CS243: Introduction to Algorithmic Game Theory

Week 8.2 Mechanism Design in Social Networks (Dengji ZHAO)

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Recap: Sponsored Search Auction Model

- A set of advertisers/bidders (n), each specify a list of pairs of keywords and bids as well as a total budget (daily/weekly/monthly).
- A search engine with $m < n$ number of ad slots. The search engine estimates a click through rate α_{ij}, the probability that a user will click on the ith slot when it is occupied by bidder j. Assume that $\alpha_{ij} \geq \alpha_{i+1j}$ for $i = 1, ..., m-1$.
- The search engine also assigns a weight w_j to each advertiser j. The weight can be thought of as a relevance or quality metric.

Recap: Generalized Second Price (GSP) Auctions

For each search of a keyword, GSP does the following to allocate ads:

- Rank advertisers by their score $b_j w_j$.
- The highest score gets the first slot, the second highest score gets the second slot and so on.
- A bider pays per click the lowest bid necessary to retain his position.

Two different variants:

1. Rank by bid (used by Overture): assume that $w_j = 1$
2. Rank by revenue (used by Google): assume that $w_j = \alpha_{1j}$

Revenue Maximization Mechanism Design

Design Goal

How can a house-seller sell her house with the "highest" profit?

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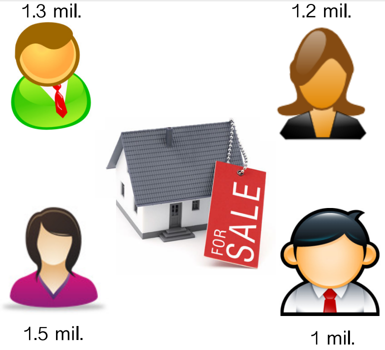

- **Challenge**: the seller doesn't know how much the buyers are willing to pay (their valuations).

Revenue Maximization Mechanism Design

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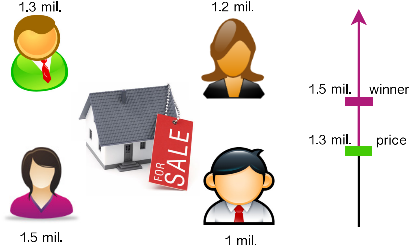

Solution: Second Price Auction (Vickrey Auction/VCG)

- Input: each buyer reports a price/bid to the seller
- Output: the seller decides
  - *allocation*: the agent with the highest price wins.
  - *payment*: the winner pays the second highest price.

Revenue Maximization Mechanism Design

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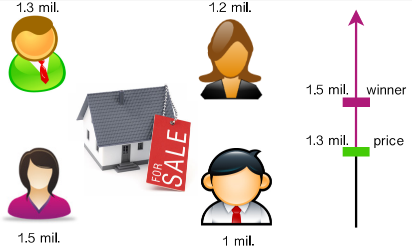

Solution: Second Price Auction (Vickrey Auction/VCG)

Properties:

- Efficient: maximising social welfare
- Truthful: buyers will report their highest willing payments

Is this the best the seller can do?

Question

What can the seller do to further increase her profit?

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- estimate a good reserve price [Myerson 1981]
- promotions: let more people know/participate in the auction [ads]

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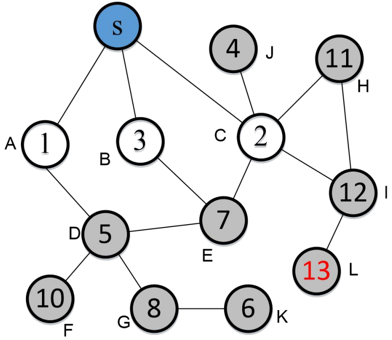
Promote a Sale in Social Networks



- The seller (blue node) sells one item and has only three connections in the network (A,B,C).
- Each node is a potential buyer and the value is her highest willing payment to buy the item (valuation).
- Profit of applying second price auction without promotion is 2.
- but the highest willing payment of the network is 13.

Traditional Sale Promotions

Traditional sale promotions:

- Promotions in shopping centres
- Keywords based ads via search engines such as Google
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Challenge

- The return of these promotions are unpredictable.
- The seller may lose from the promotions.

To Tackle the Challenge

Build promotion inside the market mechanism such that

1. the promotion will never bring negative utility/revenue to the seller.
2. all buyers who are aware of the sale are incentivized to diffuse the sale information to all her neighbours.

