CAWP
A Combinatorial Auction Web Platform

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Keywords: Online Auctions, Combinatorial Auctions, e-Commerce, Winner Determination Problem.

Abstract: Online auctions, including online Combinatorial Auctions, are important examples of e-commerce applications. In this paper, a Combinatorial Auction Web Platform (CAWP) is introduced. The platform enables both product selling and buying capabilities that can be realized in a combinatorial way. CAWP supports a Sealed-Bid Single-Unit type of Combinatorial Auctions. Easy customization for any selected problem domain is a distinguished feature of CAWP. Platform users are not expected to have any technical knowledge about how to solve the Winner Determination Problem (WDP) known to be critical for profit maximization of the auctioneers in Combinatorial Auctions.

1 INTRODUCTION

Auction is a trading process where auctioneer provides goods or services and buyer bids to these goods or services. At the end, the highest bidder wins. Online auctions are the auctions which are held over the internet. Rapid growth of internet makes online auctioning important, as it reduces the time and space cost of the offline auctioning mechanisms. Combinatorial Auctions (CA) are the auctions that bidders place bids on combinations of items rather than a single item (Vries and Vohra, 2010). CAs are commonly used in application areas like transportation (Kwon et.al., 2005), bus routes, airport landing rights, power exchanges, carbon permits, and radio spectrum for wireless communications services (Milgrom, 2000) For example, in 2002, Nigeria sold regional fixed wireless access licenses on a sealed-bid combinatorial auction (Koboldt et.al., 2003). Similarly, allocation of web services via CAs is possible. The requirement of more than one web services to be elaborated at the same time implies a form of bidding that supports web services combinations (Lin et.al., 2008). CAs also used in Supply Chain Formation. The supply chain formation demands difficult coordination issues for distributed negotiation of the protocols to be solved. Parties must negotiate for multi level production relationships with important interdependencies among inputs and outputs of each level. CAs addresses this problem by global optimization over expressed offers to engage in compound exchanges (Walsh et.al., 2000).

In practice, CAs are popular because they give bidders a capability to express their complete preferences. Especially, if the items in the auction are complementary, set of items may be valued as more than the sum of values for each individual item. At the same time, the auctioneer may obtain higher benefit by initiating a CA instance. This is because of allowing bidders to express their preferences in combinatorial way, which may results in better auction revenues (Cramton et.al., 2007). Automation of the CA is clearly important, because sellers may want to maximize their revenues and let their bidders flexibly express their preferences while bidding for the items in the auction over the internet.

One of the main problems for the auctioneer in an online CA is to decide about which bid(s) will be allocated (or chosen as the winner(s)). CA allows bidder to bid bundles of items in an auction while these bundles may overlap. The aim is to find a subset of all given bids that will maximize the resulting revenue of the seller. In literature, this problem is called as Winner Determination Problem (WDP) known to be NP-complete (Gottlob and Greco, 2007). Online CAs cannot perform well for the unbounded large scale problems. But with giving limitation to maximum number of items in an auction, problem size can be reduced to a solvable instances. To the best of author’s knowledge, there

Cereci Äř. and Kılıç H. (2010).
CAWP - A Combinatorial Auction Web Platform.
In *Proceedings of the International Conference on e-Business*, pages 82-88
DOI: 10.5220/0002998200820088

is no CA platform realizing Consumer to Consumer (C2C) auctions. In this paper, an online configurable Combinatorial Auction Web Platform (CAWP) is introduced (Cereci, 2009). The platform can be used by consumers who want to sell or buy goods in a combinatorial way. Basically, the consumers are not required to know the details about how to solve the WDP. CAWP is developed by using open source tools and technologies. It is operating system independent. The sellers and buyers can interact with the system through a simple web browser without any additional program installation.

The rest of the paper has the following organization. In Section 2, a background information about general auctions and their automation are provided. In Section 3, combinatorial auctions and the winner determination problem are explained. Also, two alternative solutions to WDP are discussed. In Section 4, technical details, performance results and an example usage of CAWP are given. The last section includes the conclusion and future works.

2 ONLINE AUCTIONS

Emergence of the Internet has changed the way people buy and sell goods. New types of electronic marketplaces have been developed to create more efficient markets (Bakos, 1998). Online Auctions have been one of the most successful electronic markets (Wolfram|Alpha, 2009). Success of the online auctions comes from the capabilities that they provide both to buyers and sellers. As a buyer, one can bid on large number of items from different sources and he/she has the potential to find goods in lower prices. As a seller, you can reach great number of potential buyers.

