview

The seminar included 37 lectures as well as a rump session on diverse problems such as winner determination for combinatorial auctions, the trade-off between the informational and economic efficiency of markets, implementation of incentive compatible mechanisms as well as analyses of the strategic consequences of the design of real-life auctions on and off the Internet as they currently exist, in particular the UMTS spectrum auctions, eBay, and the electricity auctions.

Because of the diverse background of the participants the central issues in electronic market design were approached from many different angles. Specifically the following four different aspects of market design were discussed extensively.

1. *economic efficiency* From an economic perspective auctions and markets are instruments that can be used to allocate scarce goods in an efficient way, meaning that the goods are to be divided among the agents participating in the auction or the economy in such a way that the overall welfare of the agents is maximized. In for example combinatorial auctions or markets for perishable goods (with severe time

constraints) enforcing economic efficiency may be a complicated or sometimes even impossible task.

2. *strategic behavior* Market design relies on the assumption that the agents engaged in trade within the market behave according to the ideas envisaged by the designer. Thus it is of crucial importance that the design is immune to manipulation by the participants in the market. Especially in electronic markets, where buyers and sellers engage in anonymity, shill bidding, sniping, and false-name bidding do often occur. It is an important task for designers to develop trading mechanisms that discourage manipulation of this type.

3. *computational complexity* Trade that takes place in a complex environment, such as a combinatorial auction or market for heterogeneous goods, puts a heavy computational burden on the buyers and sellers in such an environment. One of the problems market designers face is to develop trading mechanisms for these complex situations that are still transparent from the trader's perspective and nevertheless guarantee outcomes that also are sufficiently close to efficiency in the economic sense of the word.

4. *evidence from the field* Case studies from the day-to-day ongoing practice of electronic trade such as the sales on eBay, the FCC and UMTS auctions and the auctions for surplus electricity indicate that electronic market design is an area of research that is and still very much needs to be developed further. The call for faster, simpler and more robust designs is heard everyday and everywhere throughout the internet!

Related to each of these topics, most recent research results were presented. In comparison to a previous seminar, organized by the same organizers at the International Institute of Infonomics in the Netherlands (see www.etrade.infonomics.nl/workshop), several scientific breakthroughs were presented. For example the development of fast algorithms for combinatorial auctions has reached a strength such that these auctions can be used by the FCC in future spectrum auctions in the US. Experimental and empirical results let us better understand the strategic behavior in online auctions. Several presentations illustrated new iterative auctions with bundle bids. Furthermore, new insights in the interplay of complexity of communication, computation, and bidders decision making were presented, for example by Daniel Lehmann and Noam Nisan and their students from Hebrew University, researchers from Universiteit Maastricht, and from Tuomas Sandholm and his team from Carnegie Mellon University. Notably, most of these results strongly benefit from the interplay between economics, game theory and computer science. Without the fruitful exchange of ideas between disciplines, like it has been facilitated by this Dagstuhl seminar, many of them would not have been possible. Finally, this seminar contributed to lay out a research agenda on electronic market design for the following years. For example, it remains still a big puzzle how integer programming theory can be successfully applied to understand auction markets with budget constraints.

Impact

Very remarkable for the seminar was the intensity of communication between very different fields, and between junior and senior researchers. This communication is even more remarkable given the heterogeneous scientific background of the participants. Almost half of the lectures were given by young researchers, many of them still PhD students. For many young colleagues, this was likely the first time that they got the opportunity to meet the senior

colleagues from the field. All presentations enjoyed a large audience, and presenters got plenty of feedback, despite a dense schedule. At the same time it was observable that the tutorial speakers as well as other senior speakers had put a big effort into their presentations, such that PhD students could get a maximum out of it.

It has to be said that the field is still not very well developed inside Europe, at least when it comes to the theoretical foundation of electronic markets. European research seems to focus more on the adoption of technologies in business settings. Nevertheless several research groups were present (e.g., Maastricht, Karlsruhe, Kiel, München, Cambridge), including PhD students from these groups. For these groups, and for others in Europe hopefully too, the seminar provided certainly a large stimulation to catch-up with the international research agenda.

Partly inspired by the seminar, a European consortium on the field of market design is currently emerging, and preparing project proposals for the sixth framework program (see www.etrading-europe.org).

ABSTRACTS

CONCURRENT AUCTIONS ACROSS THE SUPPLY CHAIN

Moshe BABAIOFF (Hebrew University Jerusalem) and Noam Nisan

With the recent technological feasibility of electronic commerce over the Internet, much attention has been given to the design of electronic markets for various types of electronically-tradable goods. Such markets, however, will normally need to function in some relationship with markets for other related goods, usually those downstream or upstream in the supply chain. Thus, for example, an electronic market for rubber tires for trucks, will likely need to be strongly influenced by the rubber market as well as by the truck market.
In the talk I will present our paper were we design protocols for exchange of information between a sequence of markets along a single supply chain. These protocols allow each of these markets to function separately, while the information exchanged guarantees efficient global behavior across the supply chain. Each market form a link in the supply chain operates as a double auction, where the bids on one side of the double auction come from bidders in the corresponding segment of the industry, and the bids on the other side are synthetically generated by the protocol to express the combined information from all other links in the chain. The double auctions in each of the markets can be of several types, and we study several variants of incentive compatible double auctions, comparing them in terms of their efficiency and of the market revenue.

ALLOCATION OF MULTI-ATTRIBUTE AND CONFIGURABLE OFFERS

Martin BICHLER (IBM T.J. Watson Research Center – Yorktown Heights)

Multi-attribute reverse auctions allow negotiation over price and qualitative attributes such as color, weight, or delivery time. Previous work assumes that multi-attribute bids are described as attribute value pairs and that the entire demand is purchased from a single supplier. We will introduce research issues in multi-attribute bid evaluation, and will then focus on configurable multi-attribute offers. Configurable offers allow suppliers to specify multiple values and price markups for each attribute. In addition, suppliers can define configuration and discount rules in form of propositional logic statements. We will present an MIP formulation of the resulting allocation problem and an implementation.

