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A combinatorial procurement auction featuring bundle price revelation without free-riding

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Abstract

Combinatorial auctions are currently becoming a common practice in industrial procurement, allowing bidders (sellers of goods and services in the procurement setting) to avoid the risk of selling good or service bundles that are incomplete, inefficient, or excessively expensive to deliver. Two major concerns in combinatorial auction design are the revelation or discovery of market price information over the course of the auction, and the inherent computational difficulty (*NP*-hardness) of the underlying "winner-determination" problem. In this paper we describe a new general auction format maintaining the benefits of the adaptive user-selection approach without the problems of free-riding, inefficiency, or distortionary linear prices. This auction format is particularly well-suited to the largest combinatorial auctions for which winner-determination is computationally tractable, because it provides bundle synergy information that is computable in polynomial time for all interactive phases.

Keywords: Auction design; Combinatorial auctions; Free-riding; Iterative auctions; Procurement

1. Introduction

Early reports on the use of combinatorial procurement auctions (see [18,23,25] for examples) emphasize the robust ability of auction mechanisms to fairly price goods or services provided to a central buyer, allowing benefits on both sides of the market. Suppliers are able to pursue only combinations of goods or services that are cost-efficient to produce, while the buyer or procurer of services benefits from the price competition among several sellers. De-emphasized in the available literature is the complex interplay between the need for market revelation, allowing competing participants the ability to learn about one another, and the strategic leverage that becomes available when too much information about a bidder is made available through the auction's revelation environment.

One of the main strengths of traditional single item auctions is that a bidder has the ability to learn about her own true preferences by observing the behavior of her opponents (see the text by Krishna [20]), a feature that is also beneficial in the combinatorial procurement setting. In the industrial procurement of food materials, for example (see the Mars Inc. procurement auction described in [18]), industrial growers of sugar may each hold some private knowledge on the yield of this year's crop, which in aggregate will determine the relative scarcity of the commodity and thus influence market behavior. Similarly, several transportation providers participating in

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a shipping lane auction (see the case of Sears Inc. described in [23]) may each have some (noisy) forecast of future oil prices, which in aggregate are much more accurate than if treated separately. Since the price of oil may heavily influence the value of future shipping contracts, these transportation firms would very much want to ascertain or estimate the beliefs of their opponents by observing their behavior in a multi-stage auction game. We may conclude from these simple examples that revelation of market information is quite beneficial in the procurement setting, and that a (one-shot) sealed-bid mechanism is undesirable for this reason.

While the importance of revealed information and the potential for over-revelation have been only scarcely explored in the combinatorial auction literature, the issue that has been most discussed is the computational difficulty (*NP*-hardness) of the underlying "winner-determination" problem. Several approaches to this computational problem are discussed in the literature (see [1,14] for surveys), but here we focus instead on the adaptive user-selection techniques which address both the computational difficulties and the revelation properties simultaneously.

1.1. Adaptive user selection techniques

The adaptive user-selection approach was first described in an early combinatorial auction paper by Banks et al. [9] who introduce a decentralized mechanism (AUSM) that shifts computational burden away from the central decision making entity and to the bidding agents themselves. Indeed, this is the essential feature of the adaptive user-selection approach; bidders adapt to a changing auction environment by carefully selecting which packages of auction items[1] is the best to bid on at the current time.

Later, this idea takes practical form under Kelly and Steinberg [19] who demonstrate a new adaptive user-selection auction format (PAUSE), in which bidders reveal demand in successive rounds by combining their own bids with standing bids of opponents. At each step the new combination of bids forms a complete assignment of auction items to bidders that offers lower total prices to the buyer than the previously proposed auction outcome. This new combination of bids thus becomes the new incumbent solution until (perhaps) displaced by the next winning combination of bids. Importantly, though each bidder has a potentially difficult problem finding a set of bids that complements her own to form a winning combination, the auctioneer has only the relatively simple job of verifying that the new outcome does not award any item to more than one bidder, and that the new combination indeed decreases buyer payments.

The PAUSE auction pursues *efficient outcomes*[2] by shifting computational burden to the bidders, who have a greater intuition as to which bundles may be of greatest value to them, and can thus focus their computational energy on relevant bundles. This contrasts a typical sealed-bid combinatorial auction, where each bidder can bid on a great number of bundles, letting the auctioneer shoulder the computational burden of sorting them all out.

Despite the nice properties associated with the decentralized computational approach of PAUSE, there is a strategic problem limiting its applicability. In particular, in order to achieve efficiency, the PAUSE auction requires unsuccessful or displaced bids to be available to all bidders for use in their own computations, so that they may be combined with new bids in order to eventually achieve the efficient solution. In Section 2.3, however, we provide an example demonstrating that this level of revelation is too much; revealing this much information causes "free-riding", which in turn may cause defensive bidders to curtail activity, thus *sacrificing efficiency*. Incentive-compatible (i.e., truth-inducing) mechanisms have also been proposed as a solution to free-riding in some practical contexts (see [7], for example, where investment in knowledge is seen as a public good subject to free-riding). In the most general settings, however, the incentive-compatible Vickrey–Clarke–Groves (VCG) mechanism and its variants result in prices that are exorbitant for the buyer in a procurement

[1] We note that as long as the buyer can set reasonable publicly known upper bounds on prices, a procurement auction can be described as a forward auction (with one seller and many buyers) with the auction items being the rights to provide various products or services, and the bids interpreted as discounts from the posted bounds that the real-life providers are offering to "buy" such rights. This allows us to discuss the revenue-maximizing forward auction methods in the context in which they were first proposed, without losing relevance to the procurement auction discussion at hand. In general, we can switch back and forth between forward and reverse (procurement) auctions with little trouble, but mostly stay within the procurement auction setting for this paper, except, at times, when referring to the forward auction research of others. All of the results presented here may be easily reformulated as results for forward auctions. Thus, the auction designs we propose here can be easily applied to the more commonly discussed (and often more strategic) forward auction environments, such as auctions for spectrum licenses.

[2] An outcome is efficient if it gives the right to supply items to those whose costs are lowest (or in the forward setting allocates goods to those who value them the most). When auctions are designed to approach the efficient outcome, we say they are designed for efficiency.