2.1 Auctions

There are four common auction types. Most of the other auction types are derived from these basic four auction types (Klemperer, 2004).

1. *First-Price Sealed Bid Auction:* All bidders submit their valuations in sealed bids, simultaneously. By this way it is guaranteed that no bidder knows the bid of the others. The highest bidder who pays the price gets the good.
2. *English Auction* (a.k.a. *open-cry ascending price* auction): English auction is the most common form of auction used today. In this form, bidders bid openly against each other. Each bid should be higher than the previous one. The auction ends when no bidder is willing to raise the final bid or bidding period is over. The highest bidder gets the good.
3. *Dutch Auction* (a.k.a. *open-cry descending price* auction): This auction type is similar to the English auction. The auctioneer begins with setting a high price to the good. Initial price is gradually lowered until one bidder accepts to pay that amount. Last announced amount is paid by the bidder.
4. *Vickrey Auction* (a.k.a. *sealed-bid second-price* auction): It is identical to the first-price sealed-bid auction except that winning bidder pays not his bid amount but the second highest bidder's amount.

2.2 Electronic Auctions

Electronic auctions became an important part of the electronic trading. In general, complete trading process of any online auction has the following steps (Kumar and Feldman, 1998):

1. *Initial buyer and seller registration:* All parties are authenticated.
2. *Setting up a particular auction event:* Goods are described; auction rules are set and auction is started.
3. *Scheduling and advertising:* Upcoming auctions are notified to attract potential buyers.
4. *Bidding:* All the bids are collected. Bid validity is verified during bidding period and bids are placed until the bidding period is over.
5. *Evaluation of bids, closing the auction:* The auction closing rules are applied and the winner bids are determined. Winners and losers are notified back.
6. *Trade settlement:* Payment and good delivery are realized.

Furthermore, for the sake of standardization, every electronic auction platform are also expected to support the following properties (Omote, 2002):

1. *Anonymity:* Loser bidders should not be identifiable.
2. *Non-cancelability:* A winner is always identified that he cannot deny having bid to the auction.
3. *Public verifiability:* Anybody could publicly verify the winning bid is really the highest value and valid.
4. *Unforgeability:* Impersonation of sellers and bidders should be prevented.
5. *Robustness:* Auction process should not be interrupted, even due to invalid bids.

6. *Fairness:* Every bid should have the same priority; there should be no favor to any individual's bids.
7. *Efficiency of bidding:* The computation of determining a winner bid and verifying that should be practical.

In CAWP, most of the above processing steps are realized together with the mentioned properties. The details of them will be given in subsection 4.2.

3 COMBINATORIAL AUCTIONS

CAs can be categorized according to certain criteria described below:

1. Categorization based on bidding style:
- *Open-Bid Combinatorial Auctions:* Bidders are aware of competing bidders' bids. All bids are publicly announced.
- *Sealed-Bid Combinatorial Auctions:* Each bidder is only aware of his/her bids. After bidding process is completed and winner is determined, it can be announced. Hiding the bids is necessary during bidding time.

2. Categorization based on the number of goods:
- *Single-Unit Combinatorial Auctions:* Amount of the each individual item is one. For example, if there are five identical items, they must be placed to the auction as different items which have the same product information.
- *Multi-Unit Combinatorial Auctions:* Amount of the individual items may be more than one.

3. Categorization based on pricing:
- *Reserve Combinatorial Auctions:* Seller may put a base acceptance price on each item during auctioning. Since in CA bundles of items are bid together, amount of bid should be more than the sum of the items' base prices in the bundle.
- *Non-Reserve Combinatorial Auctions:* Seller cannot put a base acceptance price to their items in the auction. Winner(s) pay the amount they bid and get the items even they are below their original value.
- *Reverse Combinatorial Auctions:* Buyers may want series of items and sellers bid group of that items. Least expensive bids are accepted.

CAWP implements a *Sealed-Bid Single-Unit Combinatorial Auction* mechanism where items can have reserved prices. They are set by the Auctioneer. Every item put in an auction is single unit, if two identical items is needed to be put in an auction, they should be placed separately.

In CAs, bidders are allowed to express themselves freely and place any combination of bid items for the auction. However, this comes with an explosion of the size of the solution space. Winner Determination Problem is the problem of deciding the allocation of winner bids, in a set of bids placed to the auction, so that the revenue of the auctioneer can be maximized.