SELLING INDIVISIBLE OBJECTS

Sushil BIKHCHANDANI (UCLA, USA)

An exchange economy with a single seller endowed with indivisible objects and several buyers is formulated as a linear program (LP). Although buyers' reservations values are non-additive, the problem of achieving an efficient allocation has a linear structure in which the pricing functions expressing duality are non-linear in the objects constituting the packages. The interconnections between LP formulations of the exchange economy, Walrasian equilibrium, and the core are established. Any efficient auction solves an LP formulation of the exchange economy. Ascending price auctions are primal dual algorithms for solving the LP formulation. Ascending price implementations of the Vickrey auction exist if and only if buyers are substitutes in the sense of Shapley (1962).

AUCTIONS WITH SEVERELY BOUNDED COMMUNICATION

Liad BLUMROSEN (The School of Engineering and Computer Science, The Hebrew University) and Noam Nissan

We study auctions with severe bounds on the communication allowed: each bidder may only transmit t bits of information to the auctioneer. We consider both welfare-maximizing and revenue-maximizing auctions under this communication restriction. For both measures, we determine the optimal auction and show that the loss incurred relative to unconstrained auctions is mild. We prove non-surprising properties of these kinds of auctions, e.g. that discrete prices are informationally efficient, as well as some surprising properties, e.g. that asymmetric auctions are better than symmetric ones.

HOW EFFECTIVE ARE ONLINE REPUTATION MECHANISMS? AN EXPERIMENTAL INVESTIGATION

Gary E. BOLTON (Penn State University and Harvard Business School, USA), Elena Katok and Axel Ockenfels

Online reputation –"feedback"– mechanisms aim to mitigate the moral hazard problems associated with spatially distant trading between strangers by providing traders with the type of information available in small groups where members are frequently involved in one another's dealings. We compare trading in a market in which feedback is available to a market in which it is not, as well as to a market in which the same people interact with one another repeatedly (partners market). We find that, while the reputation mechanism induces quite a substantial improvement in transaction efficiency, it also exhibits a kind of public goods problem in that, unlike the partners market, the benefits of trust and trustworthy behavior go to the whole community and are not completely internalized. We discuss the implications of this perspective for improving these systems.

ELECTRICITY MARKET DESIGN: THE GOOD, THE BAD, AND THE UGLY

Peter CRAMTON (University of Maryland, USA)

This paper examines the market design experience from electricity restructuring. Electricity provides an excellent case-study of many critical design issues in electronic markets more broadly. Examples of good market design and bad market design serve to illustrate basic lessons of effective market design. The importance of understanding incentives in designing the market is emphasized. Finally, the Federal Energy Regulatory Commission's proposed Standard Market Design is critically evaluated.

WINNER DETERMINATION IN COMBINATORIAL AUCTIONS: A LAGRANGEAN RELAXATION-BASED EXACT ALGORITHM

Thomas ELENDNER (Universität Kiel)

We present an exact algorithm for the general case of winner determination in combinatorial auctions. Upper bounds are generated via Lagrangean Relaxation ; lower bounding is done by a simple greedy heuristic. The algorithm is a depth first search branch and bound scheme.

THE USE AND ABUSE OF SHILL BIDDING

Vincent FELTKAMP (International Institute of Infonomics)

Auctions are the source of the majority of internet frauds. One of the tricks that is included in this statistic is shill bidding, where a seller in an auction bids in his/her own auction. With the advent of the online auction, this trick has become dramatically easier to pull off. All kinds of measures have been taken to minimize the risk of shill bidding on auction sites. However, from an economics point of view, it is not so clear that shill bidding is worse than setting a reserve price. We show that in some situations, it is not harmful and it can even be useful to allow shill bidding to take place.

INCENTIVE COMPATIBLE MULTI UNIT COMBINATORIAL AUCTIONS

Rica GONEN, Yair BARTAL and Noam NISAN (Hebrew University, Jerusalem)

The problem we deal with in this paper is a multi-unit combinatorial auction: there are n types of goods for sale, and for each i there are k_i units of good i. We are interested in the case where each bidder desires a relatively small number of units of each good. The simplest case is where each type of good has exactly k units (i.e. $k_i = k$ for all I), and each bidder desires at most a single unit of each good. We call this a combinatorial auction with k-duplicates. In the more general case, we assume that there exists a lower bound θ and an upper bound Θ such that each bidder desires at most Θk_i units of good I and either no unit of good I or at least θk_i units of good i. In particular the simple case is a special case with $\theta = \Theta = 1/k$. All our results are derived for the general case.

We first characterize incentive, compatible mechanisms for combinatorial auctions (both multi-unit, and regular), for the general case that bidders are not limited to be non-single minded.

Then we show that as a purely computational problem, a combinatorial auction with k duplicates is NP-hard to approximate to within a factor of $O(n^{1/(k+1)-\varepsilon})$. This generalizes the known inapproximability result for combinatorial auctions (k = 1). We then proceed to derive an incentive compatible general algorithm that achieves a nearly matching approximation factor. From that general algorithm two cases are derived: An On-Line algorithm and an Off-Line algorithm, both incentive compatible for non-single minded bidders with nearly matching approximation factor.

PRIVATE VALUE SINGLE ITEM BISECTION AUCTION

Elena GRIGORIEVA (International Institute of Infonomics, Maastricht, The Netherlands), Jean-Jacques Herings, Rudolf Müller and Dries Vermeulen

We study in this paper a new second-price auction for selling a single item. The auction shares with a sealed bid, second price auction the computational efficiency, while it shares with the English ascending price auction its iterative nature. While the English auction requires a minimum bid increment in order to finish in reasonable time, the bisection auction has always a running time that is logarithmic in an upper bound of the bidders valuations. The auction starts with a lower and upper bound on the valuations. Bidders report their demand at a current ask price by sealed bids. The price sequence starts with the middle of the two values. If more than one bidder announces demand the price increases to the middle of the current price and the current upper bound. The lower bound becomes the current price. If at most one bidder announces demand at the current price, the price decreases to the middle of the current lower bound and the current price. The new upper bound is the current price. We model the

bisection auction as an extensive form game and show that truth telling is a weakly dominant strategy.

