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Theory of Internet Auctions

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Abstract— **Electronic Commerce (EC) is a promising field for applying agent and Artificial Intelligence technologies. This article shows an overview of the theory of Internet auctions. First, we explain the basic terms and concepts used in auction and game theory literature. Then, we describe various auction protocols and examine the theoretical characteristics of these protocols.**

I. INTRODUCTION

In this article, we give an overview of the theory of Internet auctions. Internet auctions have become an integral part of Electronic Commerce (EC) and a promising field for applying agent and Artificial Intelligence technologies. Commercial auction sites such as eBay have been very successful and continue to expand. The Internet provides an excellent infrastructure for executing much cheaper auctions with many more sellers and buyers from all over the world. On the other hand, since Internet auctions are open to the general public, it is important to design auction protocols that provide some theoretical supports for its outcome or robustness against various types of fraud. Studies on designing auction protocols that can achieve socially desirable outcomes have been actively pursued in the field of microeconomics [8].

In this article, we first illustrate issues in auction studies through an example (Section II). Then, we explain the basic terms and concepts used in auction literature (Section III). Next, we describe various auction protocols (Section IV) and examine the theoretical characteristics of these protocols (Section V).

II. EXAMPLE

Let us start with a simple example to illustrate the issues in auction studies (this example is based on the scenario described in Reference [11]).

- A customer picks up a cell phone and dials a call. Each of the long-distance carriers responds with a price quote for the call at that moment. These carriers do not need to use fixed rates; they can dynamically change the prices according to the current traffic and other factors. The computer in the telephone automatically chooses the carrier based on the price quotes.

A reasonable method for choosing the carrier is to choose the one that offers the lowest quote, and the customer pays the price that is equal to the lowest quote. This method is called *first-price sealed-bid* auction. For example, if MCI bids 18 cents, AT&T bids 20 cents, and Sprint bids 23 cents

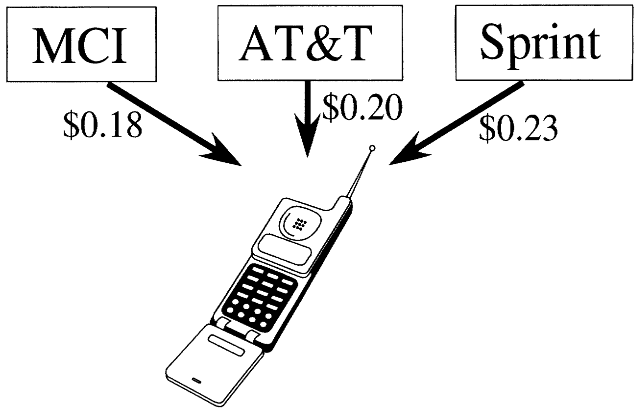

Fig. 1. Auction among Long-distance Carriers

(Figure 1), then MCI wins and provides the service at 18 cents.

Although it is difficult to consider any reasonable alternatives, applying this method in practice involves certain difficulties. For each carrier, setting the right value for its quote is very difficult. Ideally, the quote should be its true cost plus an appropriate profit. However, we cannot define what is an appropriate profit. In reality, each carrier wants to maximize its profit, but if it loses, it cannot gain any profit.

For each carrier, estimating the possible quotes of the other carriers as precisely as possible becomes crucial. Thus, it seems likely that each carrier would try to spy on the quotes of other carriers by such tactics as using dummy customers. If a carrier fails to estimate the quotes of other carries and increases its quote too high, e.g., MCI increases its quote to 21 cents, then MCI would fail to win the right to provide the service. This would also be disadvantageous for the customer since he/she would miss the chance to receive the service at a lower price.

Is it possible to avoid such situations? Actually, by slightly modifying the rule for deciding the price, we can guarantee that a carrier has no incentive to do spying and truthfully declares its true cost. The modified rule is as follows.

- The computer in the telephone chooses the carrier that offers the lowest quote, and then that carrier provides the service. However, the customer pays the price that is equal to the *second lowest* quote.

In the previous example, the winner is still MCI, but the customer pays 20 cents, i.e., the price that is equal to the second lowest quote submitted by AT&T. This method is called *second-price sealed-bid* auction, or *Vickrey* auction [16], which was proposed by W. Vickrey, one of the Nobel

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Prize winners in 1996.

By using this method, spying on the quotes of other companies is totally useless. For MCI, spying on AT&T's quote and then increasing its own quote is meaningless since the price it receives does not change as long as it wins.

