Securing Auctions using Cryptography

Richard Barnes

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Outline

- Context: Definitions and roles
- Types of auctions
- Vulnerabilities and Approaches
- Cryptographic solutions
 - Adding security to a Vickrey Auction
 - Adding security to a Combinatorial Auction
 - Building in security into a novel mechanism

Context

- Once upon a time: Bartering
- Unfamiliar or unknown buyers and sellers
- Multi-party price negotiation
- Auction: An organized way for many buyers and a seller to agree on a price goods.

Types of Auctions

- English: Start low, bid up, highest bid wins. E.g. eBay, Sotheby's
- **Dutch:** Starts high, auctioneer drops price, first to bid wins. (Can go multiple rounds or sealed) E.g: Salon IPO
- **Double Auction:** Both buyers and sellers submit prices, matched by auctioneer. E.g: NYSE, NASDAQ, CBOT
- First-price sealed-bid: Bidders submit closed bids; highest wins. E.g: eBay proxy bidding

Types of Auctions

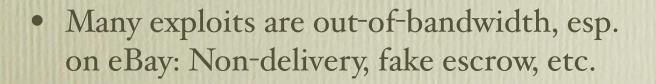
- Second-price sealed-bid or Vickrey: All bidders submit sealed bids, second-highest bid wins.
 - Maximizes seller revenue by encouraging upward bidding.
 - Optimal strategy is to bid private valuation.
 - Open to dishonest auctioneers.
- Generalizations: M-th price

Types of Auctions

- **Combinatorial Auction**: Given a pool of available goods, buyers bid on all possible allocations of these goods.
 - Maximizes seller revenue and social surplus
 - Winning allocation maximizes total price
 - Each bidder pays difference between the total price that would have been paid without him and the other bidders total payment.
- FCC uses a modified combinatorial auction to sell rights to EM spectrum.

Vulnerabilities

- Auction fraud: 46.1% of reported Internet frauds, Median loss \$320
- Bidders can collude to bid below their valuations (Insider trading) or place unreasonably high bids (Jump bidding)
- Auctioneers and sellers can insert bids to raise prices (Shill bidding) or tamper with Vickrey prices







Security Goals

- Prevent buyers, sellers, and auctioneers from tampering with the proper course of the auction.
- Provide privacy for buyers and sellers
 - Separate bid information from buyer identification.
 - Maintain secrecy of bids in sealed auction.

Approaches to Security

- Legislative: Make laws against breaking the rules of the auction, as for insider trading.
- Economic/Social: Provide economic incentives for following the rules, as with the eBay recommendation system.
- Cryptographic: Incorporate a cryptographic protocol to ensure that rules are followed.

Cryptographic Solutions

- Public auction + Cryptograpic privacy
- Combinatorial auction + Cryptographic enforcement
- Elkind & Lipmaa's novel protocol
- Many others exist, especially studying Vickrey auctions. Financial Cryptography has several recent examples.

Secure Public Auction

Lee, Kim, & Ma, Indocrypt 2001

- Provide bidders privacy and anonymity while keeping bid prices public.
- Introduce two agents:
 - Registration Manager: Tracks identities of bidders by tying their Diffie-Hellman public key to a secret string (unique for each bidder) and generates round keys.
 - Auction Manager: Prepares tickets and decides winner without knowing true identities.

Secure Public Auction

Lee, Kim, & Ma, Indocrypt 2001

- I. Bidders register with RM by providing public key, secret string. RM keeps secret string.
- II. RM creates, shuffles, and publishes a list of round keys, one for each bidder, based on public key and a hash of the secret string.
- III. AM creates "bidding tickets" consisting of a hash of a round key and an auction key.
- IV. Bidders find their tickets and place bids by posting their ticket ID and their price.
- V. The winning ticket is chosen, and the RM reveals a hash of the winner's secret string.

Secure Public Auction

Lee, Kim, & Ma, Indocrypt 2001

- At each step, the bidder can recognize information for himself, but AM, RM, and other bidders cannot:
- Round keys are shuffled, but tied to secret information.
- Tickets are based on round keys and common information.
- Bids are tied only to ticket ID numbers.

Secure Combinatorial Auction

Suzuki & Yokoo, FC2003

- Homomorphic crypto: E(ab) = E(a) E(b)
- Represent prices as "base-1" numbers:

$$\mathbf{e}(w) = (\underbrace{E(z), \dots, E(z)}_{w \text{ times}}, \underbrace{E(1), \dots, E(1)}_{n-w \text{ times}})$$

- Can find max. bid, add a constant without decrypting.
- Want to bid on allocations, i.e. maps $f: B^G \to P$
- Bid has the form: $\mathbf{E}(f) = (\mathbf{e}(f(A)))_{A \in B^G}$

Secure Combinatorial Auction

Suzuki & Yokoo, FC2003

- Each bidder has valuation function b_r
- Auctioneer creates "blank bids" E₀ = ··· = E_b = E(0)
 Each bidder adds his bid to every blank except the one with his number, so at the end,

$$\mathbf{E}_0 = \mathbf{E}(\sum_i b_i), \quad \mathbf{E}_x = \mathbf{E}(\sum_{i \neq x} b_i)$$

- E_0 tells which bid maximizes total price
- \mathbf{E}_x tells what would be paid without bidder x

Secure Combinatorial Auction

Suzuki & Yokoo, FC2003

- All calculations are performed on encrypted values.
- Neither buyers nor the auctioneer know the values of the individual bids.
- Tampering is obviated by lack of information.
- Hard part is complexity: $O(b^g)$

Elkind & Lipmaa's Auction

Elkind & Lipmaa, FC2004

- Goals:
 - Protect privacy of bidders
 - Prevent seller/auctioneer tampering
 - Minimize cognitive costs to bidders
- Perform a series of secure 2nd-price auctions until there is a stable selling price.

Elkind & Lipmaa's Auction

Elkind & Lipmaa, FC2004

- Before auction, agree on a shared masking function.
- For each round:
 - Bidders submit masked, encrypted bids to auctioneer, with a zero-knowledge proof that this bid is within a small range below the last bid.
 - All bids are published without names.
- Auction proceeds until second price stabilizes
- Identity of winner is determined by a distributed protocol matching the (unknown) max bid to its bidder.

Elkind & Lipmaa's Auction

Elkind & Lipmaa, FC2004

- Secure against shill bids, collusive bids, and jump bidding because bids are constrained to be decreasing.
- Secure against auctioneer tampering because all bids are encrypted.
- Maintains anonymity of all bidders except winner.

Summary

- Auctions play a central role, as a way of organizing price negotiations.
- Many security vulnerabilities introduced by auction mechanisms can be addressed with cryptographic auction protocols.
- Cryptographic protocols can also add privacy features lacking in normal mechanisms.
- However, protocol solutions don't address other attacks, e.g. bait-and-switch.

References

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