Formally, let I be the set of items under consideration and R^+ be the set of non-negative real numbers. Then, we say that a bid $b = (I_b, P_b)$ is an element of $S = (2^I - \{\emptyset\}) \times R^+$. That means any subset of power set of items I other than the empty set may have an assigned value decided by its bidder. Let B be a subset of S. A set $F \subseteq B$ is said to be *feasible* if $\forall b,c \in F$, $c \neq b$ and $I_b \cap I_c = \emptyset$. That is no two items in bidding subsets are the same. Also, let $\Phi(B)$ be the set of *all possible feasible allocations* for B. Further, let $I(B) = \bigcup_{b \in B} I_b$ be the set of goods contained in the bids of B.

Definition 1: *Winner Determination Problem* is to find an allocation $W \in \Phi(B)$ such that $\forall F \in \Phi(B)$ the following should hold

$$\sum_{b \in F} P_b \leq \sum_{b \in W} P_b$$

Such allocation is said to be optimal or revenue maximizing (Brown et.al., 1999).

WDP is hard because one would need to check all subset of the bids to identify whether they are feasible (no conflict of items) and how much revenue they may provide. A feasible subset of the bids that has the maximum revenue is the optimal solution. There are 2^k subsets of bids where k being the number of bids (Cramton et.al, 2006).

In general, there are three main factors affecting the solution time for a given WDP instance. These are the number of goods, number of bids and distribution of the bids. If there are some *dominant bids* in the system, solution can be found in dramatically shorter time. This is because when a solver accepts a dominant bid, it helps maximizing the auctioneer revenue and reduces the solution space, causing a solution to be found faster.

Combinatorial Auction Structured Search (CASS) (Brown et.al., 1999) and Combinatorial Auction Branch on Bids (CABOB) (Sandholm et.al., 2001) are two known algorithms for efficient solution of WDP:

1. *Combinatorial Auction Structured Search (CASS) Algorithm:* CASS uses exhaustive search for determining optimal solution. It suggests a simple brute-force search approach supported by four

significant heuristic improvements. CASS structures (or shapes) the search space in order to avoid conflicting bids with some overlaping items. It keeps the result of the searches done up to a point and prunes the search tree. Together with CASS, a test suite is developed to create sample auction setups and to test the systems performance. This test suite is known as CATS (Cramton et.al., 2007)(Brown et.al., 2000).

2. *Combinatorial Auction Branch on Bids (CABOB) algorithm:* CABOB is a tree search algorithm where tree is branched on bids. It makes a dept-first Branch&Bound search on the tree. Branch&Bound search provides a systematic enumeration of all possible solutions and it prunes large subsets of fruitless candidate solutions by using upper and lower bounding (Land and Doig, 1960). In CAWP, we prefered to use a solver that supports the CASS algorithm.

4 COMBINATORIAL AUCTION WEB PLATFORM

In this section CAWP will be introduced, with its functionalities according to the system and the user requirements. Technical details and performance results and a comparison with another CA system are also given.

4.1 General Properties of CAWP

Among the six steps describing complete trading process (given in subsection 2.2), CAWP fully supports the steps 1, 2, 4 and 5. Related to step 3, there is no advertisement support but the users can see and join directly to (or just observe) the product sets open to bidding. Also, there is neither payment nor good delivery tracking capabilities of the system. The requirements for a typical online auction system has also been given in subsection 2.2. Most of these requirements are satisfied by CAWP as described below:

Loser bids are not made known to all bidders (*anonymity*). Bidder logs in to the system before bidding so a winner is always identified (*non-cancelability*). Public verification of the winning bid is really the highest value is not possible. This is because the loser bids are not announced publicly. Note that even this could be the case; such verification would require re-solving the WDP under consideration. The only mechanism against impersonation is the username/password usage. Impersonation of another bidder is not possible without stealing their user name and password (*unforgeability*). A person can impersonate another person in the CAWP, and jeopardize the fairness of the trade, but after single act this person can be notified and receive bad comments, or it can go to account suspension. CAWP prevents bidders to place invalid bids, and keeps the auction process uninterrupted (*robustness*). In CAWP bids or bidders have no priority (*fairness*). Finally, because of the algorithmic complexity of the WDP problem, for some problem instances the computation of determining and verifying a winner bid may not be practical (*efficiency of bidding*). In CAWP, this problem is tried to be handled by putting “at most 30 item per auction” rule for sellers. By this way, one can get a response from the WDP solver in an acceptable time.

