An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Liu Qing
Supervisor: Stéphane Bressan
Introduction

- Crowdsourcing: a new form of labor market
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  - AMT, Click Worker, TopCoder, Taskcn.
- Common tasks
  - Image labeling, article translation, logo design
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  - Workers are independent
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- However, many tasks require cooperation among different workers with specific skills.
  - Updating an entry in Wikipedia, several workers may be needed, each contributes to a part of this entry based on her own knowledge.
  - Developing a software, a group of workers are needed, where some of them are good at interface design, while some others are good at algorithm, etc.
Future crowdsourcing platforms need to support collaboration [Kittur et al., 2013].
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- Experts crowdsourcing: a task need to be completed by a team of workers who have specific skills.
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- workers’ interest [DiPalantino and Vojnovic, 2009]
- effort [Chen et al., 2010]
- attractiveness to more experienced workers [Mason and Watts, 2010]
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- Whom should be selected?
- Payment?
Related Work

- Pricing mechanisms
- Team formation
- Task allocation
In [Singer and Mittal, 2013], the authors design a framework for tasks pricing and allocation by allowing workers to bid for the tasks. They aim at maximizing the number of completed tasks under a budget.
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Authors of [Minder et al., 2012] try to find the number of feasible allocations to assign $m$ tasks under time and quality constraint. They use the “VCG” mechanism to decide the payment to each worker.
The authors of [Singla and Krause, 2013] adopt the model of "multi-armed bandits", different prices are the "arms". They design a posted price mechanism for the task allocation under a budget and try to minimize the requester’s "regret".
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In [Goel et al., 2014], workers and tasks are modeled as a bipartite graph where an edge represents the worker is willing to the task. They assign the task by finding a matching and aim to maximize the utility of the completed tasks.
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The above mechanisms are primarily designed for the scenarios where tasks can be performed by single workers.
The job scheduling problem relates to the task allocation problem. It has been studied since [Graham, 1972] and many subsequent studies.
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[Azar, 1992] aims at minimizing the load of the machines who have the maximal work load, which is most related to the team formation problem.
The authors of [De Weerdt et al., 2007] propose a new variant of the task allocation problem.
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- Workers are connected in a social network, they only have local knowledge about resources.
- Tasks can only be assigned to its neighbour workers.
- This problem aims at maximizing the total utility of the completed tasks and is proved to be NP-hard.
In [Balog and De Rijke, 2007, Lappas et al., 2009], the authors select a team of workers for a task by considering both individual skills profile and communication costs between workers.

The authors of [Anagnostopoulos et al., 2010] select a team in a way of minimizing the load of workers who have maximal work load.

Same authors consider both workload and communication costs when selecting a team to perform the task [Anagnostopoulos et al., 2012].
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Related Work - Our work

- Task allocation
- Pricing mechanisms
- Team formation
### Background - Auctions

#### Example

<table>
<thead>
<tr>
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<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
<tr>
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- 1 item
Background-Auctions

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- 1 item
- 5 bidders: A, B, C, D, E
Background-Auctions

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- 1 item
- 5 bidders: A, B, C, D, E
- Sealed bid auction
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Background

Auction

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- 1 item
- 5 bidders: A, B, C, D, E
- Sealed bid auction
- Valuation: maximum willingness-to-pay for the item (private)
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- 1 item
- 5 bidders: A, B, C, D, E
- Sealed bid auction
- Valuation: maximum willingness-to-pay for the item (private)
- Strategies: the bid
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Auction

Background-Auctions

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\[
\text{Payoff} = \begin{cases} 
\text{valuation} - \text{payment} & \text{if win} \\
0 & \text{if lose} 
\end{cases} \tag{1}
\]
Background-Auctions

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Table: Results

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Background

Definition
A mechanism \((f, p_1, ..., p_n)\) is called **truthful** if for every bidder \(i\), every \(v_1 \in V_1, ..., v_n \in V_n\) and every \(v'_i \in V_i\), if we denote \(a = f(v_i, v_{-i})\) and \(a' = f(v'_i, v_{-i})\), then
\[
v_i(a) - p_i(v_i, v_{-i}) \geq v_i(a') - p_i(v'_i, v_{-i}).\]
[Nisan et al., 2007]

