On the Design of Multidimensional Procurement Auction Protocols
Lessons Learned from Real-World Implementations

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Outline

- Auctions in procurement – pros & cons
- Combinatorial procurement auctions
- What properties do we look for in a combinatorial auction?
- Why is the design of combinatorial auction protocols a difficult problem?
- Approaches to making the design tractable
Auctions as Negotiation Protocols for Procurement

- **Goal:**
  - Support for Industrial Procurement Negotiations

- **Pros**
  - Speed
  - (Pareto-) Efficiency
  - Stability
  - Fairness

- **Cons**
  - Price-only negotiations
  - Mostly single item / single unit
  - 1:n and m:n, not 1:1
  - Adding new issues: Can we make the cake bigger??

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Multidimensional Auctions

- The Internet allows to communicate and evaluate large amounts of market-relevant data in (quasi-) real-time

* Bichler et al., IBM Systems Journal, 2002
Combinatorial Auctions

- Complementarities between different assets
  - Bidders have preferences not just for particular items but for sets of bundles of items
  - Traveling to Banff
    - (restaurants and hotels for the intermediate cities, car)
    - or (airline ticket, taxi)

- Auctions where bidders submit bids on bundles
  - Internet + increases in computing power

Example

\begin{tabular}{|c|c|c|c|}
\hline
\text{Item} & \text{Bid} \\
\hline
\text{A, B} & 500 \\
\text{B, C} & 400 \\
\text{A, C} & 450 \\
\text{C} & 200 \\
\hline
\end{tabular}

\text{winners}

\begin{tabular}{|c|c|}
\hline
\text{A, B} & 500 \\
\text{C} & 200 \\
\hline
\end{tabular}
Examples of Bundles I

- Direct/indirect materials procurement
  - PC, Printer, UPS
  - Examples: WWRE; Mars, Incorporated; School meals in Chile
- Task allocation
  - Timeslot on M1, slot on M2, slot on M3
- Spectrum allocation
  - License for Spectrum 1, License for Spectrum 2
- Airport slot allocation
  - Slot at airport 1, slot at airport 2

Examples of Bundles II

- Logistics marketplaces
  - Munich to Calgary, Calgary to Banff, Banff to Munich
  - Applications: Sears, Home Depot, Logistics.com
- Bandwidth trading
  - Bandwidth for sector 1, sector 2
- Stock markets
  - Stock of company 1, Stock of company 2

➢ CAs are good for resource allocation problems where multiple items are traded and bids are submitted for (partial) bundles
Complexity Problems

- Winner Determination Problem
  - Set packing as an NP-hard optimization problem
- Valuation Complexity
  - Bidders need to determine valuations for $2^k - 1$ possible bundles
- Strategic Complexity
  - Which of the $2^k - 1$ bundles to bid on?
  - What is the best strategy for bidding?
- Communication Complexity
  - How many messages do bidders and auctioneer have to exchange until an equilibrium price is reached?

What do we want to achieve?

- Some yardsticks from mechanism design
  - Revenue maximization: The bid taker should extract the highest possible price
  - Efficiency: Maximize the valuations of all participants
- Classic mechanism design is based on the following foundations
  - Revelation Principle
  - VCG mechanisms / Vickrey auctions
- Can we pull the same trick on combinatorial auctions?
Generalized Vickrey Auctions

- **Rules**
  - Bidders with the highest overall revenue win
  - Winning bidders pay what they bid, but receive a Vickrey payment
  - Bidders have a simple dominant strategy of bidding their true valuation

\[ p_i = \sum_{j=1}^{m} \sum_{k=1}^{n} b_{ij} x_{jk} - \sum_{j=1}^{m} \sum_{k=1}^{n} b_{ij} x_{jk}^*. \]

- **Problems**
  - Bidders need to submit valuations for all possible bundles (valuation complexity!)
  - Winner determination on all possible bundles of all bidders
  - Computation of Vickrey prices in a GVA is again NP-hard
  - Bidders need to trust the auctioneer

GVA Example

Suppose seven bids only:

- \( b_1(\boxed{\text{green}}) = 4, \)
- \( b_2(\boxed{\text{blue}}) = b_3(\boxed{\text{blue}}) = b_4(\boxed{\text{blue}}) = b_5(\boxed{\text{gray}}) = b_6(\boxed{\text{gray}}) = 1 \)

- Bids 2, 3, 4, 5, 6 define the revenue maximizing collection
- Each winner get’s the goods for free!
What is the Challenge?

- Make the mechanisms "computationally feasible"
  - valuation complexity
  - strategic complexity
  - winner determination complexity
  - communication complexity

- "without compromising" on useful economic properties such as
  - allocative efficiency
  - strategy proofness or (less ambitious) incentive compatibility
  - individual rationality
  - budget balance
Alternatives

- First-price sealed bid auctions are strategically difficult
- Ascending auctions work well for single-item auctions
- Ascending auctions allow agents to provide information in an incremental way (→ APV)
- … they do have many other problems …

Problems … more Problems ;-)

- The source of many problems: Currently losing bid can become winner later due to action on other items.
  - invites bidder coordination and collusion
  - complicates the selection of active bids
- Exposure Problem
- Threshold Problem
- Winner Determination Problem
Winner Determination Problem

- Tight time constraints on the WDP
  - Approximate solutions are not an option
  - Many real-world instances are not too “large”
- Approaches to solve large problems
  - IP approaches (e.g., B&B, B&C)
  - Relegating complexity to the bidders (AUSM, PAUSE,...)
  - Limiting biddable combinations (Rothkopf 98)
  - Limiting use of combinatorial bids (max n bids)

Additional Challenges

- Tie Breaking
- Determining minimal bid increments
- Pricing and „helpful“ feedback for bidders
- Procedures for prevention of strategic bidding and signaling
- Procedures for keeping bidding moving
Conclusions

- Combinatorial auctions are an interesting approach to automate multi-item procurement negotiations
- Real-world applications pose a number of non-trivial design problems
- A number of iterative designs has been proposed, but there is no overall theory and little experimental evidence yet
- Finding „good“ designs needs experimental evaluation to see how bidders cope with complexity
- e-Negotiation session TC26: Computational challenges in iterative combinatorial auctions

Dilbert says …