Below is the list of implemented CAWP properties based on system/user requirements that are considered during development:

- Authentication of the users is a must for both bidding and creating auctions.
- Any internet user can enter to the CAWP site and view the products information and auctions. However, user must be logged in to get bidding and auctioning capabilities.
- There is no hierarchy or priority between users of the system.
- The system provides its auctioneers to set some parameters of the auction including auction name, auction end time, items in the auction, items’ base prices.
- Bidders can bid any bundle of items as long as they are in the same auction.
- The system assists bidders with the minimum acceptable amount of bid being the sum of base prices of items in the bid.
- Users can withdraw their bids until bidding session is over.
- Auctioneer can drop an auction if there are no bids placed on any goods in the auction.
- Buyers and sellers can write comments about the people they trade with.
- Platform has an internal messaging system. Sellers and buyers can send private messages to each other.
- Number of items that can be on a single auction is maximum 30.
- Real procurement of the goods is realized between seller and buyer. CAWP only gives buyers and sellers capability to comment about their actual trading experiences.

4.2 Technical Details and Performance Results

Technically, CAWP is constituted from four main components. The first one is the *web-component* using which users can create auctions, and make bid. The winner determination problem is generated and results are notified via this component. Second component is the *solver-component* that gets the problems generated by the *web-component*, solves them and returns the solution. Third component is the *database-component* which is used by the web and solver components. Bid, auction, and bidder information are all kept by *database-component*. *Solver-component* gets necessary data from the *database-component* to create the winner determination problem file. After the solver's execution, results are put back into the database. The last component is the *customization- component*. This component is necessary to enable CAWP without knowing web programming. Site customization can be achieved by using this component. Figure 1 shows how WDP solver program interacts with the remaining components of the platform. *Optimizer-handler* seen in Figure 4 aims to provide interoperation of CAWP web platform and the CASS solver. Throughout the process, the handler plays the main *control-unit* role. It first checks whether there exists a WDP to be solved or not. If any, it translates the problem description kept in the database to the acceptable format of the CASS solver. Concurrently, it calls the CASS solver. Consequently, the problem is solved, the result is taken as generated output file, and put back into the database.

All technologies used in CAWP are open source. The overall system performance clearly depends on the performance of the technologies used. Performance issues related to the database system and web server that are used can be found in (MySQL, 2005) and (Apache, 2009), respectively. Aside from these, the critical component that effects the general performance is clearly the WDP solver. The relative performance of the CASS solver has been evaluated in (Brown and Shoham, 2009). In order to be able to better tuning of the CAWP system, we executed a series of performance test scenarios on Intel® Core™2 Duo 2.66 GHz CPU, 4GB Ram, Windows XP Professional environment. We created 10 different scenarios for every different number of good and bid instances. The test scenarios are generated with CATS tool (Brown et.al., 2000).Table 1 shows the average completion time of the executions in seconds. Even if there are 5000 bids to a single auction, the solver can still produce an answer within minutes. Also, if the number of bids is small even the auctions with greater number goods can be solved quickly. But still the major parameter that effects the solution time is the number of goods.

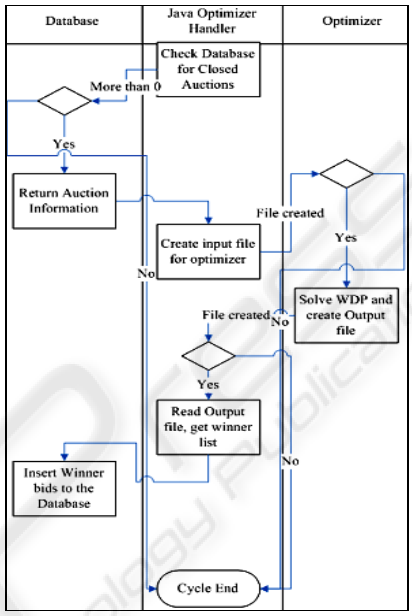

Figure 1: WDP solver interaction schema.

When we keep the number of bids as 5000 and increase the number of goods from 30 to 50 the completion time of the problem increases from 151.860 seconds to 3713.246 seconds, dramatically.

Increasing number of concurrent CASS solvers running on a single machine reduces the overall performance of the system (see Table 2). If aim is to increase the throughput of the system, concurrent solvers should run on different machines. One solver per processor gives the highest expected performance. The results in Table 2 are obtained by taking runs on a dual core machine where two or more solvers run on different CPUs.

