Prior Free Profit Maximization: Random Sampling Auctions

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- Can we think about revenue in a distribution independent way?
- This lecture: A case study "digital goods auctions"

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Definition

A digital goods auction is a single parameter domain with a set of alternatives $A = \{S \subseteq [n]\}$ – i.e. *any* set of bidders is a feasible outcome. For $a \in A$ we write $a_i = \begin{cases} 1, & \text{if } i \in S; \\ 0, & \text{otherwise.} \end{cases}$. Each bidder's valuation function is parameterized by $v_i \in \mathbb{R}_{\geq 0}$, and $v_i(a) := v_i \cdot a_i$.

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- To maximize revenue, we'll need to artificially limit supply.
- But first, what should our benchmark be?

Revenue Benchmark

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- When we had a prior distribution D, we could define the *optimal* revenue.
- But what is a reasonable benchmark?
- If we knew D, the revenue optimal auction would correspond to a fixed price $p = \phi^{-1}(0)$.
- So if we could compete with the revenue of the *best* fixed price we'd be competing with the (unknown) Bayesian optimal benchmark.

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- The best fixed price in hindsight is always $p \in \{v_1, \ldots, v_n\}$. (why?)
- The revenue of the best fixed price is therefore:

$$\mathrm{OPT}(v) = \max_i v_i \cdot |\{j : v_j \geq v_i\}| = \max_i (i \cdot v_{(i)})$$

where $v_{(i)}$ is the i'th highest valuation in sorted order.

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  where $v_{(i)}$ is the i'th highest valuation in sorted order.
- ... But this isn't attainable by any truthful mechanism when $i = 1$. Consider the case of $n = 1$.

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- A slightly weaker benchmark: the revenue of the best fixed price *that sells to at least 2 people*.

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- How should we obtain it?
- Attempt 1: Just compute the best fixed price v_j from the bids and use that. (Not truthful).

Fixed Price Benchmarks

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Example

Suppose we have 90 "low value" agents with $v_i = 1$, and 10 "high value" agents with $v_i = 10$. $\mathrm{OPT}^{\geq 2}(v) = 100$, achieved by charging either $p = 10$ or $p = 1$. But for $v_i = 1$, $\mathrm{OPT}^{\geq 2}(v_{-i}) \leftrightarrow p_i = 10$, and for $v_i = 10$, $\mathrm{OPT}^{\geq 2}(v_{-i}) \leftrightarrow p_i = 1$. So this auction gets profit only 10... (And the ratio to $OPT^{\geq 2}(v)$ can be made arbitrarily bad.)

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Definition

The digital goods profit extractor with target profit R (Extract(R, v)) does the following: it finds the largest value k such that $v_{(k)} \geq R/k$, and then sells to the top k bidders at price R/k. If there is no such k, it sells to nobody.

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Lemma

Extract(R, v) is dominant strategy truthful.

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- Similarly, accepting an offer of $p > v_i$ is a dominated strategy since prices only rise.
- Hence the dominant strategy for every bidder i is to report their true value.

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- Hence, the profit extractor finds some $k' \geq k$ such that $v_{(k')} \geq R/k'$, and obtains profit $k' \cdot R/k' = R$.

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- Hence, the profit extractor finds some $k' \geq k$ such that $v_{(k')} \geq R/k'$, and obtains profit $k' \cdot R/k' = R$.
- If $R > \mathrm{OPT}^{(2)}(v) = \max_k k \cdot v_{(k)}$, then there is no k such that $v_{(k)} \geq R/k$. So the mechanism halts without selling to anybody.

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- But we're not done, since we don't know R.
- We've reduced our problem to finding a good *estimate* of the true optimal revenue R^*.
- For truthfulness, it is important that R is defined independently of the bidders we run the profit extractor on.

The Random Sampling Auction

Idea: Try and estimate R^* from a random sample of the bidders, and then run the profit extractor on the remaining bidders.

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RS(v):

Randomly partition the agents by assigning each agent uniformly at random to one of two sets: S' or S''.
Calculate $R' = \mathrm{OPT}^{\geq 2}(v_{S'})$ and $R'' = \mathrm{OPT}^{\geq 2}(v_{S''})$.
Run Extract$(R', v_{S''})$ on S'' and Extract$(R'', v_{S'})$ on S'.

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Proof.

Extract(R, v) is truthful whenever it is run with a value R computed independently of the bidders it is run on. □

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So it remains to understand $\min(R', R'')$ as a function of $R := \mathrm{OPT}^{\geq 2}(v)$.

Some Simple Math

Theorem

If we flip $k \geq 2$ coins, then $\mathbb{E}[\min(\#heads, \#tails)] \geq k/4$.

Proof.

$\square$

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- Now define $X_i := M_i - M_{i-1}$, the expected change to $\min(\#\text{heads}, \#\text{tails})$ after we flip the i'th coin.

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- By linearity of expectation:

$$M_k = \sum_{i=1}^{k} X_i$$

so we are done if we can compute X_i for all i.

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So:

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(Actually, we were a little sloppy... we only showed that $M_k \geq \lfloor \frac{k}{2} \rfloor \cdot \frac{1}{2}$, which might be a little less than $k/4$. To be fully rigorous, we have to directly verify that $X_3 = 1/4$ which makes up the difference).

The Random Sampling Auction

Theorem

Let Rev be the expected revenue of the random sampling auction. Then:

$$Rev \geq \frac{\mathrm{OPT}^{\geq 2}(v)}{4}.$$

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- This was only because we needed to handle the case in which the optimal auction sold to only 2 people.
- Similar ideas lead to a $(1+\epsilon)$ approximation of $\mathrm{OPT}^{\geq k}(v)$ as k becomes large.

Thanks!

See you next class — stay healthy!