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Multi-dimensional fairness for auction-based resource allocation

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ABSTRACT

Multi-attribute resource allocation problems involve the allocation of resources on the basis of several attributes, therefore, the definition of a fairness method for this kind of auctions should be formulated from a multi-dimensional perspective. Under such point of view, fairness should take into account all the attributes involved in the allocation problem, since focusing on just a single attribute may compromise the allocations regarding the remainder attributes (e.g. incurring in delayed or bad quality tasks). In this paper, we present a multi-dimensional fairness approach based on priorities. For that purpose, a recurrent auction scenario is assumed, in which the auctioneer keeps track of winner and losers. From that information, the priority methods are defined based on the lost auctions number, the number of consecutive loses, and the fitness of their loser bids. Moreover, some methods contain a probabilistic parameter that enables handling wealth ranking disorders due to fairness. We test our approach in real-data based simulator which emulates an industrial production environment where several resource providers compete to perform different tasks. The results pointed that multi-dimensional fairness incentives agents to remain in the market whilst it improves the equity of the wealth distribution without compromising the quality of the allocation attributes.

1. Introduction

Auction mechanisms offer the possibility to allocate resources and services in a market (e.g. a company which desires to externalize a production task) while optimizing the outcome of all of the participants (bidders and auctioneers). Thus, given a production task, resource providers bid for it, and the winner bid is the one that best fits the required resource specifications. The auction ends when the winner bid receives payment from the auctioneer.

The auction designer's goals include optimizing the payoff or revenue of bidders and auctioneers, so that all the participating agents are gratified and remain in the market place. To evaluate how bidders are satisfied with the auction outcome, as well as the revenue obtained by the auctioneer [5,9], social welfare measures can be defined. The utilitarian view of social welfare has been the main approach followed, and consists of aggregating all of the agents' outcomes towards maximizing their payoff or revenue. In this utilitarian approach, the aggregation does not consider the fact that there could be large differences among agents' payoffs. When auctions are repeated over time (recurrent auctions), this situation may lead to the dissatisfaction of certain participants who may eventually decide to leave the market.[1] When this occurs only the most powerful bidders remain in the market, gaining the chance to create an oligopoly, control the market price and provoke a general fall in prices, which can bankrupt the auctioneers. Literature often refers to these situations as the bidder drop problem [17] and the asymmetric balance of negotiation power [27].

To tackle these problems fairness measures have been used in auction design in what are known as egalitarian social welfare approaches [24,30,34]. In this scenario, the behaviour of bidders can be totally selfish, as it is the auctioneer agent who uses fairness measures to distribute the revenues to maintain bidders' interest in participation and, therefore, reducing the bidder drop problem. At the end, more bidders means greater competition between them, leading the market to more competitive prices. Our work concerns recurrent auction mechanisms with a fairness functionality handled by the auctioneer in order to maintain its own revenue in the long run.

In particular, we focus on the use of auctions for allocating resources to services, where prices are one of several relevant aspects to be taken into account when clearing the auction.

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[1] Note that in multi-agent systems, agents act on behalf of humans or entities that have a limited capacity. Therefore, depending on the domain, an agent withdrawal can be understood as a recommendation to the represented entity so it focus in other more productive market.

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Attributes such as service time, distance among providers, and ecological footprint, can play an important part in the process of determining which supplier best suits the production needs. Therefore, it is important to find a compromise between all the elements that condition the resources in order to obtain a satisfactory allocation. Multi-attribute[2] auctions offer the chance to consider different aspects besides the price, and become an ideal option for the problem we are dealing with. Consistently, fairness cannot be limited to the payoffs and revenues obtained by agents due to the fact that focusing the application of fairness in a single attribute (price) may involve undesirable consequences regarding the remaining attributes (e.g. unbalanced workloads or production delays). To prevent this issue, we propose to apply fairness mechanisms, and consider not only the economic aspects of the auction but also the remaining attributes involved in the resource allocation decision making process, in what we call multi-dimensional fairness.

In this work, we explore a multi-dimensional fairness mechanism based on priorities in order to increase the social welfare resulting from a large sequence of auction allocations. Priorities are computed using information regarding all of the attributes involved in the resource allocation process, avoiding unwanted behaviours. For example, the situation in which the auctioneer achieves a cheap price but a long delay when performing some tasks, as other fairness mechanisms based exclusively on price could exhibit. We present a collection of different priority methods for including multi-dimensional fairness to a multi-attribute auction mechanism: two qualitative and two quantitative approaches with a deterministic version and a stochastic version of each one. To illustrate and test the auction mechanism, we simulate an industrial environment where different agents auction services, which must be carried out by external service providers, while trying to obtain a service at a reasonable price and time.

