Algorithmic Game Theory

Mechanism Design: Multi Parameter Environments

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Based on slides by Alexandros Voudouris

General environments

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- A finite set Ω of **outcomes**

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- **Our goals:**
  - Incentivize the agents **to truthfully report their values**
  - Choose an outcome that **maximizes the social welfare**

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- In general, the agents might have different values for the possible winners of the item

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- Each agent i has a private value $v_i(S)$ for every possible bundle $S \subseteq M$ of items
  - Each agent i has 2^m parameters

Valuation Functions

A function f is

- Submodular: $f(S \cup \{j\}) - f(S) \geq f(T \cup \{j\}) - f(T)$
  for any $S \subseteq T$, and $j \notin T$
- Supermodular: $f(T \cup \{j\}) - f(T) \geq f(S \cup \{j\}) - f(S)$
  for any $S \subseteq T$, and $j \notin T$
- Symmetric: $f(S)=f(T)$ when $|S|=|T|$
- Symmetric Submodular: Submodular and Symmetric
- Subadditive: $f(S \cup T) \leq f(S) + f(T)$, for any S, T

Symmetric Submodular ⊆ Submodular ⊆ Subadditive

VCG mechanisms

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- **Allocation rule:** Maximize the social welfare according to the input

$$\boldsymbol{x}(\boldsymbol{b}) = \arg\max_{\omega \in \Omega} \sum_i b_i(\omega)$$

- **Payment rule:** For a set of functions $h_1, \ldots, h_n$ such that h_i is independent of the bid of agent i,

$$p_i(\boldsymbol{b}) = h_i(\boldsymbol{b}_{-i}) - \sum_{j \neq i} b_j\big(\boldsymbol{x}(\boldsymbol{b})\big)$$

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&= v_i\big(\boldsymbol{x}(\boldsymbol{b})\big) + \sum_{j \neq i} b_j\big(\boldsymbol{x}(\boldsymbol{b})\big) - h_i(\boldsymbol{b}_{-i})
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The social welfare according to the true value of agent i and the bids of the other agents

VCG mechanisms

- Agent i cares about the welfare of all agents (based on the reported valuations) and aims to maximize the quantity

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- Therefore every agent i truthfully reports her true values
- The mechanism is designed so that the incentives of the agents are aligned with the goal of maximizing the social welfare ▢

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- There are a lot of different VCG mechanisms, depending on how we choose the h-functions
- We would like to have reasonable payment rules, that satisfy a couple of properties:
  - **Individual rationality:** Every agent has non-negative utility, and therefore incentive to participate
  - **No positive transfers:** The mechanism does not pay the agents, the agents pay the mechanism

Clarke payments

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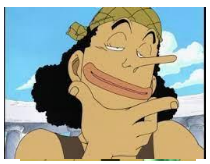
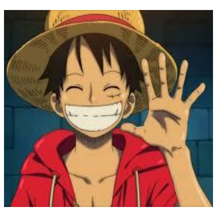
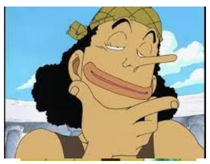
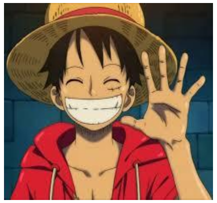
- The payment of agent i is the difference between the maximum social welfare of the other agents when she does not participate, and the social welfare when she participates
- Agent i pays the loss in welfare due to her participation

Example

		
	5	4
	2	6

Example

		
	5	4
	2	6

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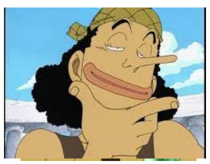
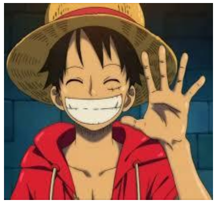
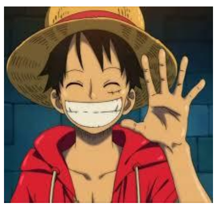
	5	1
	3	2

Payment of agent 1:

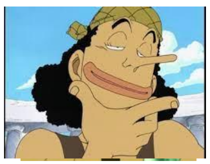
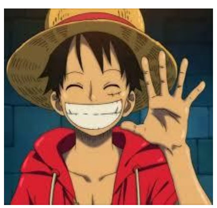
Example



3 2

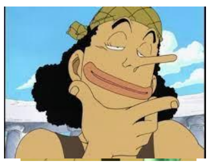
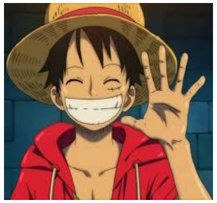
Payment of agent 1: 3-…

Example

		
	5	1
	3	2

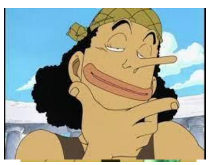
Payment of agent 1: 3-2=1
Utility of agent 1: 5-1= 4

Example

		
	5	1
	3	2

Payment of agent 2:

Example



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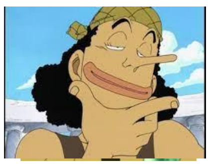
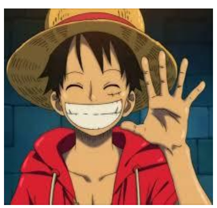
1

Payment of agent 2: 5-...

