Han La Poutré
Norman M. Sadeh
Sverker Janson (Eds.)

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Agent-Mediated Electronic Commerce

Designing Trading Agents and Mechanisms

AAMAS 2005 Workshop, AMEC 2005
Utrecht, Netherlands, July 2005
and IJCAI 2005 Workshop, TADA 2005
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Preface

As use of automated agent trading, online auctions and other forms of agent-mediated electronic commerce is gaining prominence in everyday economic activities, interest in further advancing these technologies is also continuing to grow. The present volume presents a snapshot of research on Designing Trading Agents and Mechanisms for Agent-Mediated Electronic Commerce. The book has been built around a collection of articles initially presented at two highly respected international workshops held in the summer of 2005:

- The 2005 workshop on Agent-Mediated Electronic Commerce VII: Designing Mechanisms and Systems (AMEC VII, 2005) collocated with the AAMAS 2005 conference held in Utrecht, The Netherlands, in July 2005. AMEC 2005 was the seventh in a series of international workshops on research at the intersection between computer science, operations research, artificial intelligence, distributed systems, and economics, including game theory. Research presented at this workshop has traditionally addressed a mix of both theoretical and practical issues, looking at behavioral and organizational dimensions of agent-mediated electronic commerce as well as at complex computational, information and system-level challenges. An extended version of an article originally presented at AMEC2004 has also been included.
- The 2005 workshop on Trading Agent Design and Analysis (TADA 2005), collocated one week later with the International Joint Conference on Artificial Intelligence (IJCAI 2005) in Edinburgh, Scotland. The TADA workshop was the third of its kind and focused more specifically on trading agent technologies and mechanism design. This includes discussions of agent architectures and decision-making algorithms along with theoretical analyses and empirical evaluations of agent strategies in different trading contexts. The workshop also serves as the primary discussion forum for the Trading Agent Competition (TAC) research community. TAC is an annual tournament that currently revolves around two different trading scenarios: a scenario that focuses on trading for flight reservations, hotel bookings and tickets at special events ("TAC Travel") and a scenario that models trading for consumer orders and component procurement in a PC assembly supply chain ("TAC Supply Chain Management" or "TAC-SCM"). Participants in the competition develop software agents that compete against one another through several rounds. The rounds, enabled by game servers at SICS (www.sics.se/tac), span several weeks and feature hundreds of games pitting different groups of agents against one another. The competition, which over the years has attracted the participation of several hundred researchers, has grown to become a major catalyst for automated trading and agent-mediated e-commerce research.

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We hope that this book will be both a useful resource and a source of inspiration for researchers, students, and practitioners in agent-mediated electronic commerce and trading agents.

Han La Poutré
Norman Sadeh
Sverker Janson

Short Bios

Han La Poutré is research group leader at CWI in Amsterdam (The Netherlands), heading the theme group "Computational Intelligence and Multi-agent Games." He also is a full professor of "e-Business and Computer Science" at the Department of Information Systems at Eindhoven University of Technology. Both in 1999 and 2005, his research group was rated excellent in the six-yearly evaluation of the CWI by NWO (the Netherlands Organization for Scientific Research). Han served as Co-chair of the AMEC-VII workshop.

Norman Sadeh is an Associate Professor in the School of Computer Science at Carnegie Mellon University (CMU), where among other things he founded and directs the e-Supply Chain Management Laboratory. He is also the original proposer of the Supply Chain Trading Agent Competition (TAC- SCM), which over the years has been refined under a collaboration between CMUs e-Supply Chain Management Laboratory, SICS and the University of Minnesota. Norman served as Co-chair of the AMEC-VII workshop.

Sverker Janson is director of the Intelligent Systems Laboratory at SICS, Swedish Institute of Computer Science. He is co-designer of the original 2003 TAC SCM game, with Raghu Arunachalam, Norman Sadeh, Joakim Eriksson, and Niclas Finne. His lab designed and developed the game servers and agentware for TAC, TAC Travel and TAC SCM, and operates the competition since 2002. Sverker served as Chair of the TADA 2005 workshop.