AUCTIONS FOR HOMOGENEOUS GOODS WITH INCREASING RETURNS: EXPERIMENTAL COMPARISON OF ALTERNATIVE "DUTCH" AUCTIONS

Elena KATOK (Penn State University) and Alvin E. Roth

Multi-unit auctions of goods that may have increasing returns to scale—i.e. goods such that bidders may value multiple units at a higher unit price than single units—present challenges for both auctioneers and bidders. We compare two commonly used auction formats for selling multiple homogeneous objects, both sometimes called "Dutch" auctions, in a set of value environments that potentially subject bidders to the "exposure" and "free riding" problems. We find that overall the descending price auction, best known for its use in the Dutch flower auctions, is robust and performs well in a variety of environments, although there are some situations in which the ascending uniform-price auction similar to the one used by internet auctions such as eBay, better avoids the free riding problem. We discuss the factors that influence each mechanism's performance in terms of the overall efficiency, the informational requirements, the seller's revenue, and the buyer's profit.

COMPETITIVE MARKET-BASED ALLOCATION OF CONSUMER ATTENTION SPACE : CONCEPTUAL SYSTEM, AGENT ARCHITECTURE, AND LEARNING SOFTWARE AGENTS

Han LA POUTRE (CWI – Amsterdam), S. Bohte, E. Gerding and P.J. 't Hoen

Key-words: market mechanism, agent system, on-line learning of bids in an auction, agent architecture, attention space distribution (e.g. advertisements).

The amount of attention space available for recommending suppliers to consumers on e-commerce sites is typically limited. We present a competitive distributed recommendation mechanism based on adaptive software agents for efficiently allocating the ''consumer attention space", or banners. In the example of an electronic shopping mall, the task is delegated to the individual shops, each of which evaluates the information that is available about the customer and his or her interests (e.g. keywords, product queries, and available parts of a profile). Shops make a monetary bid in an auction where a limited amount of "consumer attention space" for the arriving consumer is sold.

Each shop is represented by a software agent that bids for each customer. This allows shops to rapidly adapt their bidding strategy to focus on customers interested in their offerings.

For various basic and simple models for on-line customers, shops, and profiles, we demonstrate the feasibility of our system by evolutionary simulations as in the field of agent-based computational economics (ACE).

We subsequently present a scalable and extensible software agent architecture and prototype for distributed market-based allocation of the customer attention space. The agents can operate in multiple markets concurrently. The protocol for communication between the agents is designed for optimal performance of the system.

Finally, we present two types of adaptive software agents that learn bidding-strategies based on feedback by the market mechanism for the various customers. One type is based on neural networks and strategy exploration heuristics. The other type is based on evolutionary computing techniques, where bidding strategies are evolved based on on-line feedback by the market mechanism.

The mechanism we describe is not limited to the example of the electronic shopping mall, but can easily be extended to other domains.

EQUILIBRIUM STRATEGIES FOR BIDDERS WITH HARD VALUATION PROBLEMS

Kate LARSON (Carnegie Mellon University, Pittsburgh, USA) and Tuomas Sandholm

We investigate deliberation and bidding strategies of agents who are limited in their deliberation capabilities by either deadlines or cost and who are participating in auctions. The agents do not a priori know their valuations for the items being auctioned. Instead they devote computational resources to compute their valuations. We present a normative model of bounded rationality where deliberation actions of agents are incorporated into strategies and deliberation equilibria are analyzed for standard auction protocols. We show that even in settings such as English auctions where information about other agents' valuations is revealed for free by the bidding process, agents may still compute an opponents' valuation problems, incurring a cost, in order to determine how to bid. We compare the costly computation model of bounded rationality with the model where computation is free but limited. For the English and Vickrey auctions the equilibrium strategies are substantially different in that in free but limited computation agents will not compute on each others' problems, but under the costly model there exist instances where agents may compute on each others' problems in equilibrium. It can be concluded that the model of bounded rationality impacts the agents' equilibrium strategies and must be considered when designing mechanisms for computationally limited agents.

COMPETITIVE ANALYSIS OF ON-LINE AUCTIONS

Ron LAVI (University of Jerusalem) and Noam Nisan

We consider auctions in a setting where the different bidders arrive at different times and the auction mechanism is required to make decisions about a bid as it is received. Such auctions may be called for in many computational settings as well as other settings.

Specifically, K identical items are sold in an auction. Each bidder i learns his valuation at a certain time and makes a bid at that time. The bidders' valuation may be any downward sloping function $b_i(*)$ where $b_i(q)$ represents his private valuation for the q-*th* item received. The auction mechanism must decide, as the bid is received (and before seeing future bids), how many items to allocate to this bidder and at what price.

Our first result is a complete characterization of *incentive compatible* online auctions, i.e. such online auctions where the truth is dominating for all bidders.

DEFINITION 1. *An online auction is called ``based on supply curves'' if before receiving the i-th bid it fixes a non-decreasing function (supply curve) $p_i(q)$ based on previous bids and,*

1. *The quantity q_i sold to bidder i is the largest value q satisfying $b_i(q) \geq p_i(q)$.*
2. *The price paid by agent I equals the sum over j from 1 to q_i of the prices $p_i(j)$. I.e. agent I pays for each unit received the minimum amount required to win it.*

For a divisible good (i.e. K large) q_i becomes the unique solution of the equation $b_i(q) = p_i(q)$ and the price p_i becomes the integral over q from 0 to q_i of $p_i(q)$.