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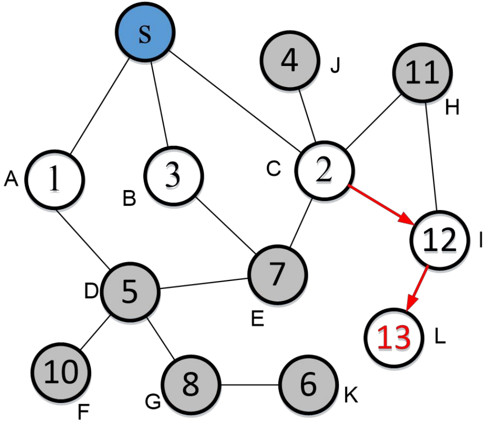
"Diffusion Mechanism Design"

The Challenge

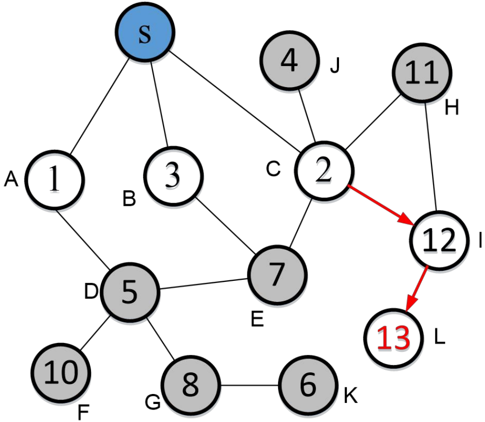
Why a buyer would bring more buyers to compete with her?



The Challenge

Why a buyer would bring more buyers to compete with her?

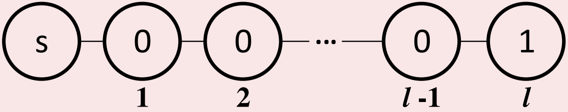
- Only if their efforts are rewarded!



Will (extended) VCG solve the challenge?

- *The allocation*: allocate the item to the highest bidder
- *The payment*: every bidder pays the social welfare loss of the others caused by the bidder's participation

Problem: negative revenue to the seller



The revenue of the seller is $-(l-1)$.

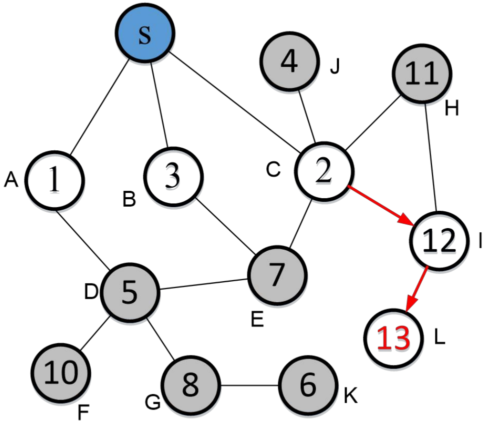
Our Solution

Information Diffusion Mechanism [Li et al. 2017, AAAI]

Information Diffusion Paths

One information diffusion path from the seller to node L:

$s \to C \to I \to L$



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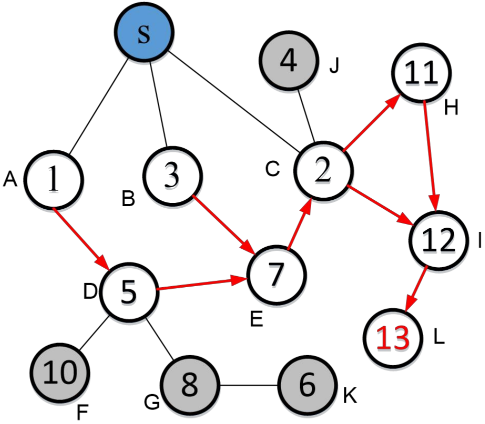
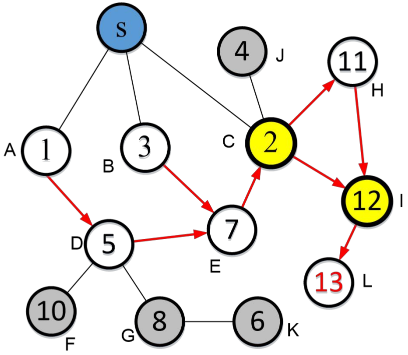


Diffusion Critical Nodes



Definition

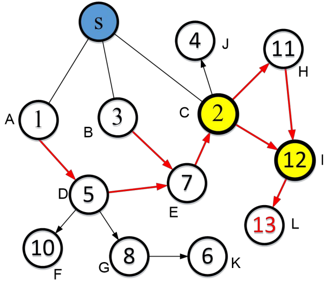
i is j's diffusion critical node if all the information diffusion paths started from the seller s to j have to pass i.