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PART 3: AMEC VI 2004

Learning Environmental Parameters for the Design of Optimal English Auctions with Discrete Bid Levels

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Abstract. In this paper we consider the optimal design of English auctions with discrete bid levels. Such auctions are widely used in online internet settings and our aim is to automate their configuration in order that they generate the maximum revenue for the auctioneer. Specifically, we address the problem of estimating the values of the parameters necessary to perform this optimal auction design by observing the bidding in previous auctions. To this end, we derive a general expression that relates the expected revenue of the auction when discrete bid levels are implemented, but the number of participating bidders is unknown. We then use this result to show that the characteristics of these optimal bid levels are highly dependent on the expected number of bidders and on their valuation distribution. Finally, we derive and demonstrate an online algorithm based on Bayesian machine learning, that allows these unknown parameters to be estimated through observations of the closing price of previous auctions. We show experimentally that this algorithm converges rapidly toward the true parameter values and, in comparison with an auction using the more commonly implemented fixed bid increment, results in an increase in auction revenue.

1 Introduction

The popularity of online internet auctions has increased dramatically over recent years, with total online auction sales currently exceeding $30 billion annually. This popularity has prompted much research into agent mediated auctions and specifically the development of autonomous software agents that are capable of fulfilling the role of auctioneer or bidder on behalf of their owner. Now, much of the theoretical work on these agent mediated auctions has focused on direct sealed bid protocols, such as the second-price (Vickrey) auction. These protocols are attractive as they are economically efficient and provide simple dominant bidding strategies for participating agents. However, despite these properties, such sealed bid protocols are rarely used in practice [14]. The vast majority of current online and real world auctions implement variants of a single auction protocol, specifically, the oral ascending price (English) auction with discrete bid levels [8]. Under this protocol, the auctioneer announces the price of the next bid and waits until a bidder indicates their willingness to pay this amount. Upon receiving such an indication, the price moves on to another higher discrete bid price, again proposed by the auctioneer. The auction continues until there are no bidders willing to pay the bid price requested by the auctioneer. At this point, the object is allocated to the current highest bidder and that bidder pays the last accepted discrete bid price.

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Now, despite its apparent popularity, an auctioneer implementing an English auction with discrete bid levels is faced with two complementary challenges. Firstly, it must determine the actual discrete bid levels to be used. The standard academic auction literature provides little guidance here since it commonly assumes a continuous bid interval, where bidders incrementally outbid one another by an infinitesimally small amount. However, discrete bid levels do have an effect, and have been investigated by Rothkopf and Harstad [13]. They showed that the revenue of the auction is dependent on the number and distribution of discrete bid levels implemented and, in general, the use of discrete bid levels reduces the revenue generated by the auction. Conversely, the discrete bid levels also act to greatly reduce the number of bids that must be submitted in order for the price to reach the closing price. This has the effect of increasing the speed of the auction and, hence, reduces the time and communication costs of both the auctioneer and bidders. By analysing the manner in which the discrete bid auction could close and then calculating the expected revenue of the auctioneer in a number of limited cases (which we detail in section 2), they were able to derive the optimal distribution of bid levels that would maximise this revenue. In previous work, we extended this result to the general case, and we can now determine the optimal bid levels for an auction in which the environmental parameters are given [4]. Specifically, these parameters are the number of bidders participating in the auction and the bidders' valuation distribution .

Thus, performing this optimal auction design introduces the second of the two challenges; that of determining, for the particular setting under consideration, the values of these environmental parameters. While, in some settings these may be well known, in most cases they will not. Thus, in this paper, we tackle the problem of determining the optimal discrete bid levels when these values must be estimated through observations of previous auctions. In so doing, we extend the state of the art in three ways:

1. We extend previous work by deriving an expression that describes the expected revenue of a discrete bid auction when the number of bidders participating is unknown but can be described by a probability distribution.
2. We use this expression to calculate the optimal bid levels that maximise the auctioneers' revenue in this case. We demonstrate that the optimal discrete bid levels produced by this method are dependent on the distribution of the number of participating bidders and on the distribution that describes the bidders' valuations.
3. We show that this expression allows us to use machine learning, and specifically Bayesian inference, in an online algorithm that generates sequentially better estimates for the parameters that describe the two unknown distributions (i.e. the distribution of the number of bidders participating in any auction and the distribution of the bidders' valuation) by observing only the closing price of previous auctions.