THEOREM 1. *Any auction that is based on supply curves is incentive compatible. Furthermore, all incentive compatible auctions are based on supply curves.*

We then employ a competitive distribution-free analysis of online auctions. Specifically, we assume that bidder's valuations all belong to some range $b_i(q) \in [\underline{p}\ldots p^*]$, and we do not assume any probability distribution on them. We also assume that the seller has reservation price $\underline{p}$. We compare, in the worst case, the revenue and the social efficiency achieved by the online auction to those obtained by the Vickrey auction. Using results from online algorithms

we determine the optimal competitive supply curve. The most interesting case is for a large number K of identical items – treated as a continuum. For this case the optimal competitive supply curve is defined as follows: $p_i(q) = f(q+\Sigma q_j)$, where $f(*)$ is the solution to the differential equation introduced in [R. El-Yaniv, A. Fiat, R. Karp and G. Turpin, Competitive Analysis of Financial Games, in Proc. Of the 33rd FOCS]. This is c-competitive, where c is the solution to the equation $c = ln(((p*/p)-1)/(c-1))$.

THEOREM 2. *For any sequence of valuations, the online auction based on the optimal competitive supply curve achieves (A) social efficiency which is at least Opt/c where Opt is the optimal social efficiency obtainable for the given valuations; and (B) revenue which is at least Vic/c where Vic is the revenue raised by the Vickrey auction for the given valuations. Furthermore, no other online auction achieves a better competitive ratio.*

For comparison, we also analyze this auction in the case of uniformly distributed valuations in the range [1,2]. In this case, for two bidders, this auction achieves expected revenue of 1.32… as compared with 1.33… for the Vickrey auction.

WHAT IS THERE WHEN THERE IS NO WALRASIAN EQUILIBRIUM ?

Daniel LEHMANN (University of Jerusalem)

Kelso and Crawford showed that there is always a Walrasian equilibrium among gross-Substitutes agents. Gul and Stacchetti showed that, given any agent who is not gross-substitutes, there are very simple agents which, together with it, constitute a society in which no Walrasian equilibrium exists. Bikhchandani and Mamer have shown that there is a Walrasian equilibrium if and only if the integral gap of a certain Integer Program is zero.
These results suggest that most markets do not possess a Walrasian equilibrium. I will argue that the ubiquity of prices speaks for a positive role for prices even in the absence of a Walrasian equilibrium. I will show that the integral gap for a set of submodular agents is at most 2. I will suggest that markets exhibiting small integral gaps possess "almost-equilibria". Different possible notions of "almost-equilibrium" will be discussed. More questions will probably be asked than answers provided.

LEARNING THE EMPIRICAL HARDNESS OF COMBINATORIAL AUCTION WINNER DETERMINATION

Kevin LEYTON-BROWN (Stanford University), Eugene Nudelman and Yoav Shoham

We propose a new approach to understanding the algorithm-specific empirical hardness of NP-Hard optimization problems, focusing the combinatorial auction winner determination problem when solved by ILOG's CPLEX software. We consider nine widely-used problem distributions and sample randomly from a continuum of parameter settings for each distribution. First, we contrast the overall empirical hardness of the different distributions. Second, we identify a large number of distribution-nonspecific features of data instances and use statistical regression techniques to learn, evaluate and interpret a function from these features to the predicted hardness of an instance.

AUCTIONS AND EFFICIENCY

Eric MASKIN (Institute for Advanced Study, Princeton, NJ, USA)

This paper reviews the literature on auctions that achieve an efficient allocation of goods (an allocation that maximizes "social surplus") when buyers have "interdependent values," i.e., each buyer's valuation for a given combination of goods may depend on private information held by other buyers.

AUCTIONS WITH SOME BUNDLING

Moritz MEYER-TER-VEHN (Universität Mannheim)

We study multi-object auction mechanisms by introducing a bundling parameter, that enhances the probability that all objects will be sold to one bidder. This raises competition on one hand but causes inefficiency on the other. By maximizing expected revenue over this parameter we find that, for any number of objects and bidders, both the pure bundling auction and separate auctions for the single objects are revenue-inferior to an auction that involves some bundling. This implies that the revenue maximizing auction is never efficient.

ASCENDING AUCTIONS WITH PACKAGE BIDDING

Paul MILGROM (INVITED SPEAKER) and Larry Ausubel

A family of ascending package auction models is introduced in which bidders may determine their own packages on which to bid. In the proxy auction (revelation game) versions, the outcome is a point in the core of the exchange economy for the reported preferences. When payoffs are linear in money and goods are substitutes, sincere reporting constitutes a Nash equilibrium and the outcome coincides with the Vickrey auction outcome. Even when goods are not substitutes, ascending proxy auction equilibria lie in the core with respect to the true preferences. Compared to the Vickrey auction, the proxy auctions generate higher equilibrium revenues, are less vulnerable to shill bidding and collusion, can handle budget constraints much more robustly, and may provide better ex ante investment incentives.

EX-POST IMPLEMENTATION WITH INTERDEPENDENT VALUES

Benny MOLDOVANU (Universität Mannheim)

During the Infonomics workshop on electronic market design, there were many talks about multi-object auctions and CGV mechanisms – all in models with private values. This presentation is designed for the "computer-science and OR" to learn more about recent developments in a more general model.

Keywords: generalized Clarke-Groves-Vickrey mechanisms, multi-object auctions, ex-post equilibria, interdependent values.

A CHARACTERIZATION OF SYMMETRIC EX-POST EQUILIBRIA IN VICKREY-CLARKE-GROVES COMBINATORIAL AUCTIONS

Ron Holzman and Dov MONDERER (Technion, Haifa)

In a combinatorial auction, a number of goods are being offered for sale to a group of agents whose preferences for the various bundles of goods may not be separable (i.e., the utility that an agent derives from owning two of the goods need not be the sum of the utilities that he derives from owning each of them separately). A Vickrey-Clarke-Groves (VCG) mechanism for such an auction requires the agents to reveal their preferences (which are their private information), and based on the announced preferences it specifies an efficient allocation of the goods and the amount to be paid by each agent to the seller. The main feature of these mechanisms is that, thanks to a judicious choice of the monetary transfers, revealing one's true preferences is a dominant strategy.