Example

		
	5	1
	3	2

Payment of agent 2: 5-5=0
Utility of agent 2: 2-0=2

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$$= \max_{\omega \in \Omega} \sum_{j} v_j(\omega) - \max_{\omega \in \Omega} \sum_{j \neq i} v_j(\omega) \geq 0$$

□

Drawbacks of VCG mechanisms

- **Preference elicitation:** VCG mechanisms demand from each agent to communicate her values for every possible outcome
  - Not practical in many situations: communicating 2^m parameters in the case of combinatorial auctions is impossible, even for small m

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- **Social welfare maximization might be a hard problem**
- Knapsack auctions:
  - each agent i demands w_i items and has a private value v_i
  - the seller has a total amount of W items
  - Even though every agent has only one private parameter, maximizing the social welfare is equivalent to the Knapsack problem, which is NP-hard

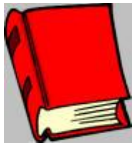
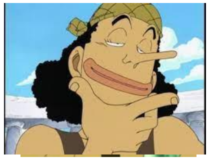
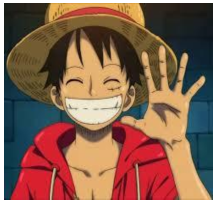
- Exercise: Consider the following setting, we have n players and m items and we want to allocate the items to the players. By allocating we mean that the players will get the items without paying something (this is a problem without payments). Each player has a value for each of the items and these values might be different. Consider the following mechanism (Round-Robin Mechanism): The players are ordered in an arbitrary way and the mechanism runs in rounds following this ordering. In each round a player, when his order comes, chooses his most desirable item among the remaining ones i.e. the first player gets his most desirable item, the second player gets his most desirable item among the ones that remain and so on. So if we have n players {1,2,..., n} the mechanism runs as follows and with each agent getting his most desirable item among the ones that remain, 1-> 2-> 3->...-> n-> 1-> 2->..., until we run out of items. Is this mechanism truthful? Explain your answer.

- Exercise 4: Consider the previous problem once again but now under the following mechanism: The players are ordered in an arbitrary way and the mechanism runs following this ordering. In each round a player, when his order comes, chooses his most desirable item among the remaining ones and the last player gets all the remaining items. Thus, there is only one round this time and the last player is the only one that might get more than one items. Is this mechanism truthful? Explain your answer.

Round Robin

- The agents declare their bids for the goods
- Round Robin
  - Order the agents in an arbitrary way
  - For $i = 1$ to n give to each agent her favorite good
    - According to what she declared
  - Repeat step 2 until there are no more goods

Example

				
	5	4	3	2
	2	4	1	3

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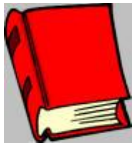
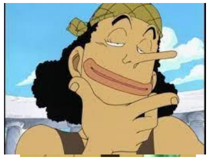
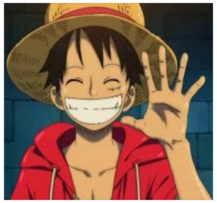
				
	5	4	3	2
	2	4	1	3

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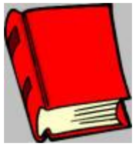
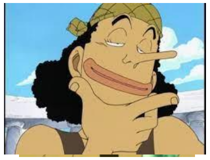
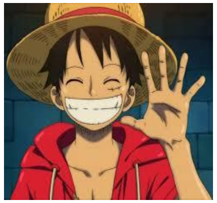
				
	5	4	3	2
	2	4	1	3

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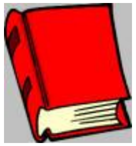
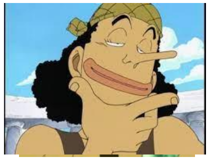
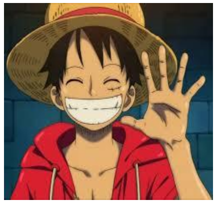
				