The results that we provide may be used in the design of online auctions or may be used by automated trading agents that are adopting the role of an auctioneer within a multi-agent system. In such settings these auction protocols are attractive as they provide a relatively simple bidding strategy for the agents, yet, unlike second price sealed bid auctions, do not require the bidders to reveal their full private information to the auctioneer. In this setting, there is a need to fully automate the design of such auction mechanisms, and the work presented here represents a key step in this direction.

The remainder of the paper is organised as follows: in section 2 we present related work and in section 3 we describe our auction model and present the previously derived results for the expected revenue of this auction (in order to make this paper self-contained). In section 4 we extend this result to the case that the number of bidders participating in the auction is described by a distribution and we use this new result to derive optimal discrete bid levels in this case. In section 5 we present our Bayesian inference algorithm and finally we conclude and discuss future work in section 6.

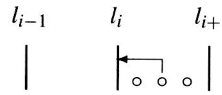
2 Related Work

The problem of optimal auction design has been studied extensively for the case of auctions with continuous bid increments [12,10]. In contrast, auctions with discrete bid levels have received much less attention, and much of the work that does exist is based on the assumption that there is a fixed bid increment and thus the price of the auction ascends in fixed size steps [15,3,16]. In contrast, Rothkopf and Harstad considered the more general question of determining the optimal number and distribution of these bid levels [13]. They provided a full discussion of how discrete bid levels affect the expected revenue of the auction and they considered two different distributions for the bidders' private valuations (uniform and exponential). In the case of the uniform distribution, they considered two specific instances: (i) two bidders with any number of allowable bid levels, and (ii) two allowable bid levels with any number of bidders. In the first instance, evenly spaced bid levels (i.e. a fixed bid increment) was found to be the optimal. In the second instance, the bid increment was shown to decrease as the auction progressed. Conversely, for the exponential distribution (again with just two bidders), the optimal bid increment was shown to increase as the auction progressed.

In previous work, we extended the analysis of Rothkopf and Harstad [13], and, rather than analyse the ascending price English auction in limited cases, we presented a general expression that relates the revenue to the actual bid levels implemented. For a uniform valuation distribution we were able to derive analytical results for the optimal bid levels, and in general, we were able to numerically determine the optimal bid levels for any bidders' valuation distribution, any number of bid levels and any number of bidders. In addition, we showed that in general, increasing the number of discrete bid levels, causes the revenue to approach that of a continuous bid auction.

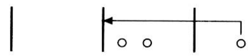
In this paper, we extend this previous work and address the problem of estimating the number and valuation distribution of the bidders through observing the closing price of previous auctions. This problem is similar to that studied in the econometrics literature, where it has been used to identify the behaviour of bidders in real world auctions [6]. More recently, it has received attention within electronic commerce, with the goal of determining the reserve price in a repeated procurement auction [2]. Typically, this work uses statistical maximum likelihood estimators to determine the parameters that describe the bidders' valuation distribution through observations of their bidding behaviour. In our case, this task is somewhat different as much of this information is lost in the discretisation of the bids. Thus, we use the expression that we have already derived for the revenue of the discrete bid auction, and use Bayesian inference to infer parameter values through observations of the closing price of previous auctions. This

Case 1



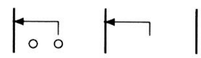
Two or more bidders have valuations between $[l_i, l_{i+1})$ and none have valuations $x \geq l_{i+1}$.

Case 2



One bidder has a valuation $x \geq l_{i+1}$, one or more bidders have valuations in the range $[l_i, l_{i+1})$ and the bidder with the highest valuation was the current highest bidder at l_i.

Case 3



One bidder has a valuation $x \geq l_i$, one or more bidders have valuations in the range $[l_{i-1}, l_i)$, and the bidder with the highest valuation was not the current highest bidder at l_{i-1}.

Fig. 1. Diagram showing the three cases whereby the auction closes at the bid level $\mathbf{l_i}$. In each case, the circles indicate a bidder's private valuation and the arrow indicates the bid level at which that bidder was selected as the current highest bidder.

method is attractive, as rather than providing a single parameter estimate at each iteration, it provides a full distribution that describes the auctioneer's belief over the entire range of possible parameter values. Thus indicating the confidence that the auctioneer should have in his current estimate [9]. In addition, Bayesian inference tends to be computationally simpler than maximum likelihood methods, since it does not require us to maximise a function over several dimensions [1].