A major difficulty that arises in applying VCG mechanisms is the prohibitive communication complexity: when there are m goods, every agent has to communicate to the organizer 2 to the power m numbers, the utilities he assigns to each and every bundle of goods. This cannot be helped if the agents are to use their dominant strategies. However, it was shown in Holzman, Kfir-Dahav, Monderer & Tennenholtz that there exist other, non truth-telling strategies, which have a lower communication complexity and still possess a high degree of incentive compatibility (The use of these strategies typically entails a loss of economic efficiency. The tradeoff between economic efficiency and communication efficiency was investigated in

detail in Holzman et al.). Namely, each of these strategies induces a symmetric ex post equilibrium. This means that if an agent assumes that the other agents use this strategy, it is optimal for him to use it as well, regardless of the agent's preferences.
The strategies considered in Holzman et al. were all of the following simple type: a certain subfamily Σ of the family of all bundles of goods is designated in advance, and the strategy $f\Sigma$ is to report only the (true) utilities the agent assigns to bundles in Σ, with the interpretation that his utility for any other bundle B equals the maximum of his reported utilities over all subsets C of B which lie in Σ. It was shown in Holzman et al. that the strategy $f\Sigma$ induces a symmetric ex post equilibrium if and only if the subfamily Σ is a quasi field, i.e., is closed under complements and disjoint unions. This means that when Σ is a quasi field –and only then—the agents will be willing to use the strategy $f\Sigma$ not only because it reduces the communication burden on the system but also because it is selfishly rational for them to do so. In this case, the resulting equilibrium was called a bundling equilibrium.
This provides a characterization of equilibrium strategies within the class of strategies of type $f\Sigma$, but left open the possibility that there might exist other strategies, not of this type, which also induce symmetric ex post equilibria. In this paper, we rule out this possibility and obtain a complete characterization of all strategies in VCG combinatorial auctions which induce a symmetric ex post equilibrium. In other (less precise) words, we prove that every equilibium is a bundling equilibrium.

TRUTHFUL APPROXIMATION MECHANISMS FOR RESTRICTED COMBINATORIAL AUCTIONS

Ahuva MU'ALEM (University of Jerusalem) and Noam Nissan

When attempting to design a truthful mechanism for a computationally hard problem such as combinatorial auctions, one is faced with the problem that most efficiently computable heuristics can not be embedded in any truthful mechanism (e.g. VCG-like payment rules will not ensure truthfulness).
We develop a set of techniques that allow constructing efficiently computable truthful mechanisms for combinatorial auctions in the special case where only the valuation is unknown by the mechanism (the single parameter case). For this case we extend the work of Lehmann, O'Callaghan, and Shoham, who presented greedy heuristics, and show how to use IF-THEN-ELSE constructs, perform a partial search, and use the LP relaxation. We apply these techniques for several types of combinatorial auctions, obtaining truthful mechanisms with provable approximation ratios.

ALLOCATION IN COMBINATORIAL AUCTIONS USING AN ORACLE MODEL

Noam NISAN (University of Jerusalem)

Most algorithmic and computational work done regarding allocation (winner determination) in combinatorial auctions used the normal Turing-machine model: the bids (valuations) are given in some bidding language; allocation algorithms were expected to run in polynomial-time (in the length of the bids); and impossibility results were proofs of NP-hardness.
In this talk we consider a "concrete-complexity" approach to allocation in combinatorial auctions: the bids are given as black boxes (oracles); algorithms can query these black boxes and are expected to make a polynomial number of queries (in the number of items and bidders); and impossibility results prove that an exponential number of queries are needed.
We first argue that this model sheds light on a number of questions including complexity on Turing-machines and information revelation complexity. We then discuss the types of access to the valuation oracles that make sense, and focus our attention on "demand oracles".
We prove several possibility and impossibility results in this model. These results deal with approximation factors, with submodularity and gross-substitutes, with procurement auctions,

with multi-unit auctions, and more. Some of these results are from my joint work with Lehmann & Lehmann, with Segal, and with Bartal & Gonen.

SNIPING AND THE RULES FOR ENDING SECOND-PRICE INTERNET AUCTIONS

Axel OCKENFELS (Universität Magdeburg)

In second price internet auctions with a fixed end time, such as those on eBay, many bidders 'snipe', i.e., they submit their bids in the closing minutes or seconds of an auction. Late bids of this sort are much less frequent in auctions that are automatically extended if a bid is submitted very late, as in auctions conducted on Amazon. We propose a model of second price internet auctions and show that sniping in a fixed deadline auction can occur even at equilibrium in private value auctions, as well as in common value auctions. The reason is that very late bids have a positive probability of not being successfully submitted, and this opens a way for bidders to implicitly collude and avoid bidding wars. Sniping in fixed-deadline auctions also arises away from equilibrium, as a best reply to incremental bidding. However, the strategic advantages of sniping are eliminated or severely attenuated in auctions that apply the automatic extension rule. The strategic differences in the auction rules are reflected in experimental and field data. There is more sniping on eBay than on Amazon, and this difference grows with experience.

JEL C73, C90, D44. Keywords: Internet auctions, field study, experimental study.

NETWORKS AS GAMES

Christos H. PAPADIMITRIOU (University California, Berkeley, USA)

No abstract available.

MINIMAL REVELATION VCG MECHANISMS FOR COMBINATORIAL AUCTIONS

David C. PARKES (Harvard University)

Preference elicitation in the classic direct-revelation Vickrey-Clarke-Groves (VCG) mechanism is oblivious. Every agent's dominant strategy is to provide complete information about its preferences to the auctioneer. Yet, the cost of preference elicitation is often the key bottleneck in business applications of combinatorial auctions. Recently, a number of iterative VCG mechanisms have been proposed, in which preference elicitation is adaptive.

