Mechanism Design for Dynamic Environments: Online Double Auctions [*]

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Abstract

This paper states the challenges of mechanism design for dynamic environments, especially dynamic double auctions. After a brief review of related work, we specify the problem we are tackling, and then briefly outline our research plan, the results we have achieved to date, and the ongoing directions.

1 Problem Statement

A mechanism is a specification of how economic decisions are determined as a function of the information that is known by the individuals in the economy. Mechanism design is the discipline of designing mechanisms that lead to socially desirable outcomes in a context where individuals are selfish. Traditionally, mechanism design has focused on static settings where the individuals (participants) are known before the mechanism makes any decision. However, many real environments are dynamic, e.g. stock exchanges, where the participants are dynamically arriving and departing. Mechanism design for dynamic settings is necessary not only to solve problems in actual dynamic environments, but also because existing solutions for static settings are insufficient in dynamic environments.

The mechanism design problem for dynamic settings is termed *online mechanism design*, where the participants are arriving and departing over time [Parkes, 2007], the private information (aka type) of each participant is changing over time [Cavallo and Parkes, 2008; Bergemann and Vlimki, 2010], or both [Cavallo *et al.*, 2009]. The main challenge in online mechanism design is that decisions of an online mechanism have to be made dynamically, without knowledge of future participants and/or types. For instance, a seller is selling a house, and each buyer comes dynamically with a price to buy the house and a waiting period within which the seller has to decide whether or not to sell to him. The challenge for the seller is deciding when and to whom to sell it.

Online mechanism design has attracted more and more interest during the last decade. Most researches have focused on one-sided dynamic market models, i.e. either the supply or the demand of the market is dynamic, but not both [Parkes,

2007]. In online double auction markets, e.g. exchange markets, the dynamics are two-sided, i.e. both the supply and the demand are dynamic. An online double auction mechanism has to match sellers and buyers dynamically and calculate a payment for each matched trader without knowing about future orders. Such uncertainty is more challenging for double auction mechanism design because modelling traders' bidding behaviour in double auctions is "immensely complicated" even in a static case [McAfee, 1992]. Because of the complexity of the dynamics, only limited studies have been conducted for online double auctions [Blum *et al.*, 2006; Bredin *et al.*, 2007]. However, online double auction markets represent the dominant type of exchange market, and traders' manipulations are very critical to an online double auction market. Thus a robust mechanism that can prevent traders' manipulations or quickly adapt to market changes is very desirable in an online double auction market.

2 Research Plan & Approaches

In this research, we will focus on a dynamic double auction setting where traders are dynamically arriving and departing. Each trader wants to sell or buy exactly one item and has a fixed private valuation of the item. An online double auction mechanism in this model consists of *winner determination*, *payment computation*, and *learning*. The winner determination determines which traders can trade, the payment computation calculates the payment for each winning trader, and learning is crucial to adapting to the changes in the environments in order to keep certain properties of the mechanism. The desirable properties that we will consider in this research are *incentive compatibility* (truthfulness) and *efficiency* (maximizing social welfare). A double auction is incentive compatible if all of the participants maximize their utilities when they truthfully reveal any private information asked for by the auction. We say a double auction is efficient if it maximizes the sum of the valuations of those traders who have an item in the end, that is, matched buyers and unmatched sellers.

Let us briefly review the related work before introduce our plan. Blum *et al.* [2006] introduced a number of online clearing algorithms for double auction markets in a dynamic environment. By using competitive analysis, they demonstrated that a truthful algorithm for maximizing social welfare with competitive ratio $2 \max(\ln(p_{max}/p_{min}), 2)$ is achievable, where p_{max} and p_{min} are the maximum and the mini-

mum valuation of all traders in the market respectively. But the optimal matching they compared with is the one with a fixed price threshold such that buy offers that are above the threshold and sell offers that are below the threshold can be matched. Bredin *et al.* [2007] also constructed a framework to build truthful dynamic double auction mechanisms by using static truthful double auction mechanisms. Instead of worst case analysis, they demonstrated the efficiency property of their mechanisms through experiments under the assumption that all traders have a bounded patience, i.e. the length of their participating time is bounded. However, to the best of our knowledge, we have not seen a double auction mechanism that is both truthful and efficient in a dynamic environment. Since online mechanism design is strongly inspired by solving problems in actual dynamic environments, deployable online mechanisms are more desirable. So far, the computational complexity of the existing online double auction mechanisms that we have seen are not considered.

Therefore, in our investigation, we would like to first find out what is the optimal (offline) solution for an online double auction mechanism in our model, i.e. to set up a target for the online mechanism design. Note that an optimal solution for an online double auction mechanism is usually multiple-priced. We will then use this optimal solution in two different ways. Obviously we will be able to analyse an online mechanism by comparing it with the optimal solution rather than the optimal fixed price solution. We will also try to directly extend the algorithm for computing the optimal solution into online mechanism, rather than use traditional static double auction mechanisms. We will also investigate how to reduce an online double auction mechanism to online one-sided auction mechanism(s). In addition, computational complexity will be another important concern. We will conduct the research through the following steps:

1. *Establish a benchmark for online double auction mechanism design.* We want to find out what kind of matching and payment satisfy truthfulness and efficiency if an online mechanism would be aware of the future dynamics. This actually provides the optimal solution for online double auction mechanism design.

2. *Online mechanism design.* We will go through two different approaches: (1) Design online mechanisms by directly using the offline algorithms for computing the optimal solution in the first step. (2) Reduce double-sided online mechanisms to one-sided online mechanisms. For instance, online bipartite matching [Karp *et al.*, 1990] and multiple-choice secretary algorithm [Kleinberg, 2005] are considered as one-sided online mechanisms. Using the optimal solution found in the first step, we will then carry out corresponding worst case analysis and/or experiments.

3 Progress to Date

We have established a benchmark by using the augmentation technique in graph theory [Zhao *et al.*, 2011]. We developed an efficient and truthful double auction mechanism (aka VCG mechanism) that is characterized by an allocation policy and a payment policy. The allocation policy determines who can trade and the payment policy computes the payment for each trader. It is found that the allocation problem can be effectively transformed into a weighted bipartite matching. We proved that an allocation policy is efficient if and only if it corresponds to a maximum-weighted bipartite matching. More importantly, our payment algorithm directly uses the allocation outcome rather than recalls the underlying allocation algorithm as the most desirable VCG payment (the *Clarke pivot payment*) [Groves, 1973]. Moreover, the independence of our payment algorithm from the allocation algorithm demonstrates significant computational advantage compared with the Clarke pivot payment. This advantage also gives potential power to reduce the computational complexities of the extended online mechanisms.

As well as efficiency and incentive compatibility, market liquidity as a flag of the success of a market is also considered in this investigation. Based on the Trading Agent Competition Market Design platform, we developed a matching algorithm that maximizes market liquidity [Zhao *et al.*, 2010].

By extending online bipartite matching and multiple-choice secretary algorithms, we have developed some online mechanisms that are truthful. We will analyse other properties of these mechanisms, e.g. efficiency. At the same time, we are extending the optimal offline mechanism we have found into online mechanism.

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