This method might sound unreasonable from the customer's side since the customer is required to pay 20 cents even though there is a quote of 18 cents. However, by using this method, for each company, submitting its true cost without adding any profit becomes the best strategy; it can still obtain some profit when it wins. More specifically, the quote submitted by each company will change according to the protocol we use. No company will submit its true cost if we use the first-price protocol. Actually, W. Vickrey proved that under certain assumptions, the expected price the customer pays becomes identical among several auction protocols, including the first-price and second-price auctions [16].

This example involves the problem of designing rules that satisfy certain desirable characteristics when multiple, self-interested agents make decisions as a group (e.g., which company should provide the service, how much the customer should pay). Such a problem is called a *mechanism design* problem and has been an active research field in microeconomics and game theory [8]. Designing rules that are guaranteed to achieve certain properties, such as robustness against cheating, will become more and more important with the advance of Electronic Commerce. In this article, we are going to give a more detailed description of the theory of auctions, which is an important sub-class of mechanism design studies.

III. PRELIMINARIES

Auctions are used for allocating goods, tasks, resources, etc. Participants in an auction include an auctioneer (usually a seller) and bidders (usually buyers). In the previous example, the auctioneer is a buyer and bidders are the sellers of a particular task. An auction has well-defined rules that enforce an agreement between the auctioneer and the winning bidder. Auctions are often used when a seller has difficulty in estimating the value of the auctioned good for buyers.

One desirable characteristic that an auction protocol (or any group decision making rule) should satisfy is *Pareto efficiency*. A situation s obtained by an auction protocol is called Pareto efficient if there exists no other situation s', in which at least one participant prefers s' to s while other participants are indifferent between s and s' or prefer s' to s. If there exists such an s', it is clear that s' is better than s, since everybody thinks s' is better than or at least equally good as s.

For simplicity, we assume that each participant's utility is represented as a quasi-linear form [8]. In a quasi-linear utility, the utility of a buyer who obtains a good is represented as the difference between the evaluation value of the allocated good and the payment for the allocated good. When a buyer cannot obtain a good, we assume that his/her utility is 0. By assuming that each participant has a quasi-linear utility, in a Pareto efficient allocation, the social surplus, i.e., the sum of all participants' utilities including the auctioneer, is maximized. In a more general setting, Pareto efficiency does not necessarily mean maximizing the social surplus. In an auction setting, however, participants can transfer money among themselves, and the utility of each participant is quasi-linear; thus the sum of the utilities is always maximized in a Pareto efficient allocation.

The buyer's evaluation value of a good can be classified into the following three categories.

- Private value
- Common value
- Correlated value

In a private value auction, each participant knows his/her own preference, and his/her evaluation value of a good is independent of the other participants' evaluation values. An example is the sale of an antique to people who will not resell it.

On the other hand, in a common-value auction, the bidders have an identical value of the auctioned good. If this common value is public, there is no need to hold the auction. However, if bidders do not know the exact value and have different estimations, holding an auction makes sense. A typical example is bidding for US treasury bills.

The correlated-value auction lies between these two extreme cases, i.e., the bidder's value of a good depends partly on his/her own preferences and partly on the other's values for it. The two extreme cases are often used to make theoretical analyses tractable.

Auctions can be classified into three types according to the number of items/units auctioned.

- Single item, single unit
- Single item, multiple units
- Multiple items

When multiple items are auctioned, even if we assume private value auctions, we must consider the interdependencies among the values of multiple items. For example, items such as tea and coffee can be considered *substitutable*, i.e., we usually need one of them, but not both at the same time. On the other hand, we can consider tea and sugar to be *complementary*, i.e., having both at the same time can boost their utilities compared with having them separately.

In this article, we use the following terms that are widely used in game theory literature.

Strategy: the way of selecting an action by a bidder, i.e., how to select the bid.

Dominant strategy: a best strategy against any possible strategy of other buyers.

Dominant strategy equilibrium: If each buyer has a dominant strategy, the combination of these dominant strategies is called the dominant strategy equilibrium.

Nash equilibrium: A combination of buyers' strategies is called a Nash equilibrium if each strategy is the best response to the other buyers' strategies.

By definition, a dominant strategy equilibrium is also a Nash equilibrium, but not vice versa.

IV. Auction Protocols

In this section, we are going to describe several representative auction protocols.