It is often possible to implement the efficient allocation without agents revealing, or even computing, complete preferences for all outcomes. In this paper we formalize the concept of minimal preference revelation, and define information certificates for statements about agent preferences. We show for a large class of efficient combinatorial auctions, it is both necessary and sufficient to elicit a certificate for competitive equilibrium (CE) prices. This informational correspondence is useful because queries to elicit minimal certificates for CE prices are easy to construct, and because it identifies the core role of price-based iterative mechanisms, such as iBundle, in the design of minimal revelation combinatorial auctions. In addition, fundamental connections between CE outcomes and VCG payments lead to a coherent integration of incentive considerations into minimal-revelation mechanism design.

BUNDLE VALUATIONS

Sasa PEKEC (Duke University, Durham, USA)

A serious analysis of any complex trading system has to address strategic behavior of its participants. While implementing such trading systems, take combinatorial auctions as an example, have plenty of their own design issues that have to be tackled and that have a strong combinatorial optimization flavor, there is an added level of difficulties that one has to deal

with when approaching analysis of (equilibrium) bidding strategies. In particular, one might get stuck with an assumption that bidders are capable of evaluating all possible combinations that they are allowed to bid on. However, assessing utilities for all 2^n-1 possible nonempty subsets of n objects (that one could submit bids on) might be highly impractical (e.g., an upcoming FCC auction will be a sale of 12 licences, which means that a telecom executive might be forced to come up with 4095 valuations).

I will concentrate on the problem of defining valuations of all possible subsets of n objects. There is a large literature adopting methodological utility function approach that usually aims to define the form of a utility function given some "acceptable" axioms. Surprisingly, apart from Luce's work on joint receipt and utilities that capture superadditivity in the case of n = 2 objects (e.g., see R.D. Luce, Utility of Gains and Losses: Measurement-Theoretic and Experimental Approaches, 2000), little has been known about this. In general, this theme seems to have an appeal beyond its practical importance and its relevance in any analysis of equilibrium behavior in complex market mechanisms. For example, understanding subset valuations is of critical importance in designing pricing strategies for bundled goods.

ASSET SHARING AMONG ARMY DIVISIONS : AN EXAMPLE OF A MARKET MECHANISM FOR OPTIMAL NEAR-TERM UTILIZATION OF LONG-TERM ASSETS

Charles W. POLK (Net Exchange, San Diego)

Increasing combat readiness is the primary goal of a U.S. Army division when it is not deployed; namely, when it is at its home base. Each division possesses a set of long-lived assets with which it trains, yet no division is supplied with all of the assets it could productively use to increase its combat readiness. Divisions are encouraged to loan assets among themselves to increase the combat readiness of each, and they are given access to military airlift resources to handle the logistics required to implement these asset loans. Both the asset loans and the provision of airlift resources are coordinated through a centralized command and control system.

These loans and their transport must be alterable in response to the occasional foreign deployment emergency, which can remove troops, assets, and airlift from the training scenario.

We model this allocation problem among a group of geographically distributed divisions and airlift transport commands. The divisions are distinguished by their ability to convert training into combat readiness -- elite, average, below average. A division's "type" is most clearly known only to itself; motivating a standard moral hazard analysis of this problem. Added to this are the stochastic shocks of occasional emergency deployments. Given this environment, we posit a valuation function for the U.S. Department of Defense and examine two alternative allocation mechanisms: the command and control status quo process and a decentralized market-based process.

The market-based process takes the form of a two-stage combinatorial exchange system. In the first stage, multilateral asset loans are arranged ahead of time for the next year of training, including the provision of airlift resources. In the second stage, training periods progress during the year under the risk and occurrence of foreign deployments; thus, re-trading needs to be facilitated. In both stages, the combinatorial exchange process is many-to-many and is assisted by simple software tools/agents embedded in the process.

Simulation results between the two allocation mechanisms indicate that the market-based system provides a 25% to 50% value increase over the status quo, while reducing the use of airlift resources.

Demonstration runs, using human participants, support these simulation results. This research is ongoing. The specific application will be enhanced over the balance of 2002. Analogous

asset sharing scenarios, such as bandwidth and electric power, will also be examined using these same approaches.

PREFERENCE ELICITATION IN COMBINATORIAL AUCTIONS

Tuomas SANDHOLM (CMU Pittsburgh) and B. Hudson

This talk would present the material from the following four papers that have been written on this new topic.

EFFECTIVENESS OF PREFERENCE ELICITATION IN COMBINATORIAL AUCTIONS

Combinatorial auctions where agents can bid on bundles of items are desirable because they allow the agents to express complementarity and substitutability between the items. However, expressing one's preferences can require bidding on all bundles. Selective incremental preference elicitation by the auctioneer was recently proposed to address this problem [Conen & Sandholm 2001], but the idea was not evaluated. In this paper we show, experimentally and theoretically, that automated elicitation provides a drastic benefit. In all of the elicitation schemes under study, as the number of items for sale increases, the amount of information elicited is a vanishing fraction of the information collected in traditional "direct revelation mechanisms" where bidders reveal all their valuation information.
Most of the elicitation schemes also maintain the benefit as the number of agents increases. We develop more effective elicitation policies for existing query types. We also present a new query type that takes the incremental nature of elicitation to a new level by allowing agents to give approximate answers that are refined only on an as-needed basis. In the process, we present methods for evaluating different types of elicitation policies.