This paper is organized as follows: first, we present a brief state of the art regarding multi-attribute auctions and fairness in auctions; second, in Section 3 we introduce some basic concepts regarding auctions and multi-attribute auctions; next, in Section 4 we propose to endow the auction mechanism with multi-dimensional fairness by means of priority-based methods; in Section 5 we test the approach proposed in a task allocation simulator in order to analyze how it affects the social welfare of the allocations and, finally, in Section 6 we present the conclusions of our work and we point some possible future lines of research.

2. Related work

Despite it being proven that preserving the number of participants in an auction increases its efficiency in the mid and long term [25] and that evaluating fairness from a multi-dimensional point of view can lead to higher customer satisfaction, little research has been done in the field of fairness in recurrent auctions. To the best of our knowledge, despite the literature has posed the need to include fairness into multi-attribute auctions [36], there are no previous auction approaches dealing with fairness from a multi-dimensional point of view. However, there are previous works involving a single factor, the price, conditioning fairness. In [17], the authors improve the welfare of the weakest agents by establishing a reservation price so that some goods cannot be sold if the prices offered by bidders are under this reservation price. The remaining goods are then distributed among the weakest agents. Regarding the implications of fairness in the resulting allocations, in [18] the authors make a comparison between fairness and efficiency concluding that there is a compromise between both. However, Murillo et al. [25] claim that this assertion may be true in the short-term but, if analyzing auction recurrence in the long-term, fairness-based methods also become efficient as auctioneers obtain as many benefits with fairness-based methods as without.

In [26], a first price single-dimension fair method, based on priorities is proposed. In this work, the auctioneers assign a priority to each agent according to its auction history. Bidders with the worst auction win record have a higher priority, meaning that they have higher chances to win the next auction. The authors propose to use the priority attribute to condition the auction clearance by aggregating the priority to the bid. However, in the payment rule, the priority attribute is omitted and does not condition the payment the winners receive. Although the authors prove that their approach solves the bidder drop problem without incurring a resource waste (leaving certain goods without a buyer), the mechanism suffers from an asymmetric balance of negotiation power [17,25] caused by the lack of incentive compatibility (the strongest winners obtain a higher utility by underbidding). Conversely to these previous approaches, when considering a single dimension, our proposal can minimize the bidder drop problem without incurring a waste of resources, as it follows a second price philosophy. Moreover, our approach can be applied in multi-dimensional scenarios.

The use of fairness in auctions has been applied in a wide range of domains. For instance, in the network communication domain, Lin et al. [19] have used a variation of priority auctions called Varyver in order to distribute broadband capacity among different broadcasters. To ensure that broadband is fairly distributed, Varyver assigns a priority to each broadcaster according to the amount of data it has already broadcast. A complementary work to this approach is the one presented in [13], where the same problem is solved using combinatorial auctions which select the fairest allocation that fulfills the network broadcast requirements. These kinds of approaches are also used in the electricity smart grid [8]. In the supply chain domain, Katok and Pavlov [14] analyze how fairness based on priorities can be used under different uni-attribute auction schemes, concluding that the use of fairness can benefit both producers and providers. All these approaches are implemented and analyzed under a uni-attribute perspective, however, their application domains might require multi-attribute allocations. In such scenarios, the multi-dimensional fairness methodology presented in this paper could play an important part to preserve the equity of the allocations.

Regarding the multi-criteria decision making community, the work presented in this paper is intended to take benefit of the existing methodologies that can be used to establish the winner in a multi-attribute auction. In particular, the approach presented is suitable for approaches that can solve the winner of the auction using multi-criteria functions (for instance vector maximization [23,40], multi-attribute utility theory [15,35], analytic hierarchy process [33] and aggregation functions [11]). In such scenarios, the priority proposed in our multi-dimensional fairness methods needs to be introduced into the multi-attribute decision process and to be treated as any other attribute. On the other hand, multi-criteria methods that do not result in a mathematical evaluation for each of the auction bids, but in an preference order or preorder (for instance, Promethee [2] and dominance-based rough set theory [39]) might not be compatible with the approach proposed in this paper. The fact of not providing a numerical evaluation for the different auction bids would prevent the proper calculation of the auction payments.

3. Background

This section provides some basic notions regarding auctions and multi-attribute auctions.

[2] Auctions, by default, consider just one attribute. In this paper we will use *uni-attribute* and *single-dimension* to refer to those auctions which only consider one attribute and *multi-attribute* and *multi-dimensional* to refer to those which consider several attributes.