A. Single item, single unit auctions

a) English (open-cry):

Protocol rule: Each bidder is free to raise his/her bid. When no bidder is willing to raise, the auction is closed. The highest bidder wins the item at the price of his/her bid.

Strategy: A bidder's strategy depends on his/her own evaluation value, the estimated evaluation values of the other bidders, and the current and past bids of bidders.

Dominant strategy (in private value auctions): If his/her bid is not the current highest bid, always bid an amount slightly higher than the current highest bid and stop when his/her private value is reached.

In the dominant strategy equilibrium, the bidder with the highest evaluation value wins and pays the value of the second highest evaluation value plus a small amount. The obtained result is Pareto efficient.

b) First-price sealed-bid:

Protocol: Each bidder submits one bid without knowing the others' bids. The highest bidder wins the item and pays the price of his/her bid.

Strategy: A bidder's strategy depends on his/her own evaluation value and the estimated evaluation values of the other bidders.

Dominant strategy: There is no dominant strategy in general.

If we put certain assumptions on the distributions of bidders' evaluation values, a Nash equilibrium can be found. For example, assume there are only two bidders, and the evaluation value of each bidder is chosen from a uniform distribution between \$0 and \$100. In this case, for each bidder, bidding half of his/her evaluation value becomes a Nash equilibrium. If a bidder bids more, the winning probability increases, but the expected utility upon winning decreases. If a bidder bids less, the winning probability decreases, but the expected utility upon winning increases. Choosing half of his/her evaluation value becomes the best response, as long as the other bidder uses the same strategy. Also, if there exist N bidders, bidding $(N-1)/N$ of his/her evaluation value becomes a Nash equilibrium.

c) Dutch (descending):

Protocol: The auctioneer starts from a very high price and continuously lowers the price until a bider stops. The bidder takes the item at that price.

Strategy: A bidder's strategy depends on his/her own evaluation value and the estimated evaluation values of the other bidders.

Dominant strategy: There is no dominant strategy in general.

Although this protocol and the first-price sealed-bid auction protocol seem very different, these two protocols are *strategically equivalent*, i.e., for a set of bidders' strategies in the first-price sealed-bid auction, there exists a set bidders' strategies in the Dutch auction that gives identical outcomes for all situations, and vice versa. At first glance, a bidder obtains more information in the Dutch auction than in the first-price sealed-bid auction, but this is not true. The information that nobody stopped before the current price does not affect the decision of whether to stop at the current price.

Dutch auctions are actually used in Dutch flower markets and the Ontario tobacco auctions. Also, the time discounting policy used in some bookstores, i.e., the discount becomes large as time passes and the item remains unsold, can be regarded as a variation of the Dutch auction.

d) Second-price sealed-bid (Vickrey):

Protocol: Each bidder submits one bid without knowing the others' bids. The highest bidder wins the item and pays the price that is equal to the second highest bid.

Strategy: A bidder's strategy depends on his/her own evaluation value and the estimated evaluation values of the other bidders.

Dominant strategy (in private value auctions): Bidding his/her true evaluation value is the dominant strategy. This property is called *incentive compatibility*.

In private value auctions, the obtained results become basically identical to the English auction, i.e., the bidder with the highest evaluation value wins the item and pays the price that is equal to the second highest evaluation value (plus a small amount in the English auction). The obtained allocation is Pareto efficient.

B. Single-item, multi-unit auctions

In a single-item, multi-unit auction, if each bidder needs only one unit, we can use a straightforward generalization of the previously described protocols. For example, the second-price sealed-bid auction can be generalized to the $M+1$-st price auction. In this protocol, if there are M units of an identical item, then from the first to M-th highest bidders win, and each pays the price that is equal to the $M+1$-st highest bid. In this protocol, as in the Vickrey auction, bidding his/her true evaluation value becomes the dominant strategy.

On the other hand, a protocol in which the first to M-th highest bidders win, and each pays the price that is equal to the M-th highest bid, is called a uniform price auction or M-th price auction[1].

On the other hand, if each bidder may require multiple units, we must consider the interdependencies among the values of multiple units, as in multi-item auctions.

C. Multi-item auctions

We are going to describe two auction protocols that can handle multiple items simultaneously, i.e., the *simultaneous multiple round* auction and the *generalized Vickrey Auction (GVA)* protocol.