In Figure 2, the NPC aspect of the problem solving operation can be seen. The completion time is sensitive to the number of goods variable I especially when I reaches to 50.Note that the CAWP system is not evaluated by their users in terms of its usability, yet.

Table 1: Average completion time results for the system tests.

Number of Goods	Number of Bids	Results (in seconds)
10	100	0.002
10	1000	0.016
10	3000	0.210
30	100	0.003
30	1000	0.047
30	3000	12.840
30	5000	151.860
40	100	0.015
40	1000	6.552
40	3000	126.017
40	5000	177.721
50	100	0.020
50	1000	8.424
50	3000	3713.246

Table 2: Performance results for many solvers running on a two- processor machine.

# of Solvers	# of Goods	# of Bids	Results (in seconds)
2	30	3000	17.34
3	30	3000	23.87
4	30	3000	35.31

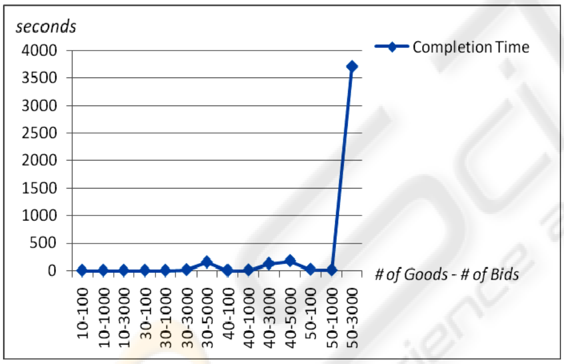

Figure 2: Completion time results for different instances of number of goods and number of bids pairs.

Finally, for our comparative purpose, we considered an example CA system namely Online Iterative Combinatorial Auction System (OICAS) (Fang and Wang, 2005). It is a prototype system implemented using Visual Basic and Microsoft Access. OICAS has following characteristics:

- The auctioneer can determine who can participate in an auction.
- Only legitimate users (bidders) can participate in an auction.
- Bidders can bid for any bundle of items with acceptable price.
- The system tells bidders the required minimum winning price for their bids automatically.

The main difference between OICAS and CAWP is that OICAS is an *offline* prototype implemented in Microsoft Visual Basic language and Microsoft Access database. On the other hand, CAWP is a true web application implemented using PHP for server side scripting, MySql for database management, Java for implementing optimizer handler, and C for the WDP solver. These components can be deployed and run on different machines. Also, although OICAS permits its auctioneers to choose their bidders, CAWP believes in the fairness for the bidders and it does not allow an auction to be limited for only a certain group of bidders.

4.3 An Example CAWP Usage For Custom Built Furniture Combinatorial Auctioning

A carpenter producing custom built furnitures can sell combinations of his products via CAWP in order to increase his revenue. However he needs a technical assistance to deploy and public his furniture combinatorial auction website, if otherwise he can do it himself. As the first step each different product categories are introduced to the system. Then an auctioneer account for the carpenter should be created. A list of available products to be auctioned are entered to the system by giving product name, category, description, picture, serial number and reserve price. Following this, an auction instance including auction name, duration and list of target items is generated. The auctioneer can open more than one auction. After this the bidding period is started. Within the auction period the system accepts bids from its registered users. For each bid the bidders should give the list of items to bid on and a valid price. By the end of auction period the system automatically initiates the optimizer in order to solve the generated WDP problem. The bidding results are announced at the site in individual basis. In other words a bidder is only informed about his winning status, rather then the others. For the time being the rest of the trading process is not supported by the system. On the other hand the auctioneer or the bidders can enter comments about their experience with the trading process.

5 CONCLUSIONS

In this paper, an online combinatorial auctioning platform CAWP is introduced. The platform provides its users to create and to participate in combinatorial auctions without having to care about either the complexity of the WDP or its efficient solution. The performance requirement of the system is clearly more higher than a typical online auctioning system. This is mainly due to the required involvement with an NP-Complete WDP problem. In our solution different technologies combined together and integrated under the platform. The technologies include server side web scripting, database management, solver handler, and the WDP solver. All these technologies, except the WDP solver have been created, originally. Using open source technologies enabled us to build an operating system independent platform.

In future, CAWP is planned to be supported by a third party payment system in order to achieve better trading opportunities. Also, the system may support a realistic mechanism to reward and penalize its users. A better WDP solver or a general purpose solver package can be adapted to the system in order to still increase the WDP solution performance.

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