3 Auction Model and Expected Auction Revenue

In this work we consider a common model of an English auction that was used by Rothkopf and Harstad [13]. In this model, n risk neutral bidders are attempting to buy a single item from a risk neutral auctioneer. Bidders have independent private valuations, x_i, drawn from a common continuous probability density function, $f(x)$, within the range $[\underline{x}, \overline{x}]$, and with a cumulative distribution function, $F(x)$, where with no loss of generality, $F(\underline{x}) = 0$ and $F(\overline{x}) = 1$. The bidders participate in an ascending price auction, whereby the bids are restricted to discrete levels which are determined by the auctioneer. We assume there are $m+1$ discrete bid levels, starting at l_0 and ending at l_m (at this point, we make no constraints on the actual number of these bid levels).

The auction starts with the auctioneer announcing the first discrete bid level (i.e. the reserve price of the auction) and asks the bidders to indicate their willingness to pay this amount. In traditional English auction houses, this indication is normally accomplished by a nod to the auctioneer, while in current online auctions such as `www.onsale.com` it requires a click of a mouse. If no bidders are willing to pay this amount within a predetermined and publically announced interval, the auction closes and the item remains unsold. However, if a bid is received, the auction proceeds and the auctioneer again requests bidders willing to pay the next discrete bid level. If no bidders are willing to pay this new price, the auction then closes and the item is sold to the current highest bidder.

Now, in order to determine the optimal bid levels that the auctioneer should announce, an expression for the expected revenue of the auction must be found. Rothkopf and Harstad considered this problem and identified three mutually exclusive cases that described the different ways in which the auction could close at any particular bid level [13]. These cases are shown in figure 1. They then calculated the probability of each case occurring in a number of limited cases. In our earlier work we have been able to use the same descriptive cases, but derive a general result for each probability [4]. Thus we are able to describe the probability of the auction closing at any particular bid level:

$$P_n(l_i) = \begin{cases} [1-F(l_i)]\left[\frac{F(l_{i+1})^n-F(l_i)^n}{F(l_{i+1})-F(l_i)}\right] & i=0 \\ [1-F(l_i)]\left[\frac{F(l_{i+1})^n-F(l_i)^n}{F(l_{i+1})-F(l_i)}+\frac{F(l_{i-1})^n-F(l_i)^n}{F(l_i)-F(l_{i-1})}\right] & 0<i\leq m \end{cases} \tag{1}$$

Note that the subscript in P_n indicates that the expression is in terms of the actual number of bidders, n, who participate in the individual auction, and that we define $F(l_{m+1})=1$. Now, the expected revenue of the auctioneer is simply found by summing over all possible bid levels and weighting each by the revenue that it generates:

$$E_n = \sum_{i=0}^{m} l_i P_n(l_i) \tag{2}$$

Thus, by substituting equation 1 into this expression and performing some simplification, we get the result:

$$E_n = \sum_{i=0}^{m} \frac{F(l_{i+1})^n - F(l_i)^n}{F(l_{i+1}) - F(l_i)} \left[l_i\left[1-F(l_i)\right] - l_{i+1}\left[1-F(l_{i+1})\right]\right] \tag{3}$$

In our previous work we used this result to generate optimal bid levels when the number of bidders and the bidders valuation distribution are known.

4 Optimising over Uncertainty in the Number of Bidders

Now, we wish to deal with the more general case that the number of bidders participating in the auction is not known by the auctioneer. To do so, we have to carefully define what we mean by participation. Thus, a bidder is said to be participating in (or has entered) the auction, if they have generated a valuation for the item being sold, are present and are prepared to bid. It is this number of bidders (plus their valuation distribution and the discrete bid levels implemented) that determines the expected revenue of the auction (as described in equation 3). However, in the English auction considered here, not all of the bidders who are participating will necessarily submit bids to the auctioneer (i.e. many will find that the other bidders have raised the price beyond their own private valuation and thus they have no opportunity to bid). Thus, the auctioneer is not able to determine the number of bidders who are participating by simply observing the bids.

In addition, in any specific setting, the number of bidders participating in an auction is unlikely to be fixed but will most likely be described by a probability distribution.

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