The simultaneous multiple round auction can be considered a generalized version of the English auction. In the

[1] Please note that the uniform price auction is sometimes called *Dutch* in auctions of government bonds, as well as at some Internet auction sites including eBay.

simultaneous multiple round auction, each bidder submits a sealed-bid for each item. Bidding occurs over rounds. The result of the round is announced before the next round starts. The auction is closed when nobody is willing to bid up from the previous round. The highest bidder for each item gets the item at the price of his/her bid. Each bidder can withdraw a bid by paying a penalty.

The Generalized Vickrey Auction Protocol (GVA) is one instance of the Clarke mechanism [1], [8], and a generalized version of the second-price sealed-bid auction protocol. It can handle multiple items with interdependent values.

The outline of the GVA is described as follows.

1) For each possible allocation G, each bidder x declares its evaluation value $v_x(G)$. The reported evaluation values may or may not be true.
2) The GVA chooses the allocation G^* that maximizes the social surplus, i.e., the sum of all bidders declared evaluation values.

$$G^* = \arg\max_G(\sum_y v_y(G))$$

3) The payment of bidder x (represented as p_x) is calculated as follows.

$$p_x = \sum_{y \neq x} v_y(G^*_{\sim x}) - \sum_{y \neq x} v_y(G^*)$$

Here, $G^*_{\sim x}$ is the allocation that maximizes the sum of all bidders' evaluation values except bidder x defined as follows.

$$G^*_{\sim x} = \arg\max_G(\sum_{y \neq x} v_y(G))$$

In the GVA, we can assume that bidder x pays the decreased amount of the other bidders' social surplus resulting from his/her participation.

In the following, we show an example of how the GVA works.

Example 1: Let us assume that three bidders are participating in an auction of two different items, A and B, and declare the following evaluation values. The evaluation values of a bidder are denoted by a triplet: (the value for A alone, the value for B alone, the value for A and B together).

- bidder 1: ($6, $0, $6)
- bidder 2: ($0, $0, $8)
- bidder 3: ($0, $6, $6)

The evaluation values of bidder 2 are all-or-nothing, i.e., having only one item is useless. In this case, A is allocated to bidder 1 and B is allocated to bidder 3. The payment of bidder 1 is calculated as follows. If bidder 1 does not participate, both items are allocated to bidder 2, and the social surplus is $8. When bidder 1 does participate, bidder 3 obtains B and the social surplus except for bidder 1 is $6. Therefore, bidder 1 pays the difference $\$8 - \$6 = \$2$. The obtained utility of bidder 1 is $\$6 - \$2 = \$4$. The payment and utility of bidder 3 are identical to those of bidder 1.

V. Characteristics of Auction Protocols

A. Single unit, single item auctions

As described above, the first-price sealed-bid auction and Dutch auction are strategically equivalent. Also, in private value auctions, the results obtained by the English auction and the second-price sealed-bid auction are identical in the dominant strategy equilibrium. Also, the revenue equivalence theorem [16] states that under certain assumptions, in a Nash equilibrium, the seller's expected revenue is the same in these four auction protocols.

B. Multi-item auctions

The simultaneous multiple round auction can be considered a generalized version of the English auction, and the GVA is a generalized version of the second-price sealed-bid auction. In single item, single unit, private value auctions, these two protocols obtain identical results. On the other hand, in multi-item auctions, while the GVA has a dominant strategy equilibrium (where truth-telling is the dominant strategy), the simultaneous multiple round auction does not have a dominant strategy equilibrium even if we allow bidding on combinations of items. Thus, the obtained results in these two auctions are different in general. One reason that the simultaneous multiple round auction does not have a dominant strategy equilibrium is the *free-rider* problem.

For example, suppose that bidder 1, bidder 2, and bidder 3 are bidding for two different items A and B. Bidder 1 bids $3 for A (where the true evaluation value is $6), bidder 3 bids $3 for B (where the true evaluation value is $6), and bidder 2 bids $7 for a combination of A and B (where the true evaluation value is $8). After the first round, they learn each other's bids. In the second round, both bidder 1 and bidder 2 have to decide whether to raise the bid. Each bidder hopes that the other bidder raises the bid, so he/she can get the item without increasing the payment, i.e., he/she can get a free ride. If neither bidder raises the bid (hoping to get a free ride), both items are allocated to bidder 2 and a Pareto efficient allocation cannot be achieved.