PARTIAL-REVELATION VCG MECHANISM FOR COMBINATORIAL AUCTIONS

Winner determination in combinatorial auctions has received significant interest in the AI community in the last 3 years. Another difficult problem in combinatorial auctions is that of eliciting the bidders' preferences. We introduce a progressive, partial-revelation mechanism that determines an efficient allocation and the Vickrey payments. The mechanism is based on a family of algorithms that explore the natural lattice structure of the bidders' combined preferences. The mechanism elicits utilities in a natural sequence, and aims at keeping the amount of elicited information and the effort to compute the information minimal. We present analytical results on the amount of elicitation. We show that no value-querying algorithm that is constrained to querying feasible bundles can save more elicitation than one of our algorithms. We also show that one of our algorithms can determine the Vickrey payments as a costless by-product of determining an optimal allocation.

MINIMAL PREFERENCE ELICITATION IN COMBINATORIAL AUCTIONS

Combinatorial auctions (CAs) where bidders can bid on bundles of items can be very desirable market mechanisms when the items sold exhibit complementarity and/or substitutability, so the bidder's valuations for bundles are not additive. However, in a basic CA, the bidders may need to bid on exponentially many bundles, leading to difficulties in determining those valuations, undesirable information revelation, and unnecessary communication. In this paper we present a design of an auctioneer agent that uses topological structure inherent in the problem to reduce the amount of information that it needs from the bidders. An analysis tool is presented as well as data structures for storing and optimally assimilating the information received from the bidders. Using this information, the agent then narrows down the set of desirable (welfare-maximizing or Pareto-efficient) allocations, and

decides which questions to ask next. Several algorithms are presented that ask the bidders for value, order, and rank information. A method is presented for making the elicitor incentive compatible.

DIFFERENTIAL-REVELATION VCG MECHANISMS FOR COMBINATORIAL AUCTIONS

Combinatorial auctions, where agents can submit bids on bundles of items, are economically efficient mechanisms for selling items to bidders, and are attractive when the bidders' valuations on bundles exhibit complementarity and/or substitutability. Determining the winners in such auctions is a complex optimization problem that has received considerable research attention during the last 4 years. An equally important problem, which has only recently started to receive attention, is that of eliciting the bidders' preferences so that they do not have to bid on all combinations [Conen & Sandholm 2001]. Preference elicitation has been shown to be extremely effective in reducing revelation [Hudson & Sandholm 2002]. In this paper we introduce a new family of preference elicitation algorithms. The algorithms in this family do not rely on absolute bids, but rather on relative (differential) value information. This holds the promise to reduce the revelation of the bidders' valuations even further. We develop a differential-elicitation algorithm that finds the optimal allocation of items to the bidders, and as a side-effect, the Vickrey payments (which make truthful bidding incentive compatible). We also present two auction mechanisms that use differential elicitation: the bitwise decrement mechanism and the difference decrement mechanism.

DYNAMIC DOUBLE AUCTIONS

Mark SATTERTHWAITE (Kellogg School of Management, Evanston, USA) and Artyom Shneyerov

Consider a large decentralized, dynamic market with an infinite horizon in which both buyers and sellers have private information concerning the value of trading. A large number of traders enter the market at the beginning of each period. The private value each buyer places on a single unit of the homogeneous, indivisible good is independently drawn from a distribution F. The private cost each seller places on his single unit of the good is independently drawn from a distribution G. Each period each buyer is matched with a seller and the pair bargains using a bilateral double auction. If the buyer succeeds in purchasing the one unit of the good that the seller is offering, then both leave the market with their realized utility. If they fail to trade, then with an exogenous probability δ each trader becomes discouraged and leaves the market with zero utility. Traders who do not leave the market move to the next period and are anonymously rematched. We solve for steady-state, perfect Bayesian equilibria. As δ becomes small, then the market in effect becomes large for each trader because, in expectation, he can stay in the market a long time—attempting with many different partners to complete a trade on favorable terms—before he becomes discouraged. We derive conditions under which all equilibrium allocations, as $\delta \to 0$, converge to the competitive allocation.

THE DESIGN OF THE UMTS/IMT-2000 SPECTRUM AUCTIONS IN THE UK AND GERMANY

Stefan SEIFERT (Universität Karlsruhe, Germany)

Auctions are an important tool as a licensing mechanism. They are suited to raise public revenues without the trade-off of deadweight losses and are supposed to allocate licenses efficiently. Unfortunately, however, it is not clear which auction design works best for the regulator, i.e. collecting maximal revenues and placing the licences in the hands of those who provide the most value to the economy. This paper describes an experiment analyzing two

auction designs, namely the ones chosen for awarding UMTS licenses in the UK and in Germany, and compares them with respect to revenues and efficiency. In the experiment, the German design leads to higher revenues while the UK design is more attractive for the bidders. Findings regarding efficiency are only weakly significant and depend on the concept of efficiency that is applied.

IT'S NOT YOUR FATHER'S MECHANISM DESIGN

Yoav SHOHAM (Stanford University)

No abstract available.

PRACTICAL ISSUES ON LARGE-SCALE COMBINATORIAL AUCTION DESIGN

(R.J. Gibbens and Richard STEINBERG (Cambridge University)

We examine the computational complexity of the bidder and auctioneer problems in the auction design proposed in Kelly and Steinberg (2000). We complement the design proposed there with a detailed specification of the tasks involved, allowing us to derive precise statements of their computational complexity. In the case of the auctioneer's tasks, we translate our specification into working code. We use this code to explore the way in which the auctioneer's problem scales with the size of the auction. We include demonstrations of the auctioneer's code running on large-scale auctions of practical interest.

APPROXIMATE WINNER DETERMINATION AND SINGLE ITEM PRICING FOR COMBINATORIAL AUCTIONS

R. Kwon, L.H. UNGAR (University of Pennsylvania) and G. Anandalingam

We present a mathematical programming approximation approach for problems such as combinatorial auctions, where repeated winner determinations are required. Most recent methods rely on exhaustive search and hence are exponential in worst case time complexity. We develop a two phase method, AWDA, where the first phase is a primal-dual type approximation algorithm that rapidly computes an initial feasible solution and the second phase is a refinement procedure that uses the dual of the LP relaxation of the winner determination problem and a greedy heuristic to improve upon the solution from the first phase. We provide novel performance guarantees for AWDA, and show that it achieves high solution quality, scales well in the number of items and bids, and is up to three orders of magnitude faster than CPLEX MIP solver 7.0 on representative problems. Equally importantly, AWDA provides approximate single item prices These prices are constructed based on the primal allocation, and can help bidders evaluate item bundles. They also support new package discovery in iterative combinatorial auctions such as iBundle.