- nodes C and I are L's only diffusion critical nodes.

The Information Diffusion Mechanism

The **payment** definition:

- If a buyer or one of her "*diffusion critical children*" gets the item, then the buyer pays the highest bid of the others (without the buyer's participation);
- otherwise, her payment is zero.



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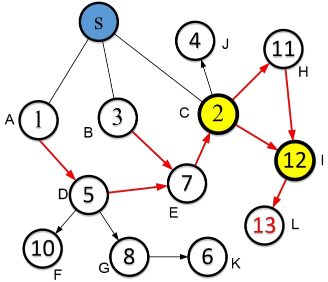


If the item is allocated to L, the payments of C, I and L are 10, 11, 12 respectively .

The Information Diffusion Mechanism

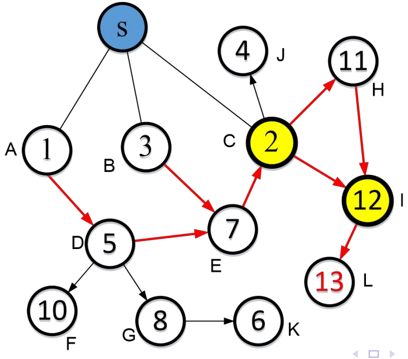
The **allocation** definition:

- Identify the node i with the highest bid and the node's diffusion critical node path $P_{c_i} = (c_i^1, c_i^2, ..., i)$.
- Give the item to the first node of P_{c_i}, the node pays to the seller and then decides to whether keep the item or pass it to the next node in P_{c_i}:
  - If pass the item to the next node in P_{c_i} and the payment of the next node is greater than the bid of the current node, then pass it to the next node and the next node makes another decision;
  - otherwise, keep the item.

The Information Diffusion Mechanism

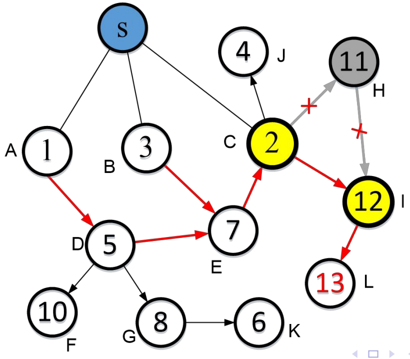
The outcome of the Information Diffusion Mechanism:

- the item is allocated to node I.
- node I pays 11 to C, C pays 10 to the seller.
- the utilities of I, C, the seller are $1, 1, 10$.

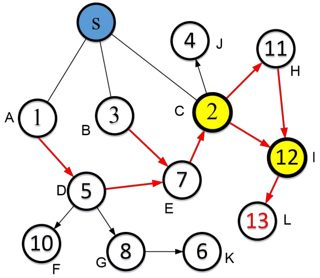


Why Buyers are Happy to Diffuse?

- buyers receive the information earlier choose earlier than those receive the information later.
- diffuse the information to more buyers will potentially increase their reward.



Properties of the Information Diffusion Mechanism



- Truthful: report true valuation and diffuse the sale information to all her neighbours is a dominate strategy.
- Individually Rational: no buyer will receive a negative utility to join the mechanism.
- Weakly Budget Balanced: the seller's revenue is non-negative and is $\geq$ that of the VCG with/without diffusion.

What Next?

- Diffusion mechanisms for combinatorial exchanges
- Diffusion with costs and delays
- Network structure based revenue analysis
- Applications/implementations in the existing social networks
- Other mechanisms to further improve the revenue and/or the efficiency

Challenge

How to generalise the mechanism to combinatorial settings?

Diffusion Mechanisms for Combinatorial Exchanges

Consider the following simple setting:

- A seller sells multiple units of the same goods, e.g. MacBook computers.
- Each buyer has a diminishing marginal utility in the the consumption of the goods.