On the other hand, in the GVA, as in the second-price sealed-bid auction, for each bidder, declaring true evaluation values for each item and each combination of items is the dominant strategy, and a Pareto efficient allocation can be achieved.

The intuitive explanation of why truth-telling is the dominant strategy in the GVA is as follows. In the GVA, items are allocated so that the social surplus is maximized. In general, the utility of society as a whole does not necessarily mean maximizing the utility of each participant. Therefore, each participant might have an incentive for lying if the group decision is made so that the social surplus is maximized.

However, the payment of each bidder in the GVA is cleverly determined so that the utility of each bidder is maximized when the social surplus is maximized. In Figure 2, we illustrate the relationship between the payment and utility of bidder 1 in Example 1. The payment of bidder 1 is defined as the difference between the social surplus when bidder 1

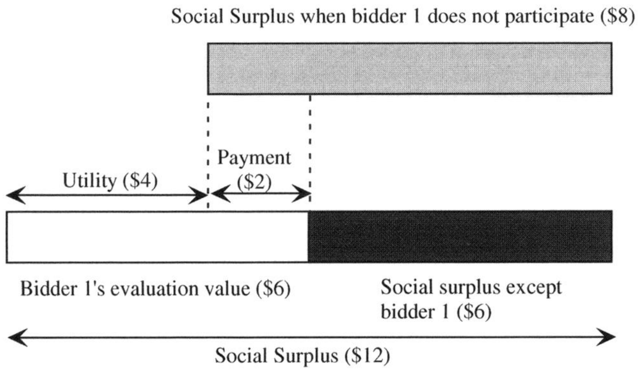

Fig. 2. Utilities and Payments in the GVA

does not participate (i.e., the length of the upper shaded bar) and the social surplus except bidder 1 when bidder 1 does participate (the length of the lower black bar), i.e., $\$8 - \$6 = \$2$.

On the other hand, the utility of bidder 1 is the difference between the evaluation value of the obtained item and the payment, which equals to $\$6 - \$4 = \$2$. This amount is equal to the difference between the length of the total lower bar and the upper bar. Since the length of the upper bar is determined independently from bidder 1's declarations, bidder 1 can maximize his/her utility by maximizing the length of the lower bar. However, the length of the lower bar represents the social surplus. Thus, bidder 1 can maximize his/her utility when the social surplus is maximized. Therefore, bidder 1 does not have an incentive for lying, since the group decision is made so that the social surplus is maximized.

Although the GVA has these good characteristics (Pareto efficiency and incentive compatibility), as described later in this article, these characteristics cannot be guaranteed when bidders can submit *false-name* bids. Also, to execute the GVA, the auctioneer must solve a complicated optimization problem. Various studies have been conducted to introduce search techniques, which were developed in the Artificial Intelligence literature, for solving this optimization problem [3], [14].

C. Common value auctions and winner's curse

In common value auctions, there is the possibility of an interesting phenomenon called *winner's curse*. Each bidder does not know the exact value of the auctioned item in common value auctions. Therefore, unless the winner has exceptionally good information, the winner tends to be the bidder who was most optimistic and made the largest positive error. If a bidder raises his/her bid close to his/her estimated evaluation value, there is a chance that the expected utility becomes negative.

Let us show a simple example. Assume that two buyers 1 and 2 are participating in a first-price sealed-bid auction. Also, let us assume that each buyer's estimated value of the auctioned item (represented as e_1, e_2) can be a true value v, an over-estimated value $v + 100$, or an under-estimated value $v - 100$. These three cases are equally likely, i.e., the possibility for each is $1/3$. Although each bidder knows that his/her estimated value is determined in this way, he/she does not know whether the estimated value is true, over-estimated, or under-estimated.

Let us consider what happens if bidder 1 thinks in the following way.

- My estimated value e_1 is correct on average; thus if I bid a value $e_1 - 40$, my expected utility would be 40.

Unfortunately, this expectation is not correct. Let us assume that bidder 2 uses the same strategy and that in the case of a tie the winner is determined by a tossed coin. There are 9 possibilities for the combination of the two bidders' bids. Let us represent one combination as (bidder 1's bid, bidder 2's bid). There are three cases in which bidder 1 certainly wins, i.e., $(v+60, v-40)$, $(v+60, v-140)$, and $(v-40, v-140)$. The probability of each combination is $1/9$. In the first two cases, the utility of bidder 1 is -60, since he/she pays more than the true value. In the last case, his/her utility is 40. There are three cases where ties are broken by tossing a coin, i.e., $(v+60, v+60)$, $(v-40, v-40)$, and $(v-140, v-140)$. The probability that bidder 1 wins is $1/18$ for each, and the utility of bidder 1 is $-60, 40$, and 140. By calculating the sum of these cases, his/her expected utility becomes negative, i.e., $-20/9$.