BRANCH-AND-PRICE AND NEW TEST PROBLEMS FOR SPECTRUM AUCTIONS

Sven DE VRIES (TU München)

When combinatorial bidding is permitted in Spectrum Auctions like the upcoming FCC auction #31, then the resulting winner-determination problems can be huge (when expressed in the usual XOR-encoding as a setpacking-problem). For the solution of these difficult problems we implemented a branch-and-price algorithm that exploits the structure of the XOR-of-OR-bidding-language as used by the FCC. As there were no suitable realistic test-problems so far, we constructed from the round-by-round-results of FCC auction #4 a set of a couple of thousand realistic test problems each involving 99 items and more than 2^{41} combinations with different values. These problems are substantially more difficult than most of the previously used benchmark problems, many of which can be solved by out-of-the-box-CPLEX already in the root-node. Nevertheless, our algorithm is able to solve all of them

within few minutes. For auction #31, the FCC is going to use a code that is based on the presented work, but extended and adapted to the details of the FCC-rules for this auction.

EXPLORING BIDDING STRATEGIES FOR MARKET-BASED SCHEDULING

Michael P. WELLMAN (University of Michigan), Jeffrey K. MacKie-Mason, Daniel M. Reeves and Sowmya Swaminathan

A market-based scheduling mechanism allocates resources indexed by time to alternative uses based on the bids of participating agents. Agents are typically interested in multiple time slots of the schedulable resource, with value determined by the earliest deadline by which they can complete their corresponding tasks. Despite the strong complementarities among slots induced by such preferences, it is often infeasible for various reasons to deploy a mechanism that coordinates allocation across all time slots (e.g., a combinatorial auction). We explore the case of separate, simultaneous markets for individual time slots, and the strategic problem it poses for bidding agents. Investigation of the straightforward bidding policy and its variants indicates that the efficacy of particular strategies depends critically on preferences and strategies of other agents, and that the strategy space is far too complex to yield to general game-theoretic analysis. For particular environments, however, it is often possible to derive constrained equilibria through evolutionary search methods.

THE EFFECT OF FALSE-NAME BIDS ON COMBINATORIAL AUCTIONS

Makoto YOKOO (NTT Communications Science Laboratories, Kyoto, Japan)

Internet auctions have become an especially popular part of Electronic Commerce (EC). Various theoretical and practical studies on Internet auctions have already been conducted (Monderer & Tennenholtz 1998; Monderer & Tennenholtz 2000; Sandholm 1996; Wurman, Wellman & Walsh 1998). Among these studies, those on combinatorial auctions have lately attracted considerable attention (Fujishima, Leyton-Brown & Shoham 1999; Klemperer 1999; Rothkopf, Pekec & Harstad 1998; Sandholm 1999). Although conventional auctions sell a single good at a time, combinatorial auctions sell multiple goods with interdependent values simultaneously and allow the bidders to bid on any combination of goods. In a combinatorial auction, a bidder can express complementary/substitutable preferences over multiple goods. By taking into account such preferences, economic efficiency can be enhanced.

Although the Internet provides an excellent infrastructure for executing combinatorial auctions, we must consider the possibility of new types of cheating. For example, a bidder may try to profit from submitting false bids under fictitious names such as multiple e-mail addresses. Such an action is very difficult to detect since identifying each participant on the Internet is virtually impossible. We call a bid made under a fictitious name a *false-name bid*. Also, we call protocol *false-name-proof* if truth-telling without using false-name bids is a dominant strategy for each bidder.

The problems resulting from collusion have been discussed by many researchers (McAffee & McMillan 1992; Milgrom & Weber 1982; McAffee & McMillan 1987; Milgrom 2000). Compared with collusion, a false-name bid is easier to execute on the Internet since getting another identifier such as an e-mail address is cheap. We can consider false-name bids as a very restricted subclass of collusion.

A concept called *group-strategy-proof* is proposed to study another restricted subclass of general collusion (Muller & Satterthwaite 1985; Moulin & Shenker 1996). Group-strategy-proof and false-name-proof are independent concepts, i.e., a group-strategy-proof protocol is not necessarily false-name-proof, and vice versa.

In this work, we analyze the effects of false-name bids on combinatorial auction protocols. The obtained results can be summarized as follows.

The Vickrey-Clarke-Groves (VCG) mechanism (Vickrey 1961; Clarke 1971; Groves 1973), which is strategy-proof and Pareto efficient if there exists no false-name bid, is not false-name-proof.

There exists no false-name-proof combinatorial auction protocol that satisfies Pareto efficiency.

We identify one sufficient condition where the VCG mechanism is false-name-proof, i.e., a surplus function is *concave* over bidders.

Furthermore, we identify a distinctive class of combinatorial auction protocols called a Price-oriented, Rationing-free (PORF) protocol, which can be used as a guideline for developing strategy-false-name proof protocols. A PORF protocol is automatically guaranteed to be *strategy-proof*, i.e., for each agent, declaring its true evaluation values is an optimal strategy regardless of the declarations of the other agents. Furthermore, if a PORF protocol satisfies additional conditions, the protocol is also guaranteed to be *false-name-proof*.
The characteristics of a PORF protocol are as follows. For each agent, the price of each bundle of goods is presented. This price is determined based on the declared evaluation values of other agents, while it is independent of its own declaration. Then, each agent can choose the bundle that maximizes its utility independently of the allocations of other agents (i.e., rationing-free).
We develop several instances of PORF protocols that are false-name proof and examine their characteristics.