	5	4	3	2
	2	4	1	3

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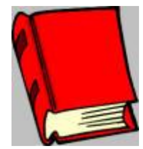
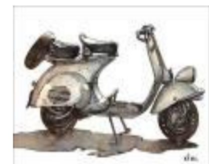
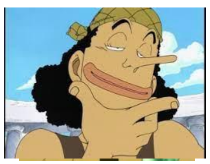
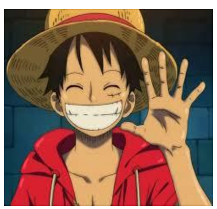
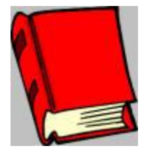
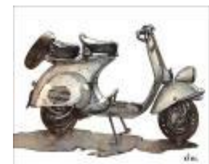
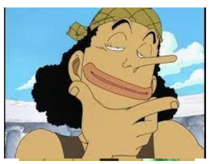
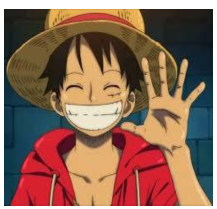
				
	5	4	3	2
	2	4	1	3

Example

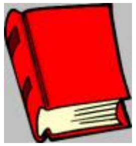
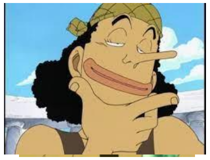
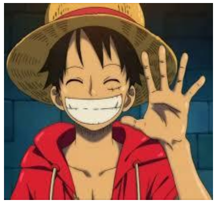
				
	5	4	3	2
	2	4	1	3

Agent 1 gets a utility of 8
Agent 2 gets a utility of 7

Round Robin and EF1

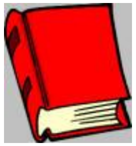
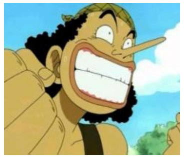
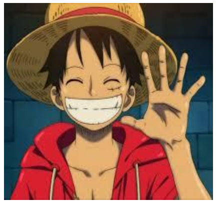
- Property: If an agent declares her true values for the goods, then the produced allocation is EF1 for her (EF if she is agent 1)

Truthful Reporting

				
	5	4	3	2
	2	4	1	3

Agent 1 gets a utility of 8
Agent 2 gets a utility of 7

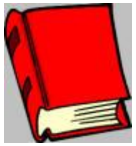
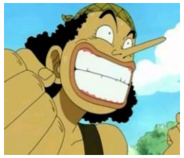
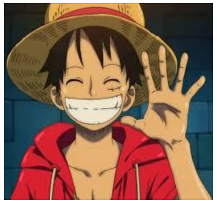
Agent 1 Deviates

				
	5	4	3	2
	4	5	3	2
	2	4	1	3

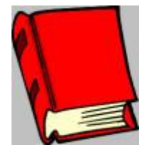
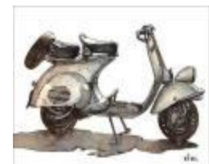
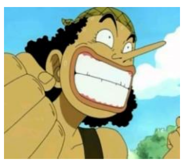
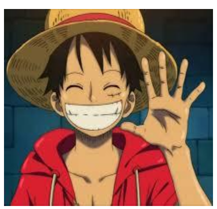
True

Reported

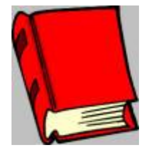
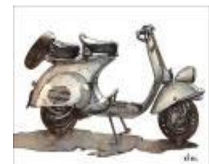
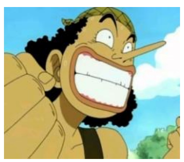
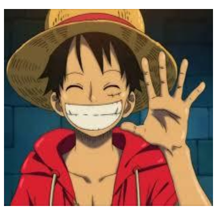
Agent 1 Deviates

				
	4	5	3	2
	2	4	1	3

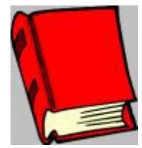
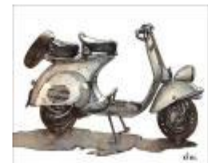
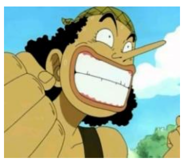
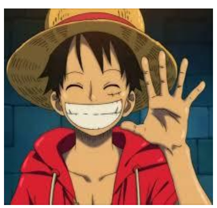
Agent 1 Deviates

				
	4	5	3	2
	2	4	1	3

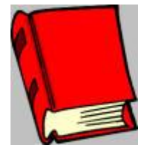
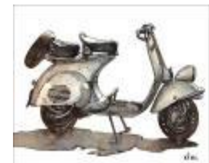
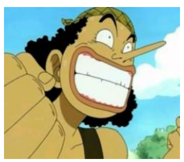
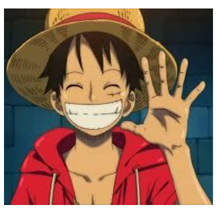
Agent 1 Deviates

				
	4	5	3	2
	2	4	1	3

Agent 1 Deviates

				
	4	5	3	2
	2	4	1	3

Utilities after the Deviation

				
	5	4	3	2
	2	4	1	3

Agent 1 gets a value of 9>8
Agent 2 gets a value of 4