If there are more bidders, the situation becomes more serious. The bidder wins basically only in the case where his/her bid is $v + 60$, and his/her expected utility becomes close to -60. Also, if the opponent is less cautious (e.g., bidding $e_2 - 10$), the expected utility for bidder 1 becomes smaller.

D. Collusion and auctioneer's lie

Let us assume that in a private value auction bidder 1's evaluation value is 20 and the other bidders' evaluation values are 18. In the English auction, the following collusive agreement is possible: bidder 1 bids 6 and the others bid only to 5 (in compensation for a small side payment from bidder 1). This agreement is strong since if other bidders bid more than 5, bidder 1 can detect this fact and can raise his/her bid. Also, in the second-price sealed-bid auction, the following collusive agreement is possible: bidder 1 bids 20 and the others bid 5 (in compensation for a small side payment from bidder 1). This agreement is also strong since the other bidders cannot beat bidder 1 without suffering a deficit.

On the other hand, in the first-price sealed-bid auction, or the Dutch auction, if bidder 1 bids less than 18, the other bidders have an incentive for breaking the collusive agreement. Also, bidder 1 cannot take any countermeasure since when bidder 1 knows the fact that other bidders broke the agreement, the auction is already closed.

Also, in the second-price sealed-bid auction, the auctioneer can increase his/her revenue by fabricating an additional bid that is close to the winner's bid. In other auction protocols, it is difficult for the auctioneer to make additional profit by lying. However, in the English auction, the auctioneer can use a shill to increase his/her revenue.

E. False-name bids

In Internet auctions, it is easy for a bidder to submit multiple bids under multiple identifiers (e.g., multiple e-mail addresses). In a single-item, single-unit auctions, a bidder cannot make an additional profit by using multiple bids. However, in auctions of multiple units or multiple items, submitting false-name bids can be profitable.

Example 2: Let us consider an auction of two items.

- bidder 1: ($6, $6, $12)
- bidder 2: ($0, $0, $8)

In the GVA, bidder 1 obtains both items and pays 8. On the other hand, bidder 1 can use a false identifier (i.e., bidder 3) to split his/her bids so that the situation becomes identical to Example 1. In this case, bidder 1 can still obtain both items, and his/her payment is only $\$2 + \$2 = \$4$. Thus, bidder 1 can increase his/her profit by using false-name bids.

As shown in this example, when a bidder can submit false-name bids, truth-telling is no longer the dominant strategy. Thus, the GVA is no longer incentive compatible and it cannot guarantee to achieve a Pareto efficient allocation. Furthermore, it is theoretically proven that there exists no auction protocol that can satisfy incentive compatibility and Pareto efficiency at the same time for all cases in multi-item auctions [22]. The author has developed a series of protocols that are false-name-proof in various settings: a combinatorial auction protocol called the Leveled Division Set (LDS) protocol [17], [18], [19], multi-unit auction protocols [4], [5], [15], [21], and double auction protocols [12], [13], [20], [23].

VI. Conclusions

In this article, we gave an overview of the theory of Internet auctions. For further reading on auction theories, Reference [10] is a good introductory level textbook (Section 12 is on auction theories). Reference [8] is an advanced textbook on microeconomics that gives detailed descriptions of the mechanism design problem including auctions and the proof of the revenue equivalence theorem in Chapter 23. References [6], [9] are survey articles on current auction literature. Also, reference [7] is an advanced level textbook, which is specialized to auction theories. Furthermore, reference [2] is an extensive collection on recent topics on multi-item/combinatorial auctions.

Electronic Commerce (EC) and Internet auctions are a promising field for applying agent and Artificial Intelligence technologies. Various papers have appeared at conferences on Artificial Intelligence such as International Joint Conference on Artificial Intelligence (IJCAI) and National Conference on Artificial Intelligence (AAAI) and at conferences on agent technologies such as International joint Conference on Autonomous Agents and Multiagent Systems (AAMAS).

References

[1] Clarke, E. H. Multipart pricing of public goods. *Public Choice*, 2:19–33, 1971.