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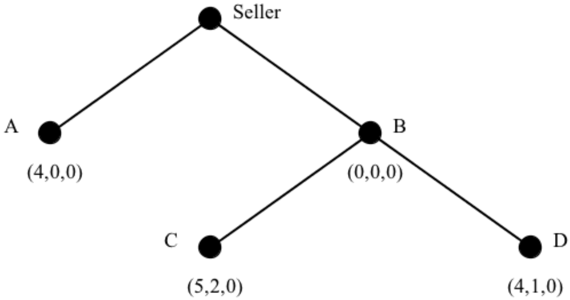
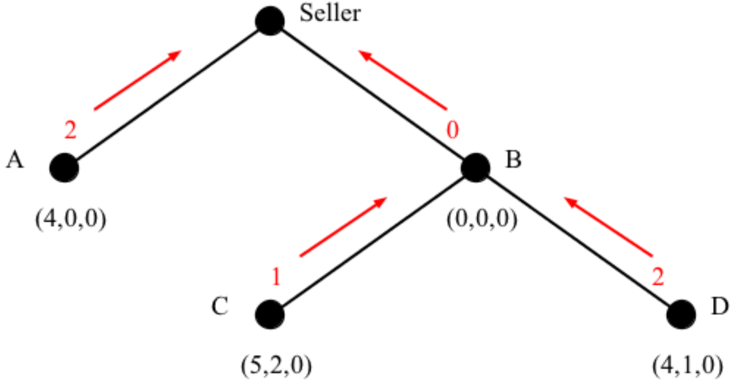


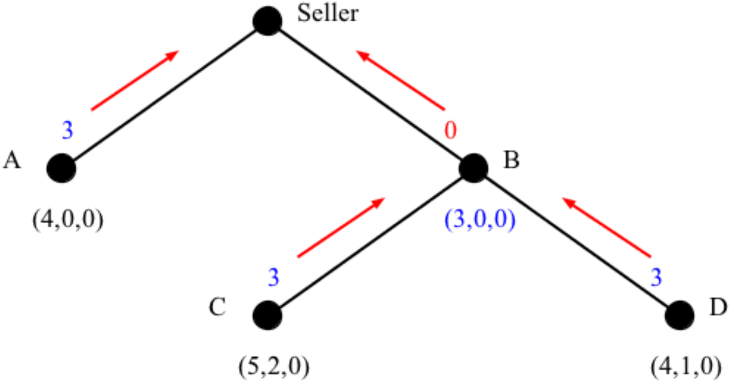
Diffusion Mechanisms for Combinatorial Exchanges

We can simply apply our information diffusion mechanism:



Diffusion Mechanisms for Combinatorial Exchanges

What if buyer B's valuation is $(3, 0, 0)$?



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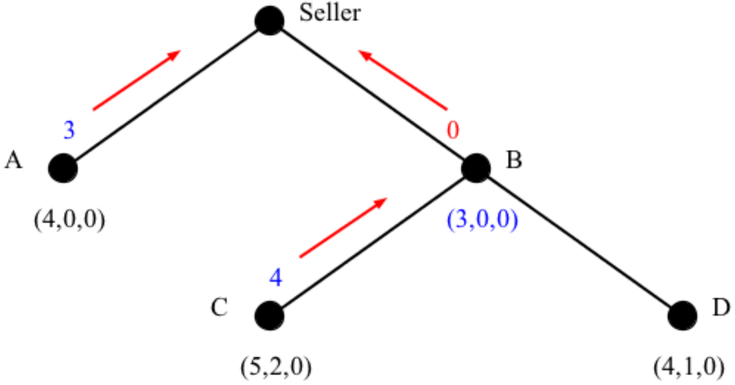
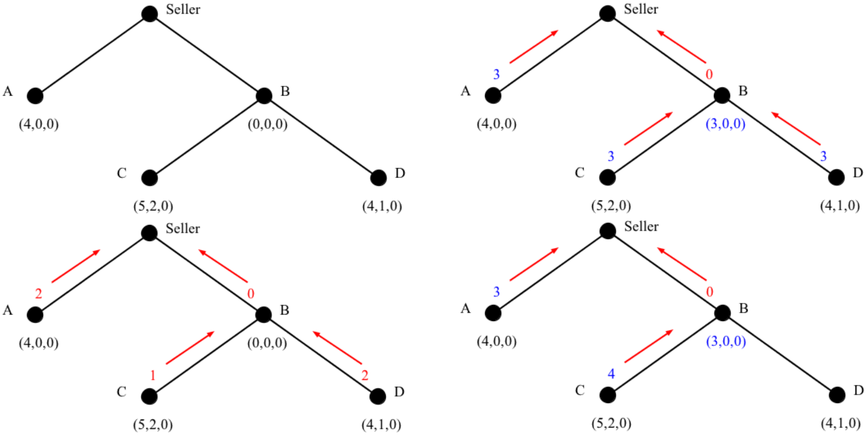


Diffusion Mechanisms for Combinatorial Exchanges

Challenge

There is a very complex Decision Making at each node!!!



Advanced Reading

- AGT Chapter 28. Sponsored Search Auctions
- Bin Li, Dong Hao, Dengji Zhao, Tao Zhou: Mechanism Design in Social Networks. AAAI 2017.