[2] Cramton, P, Steinberg, R, and Shoham, Y, editors. *Ascending Proxy Auctions*. MIT Press, 2005.

[3] Fujishima, Y, Leyton-Brown, K, and Shoham, Y. Taming the computation complexity of combinatorial auctions: Optimal and approximate approaches. In *Proceedings of the Sixteenth International Joint Conference on Artificial Intelligence (IJCAI-99)*, pages 548–553, 1999.

[4] Iwasaki, A, Yokoo, M, and Terada, K. A robust open ascending-price multi-unit auction protocol against false-name bids. In *Proceedings of the Fourth ACM Conference on Electronic Commerce (EC-2003)*, pages 85–92, 2003.

[5] Iwasaki, A, Yokoo, M, and Terada, K. A robust open ascending-price multi-unit auction protocol against false-name bids. *Decision Support Systems*, (to appear).

[6] Klemperer, P. Auction theory: A guide to the literature. *Journal of Economics Surveys*, 13(3):227–286, 1999.

[7] Krishna, V. *Auction Theory*. Academic Press, 2002.

[8] Mas-Colell, A, Whinston, M. D, and Green, J. R. *Microeconomic Theory*. Oxford University Press, 1995.

[9] Milgrom, P. R. The economics of competitive bidding: a selective survey. In Hurwicz, L, Schmeidler, D, and Sonnenschein, U, editors, *Social Goals and Social Organization*. Cambridge University Press, 1985.

[10] Rasmusen, E. *Games and Information*. Blackwell, 1994.

[11] Rosenschein, J. S and Zlotkin, G. *Rules of Encounter*. MIT Press, 1994.

[12] Sakurai, Y and Yokoo, M. An average-case budget-non-negative double auction protocol. In *First International joint Conference on Autonomous Agents and Multiagent Systems (AAMAS-2002)*, pages 104–111, 2002.

[13] Sakurai, Y and Yokoo, M. A false-name-proof double auction protocol for arbitrary evaluation values. In *Second International joint Conference on Autonomous Agents and Multiagent Systems (AAMAS-2003)*, pages 329–336, 2003.

[14] Sandholm, T. An algorithm for optimal winner determination in combinatorial auction. In *Proceedings of the Sixteenth International Joint Conference on Artificial Intelligence (IJCAI-99)*, pages 542–547, 1999.

[15] Terada, K and Yokoo, M. False-name-proof multi-unit auction protocol utilizing greedy allocation based on approximate evaluation values. In *Proceedings of the Second International Conference on Autonomous Agents and Multiagent Systems (AAMAS-2003)*, pages 337–344, 2003.

[16] Vickrey, W. Counter speculation, auctions, and competitive sealed tenders. *Journal of Finance*, 16:8–37, 1961.

[17] Yokoo, M, Sakurai, Y, and Matsubara, S. Robust combinatorial auction protocol against false-name bids. In *Proceedings of the Seventeenth National Conference on Artificial Intelligence (AAAI-2000)*, pages 110–115, 2000.

[18] Yokoo, M, Sakurai, Y, and Matsubara, S. Bundle design in robust combinatorial auction protocol against false-name bids. In *Proceedings of 17th International Joint Conference on Artificial Intelligence (IJCAI-2001)*, pages 1095–1101, 2001.

[19] Yokoo, M, Sakurai, Y, and Matsubara, S. Robust combinatorial auction protocol against false-name bids. *Artificial Intelligence*, 130(2):167–181, 2001.

[20] Yokoo, M, Sakurai, Y, and Matsubara, S. Robust double auction protocol against false-name bids. In *Proceedings of the 21st International Conference on Distributed Computing Systems (ICDCS-2001)*, pages 137–145, 2001.

[21] Yokoo, M, Sakurai, Y, and Matsubara, S. Robust multi-unit auction protocol against false-name bids. In *Proceedings of 17th International Joint Conference on Artificial Intelligence (IJCAI-2001)*, pages 1089–1094, 2001.

[22] Yokoo, M, Sakurai, Y, and Matsubara, S. The effect of false-name bids in combinatorial auctions: New fraud in Internet auctions. *Games and Economic Behavior*, 46(1):174–188, 2004.

[23] Yokoo, M, Sakurai, Y, and Matsubara, S. Robust double auction protocol against false-name bids. *Decision Support Systems*, 39:23–39, 2005.