- \(f\) is the allocation rule, input: bids, output: who gets what
- \(p_i\) is the payment of bidder \(i\)
- \(v_i\) is bidder \(i'\) valuation towards the item
- \(V_i\) is the domain of \(v_i\)
- \(v_{-i}\) is all other bidders valuation toward this item except bidder \(i\)
Background

Intuitively, this means that bidder $i$ whose valuation is $v_i$ would prefer “telling the truth” $v_i$ to the mechanism rather than any possible “lie” $v'_i$, since this gives her higher (in weak sense) utility.
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Advantages of *truthfulness*

- Easy for bidders to choose their strategies, just bid the true valuation
- Easy for seller to predict the auction’s outcome (knowing bidders’ true valuations)
Problem Definition

- Requester
  - Has a task
  - Select workers
  - Decide the payment
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- Task
  - Has value of $v$, the revenue
  - Require several skills
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- Task
  - Has value of \( v \), the revenue
  - Require several skills

- Workers
  - \textit{Skills}
  - \textit{Cost} (minimum willingness-to-get-paid)
  - Report the skills and cost
Problem Definition

- **Utility of the requester**

\[
U_R = \begin{cases} 
    v - \sum_{w_i \in S} p_i & \text{if task is completed} \\
    0 & \text{otherwise} 
\end{cases} \quad (2)
\]

$S$: set of selected workers. $p_i$: payment to worker $w_i$. 

- **Utility of the worker**

\[
u_i = \begin{cases} 
    p_i - c_i & \text{if worker } w_i \text{ is selected} \\
    0 & \text{otherwise} 
\end{cases} \quad (3)
\]

$c_i$: cost of worker $w_i$. 

Problem Definition

- Utility of the requester

\[ U_R = \begin{cases} v - \sum_{w_i \in S} p_i & \text{if task is completed} \\ 0 & \text{otherwise} \end{cases} \]  

\( S \) : set of selected workers. \( p_i \) : payment to worker \( w_i \).

- Utility of the worker

\[ u_i = \begin{cases} p_i - c_i & \text{worker } w_i \text{ is selected} \\ 0 & \text{otherwise} \end{cases} \]  

\( c_i \) : \( w_i \)'s cost.
Problem Definition

- Both the requester and the workers want to maximize their utilities
Problem Definition

- Both the requester and the workers want to maximize their utilities.
- Assumptions
  - Workers can not hide their skills. (certificate, qualification test, etc.)
  - Workers may hide their cost, $b_i \neq c_i$
Problem Definition

- Both the requester and the workers want to maximize their utilities
- Assumptions
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- Reversed auction

<table>
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<tr>
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<th>traditional auction</th>
<th>reversed auction</th>
</tr>
</thead>
<tbody>
<tr>
<td>seller</td>
<td>auctioneer</td>
<td>bidders(workers)</td>
</tr>
<tr>
<td>buyer</td>
<td>bidders</td>
<td>auctioneer(requester)</td>
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Problem Definition

- Design objectives
  - Design a mechanism for the requester
    - who to perform the task
    - how much should pay
    - minimize the total payment
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- Design objectives
  - Design a mechanism for the requester
    - who to perform the task
    - how much should pay
    - minimize the total payment
  - The mechanism should satisfy individual rationality, profitability, truthfulness and computational efficiency.
Problem Definition

- Properties
  - Individually Rational.
    - Each worker’s utility should be non-negative if selected.
  - Profitable.
    - Requester’s utility should be non-negative if task is completed.
  - Truthful.
    - \( u_i \geq u'_i \).
    - \( u_i \) is the utility of worker \( w_i \) when she bid truthfully, \( b_i = c_i \).
    - \( u'_i \) is the utility of worker \( w_i \) when she bid untruthfully, \( b'_i \neq c_i \).
  - Computationally Efficient.
    - Compute in polynomial time.
The first Mechanism OPT

- choose the team from the $2^n - 1$ possible teams ($n$ is num. of workers)
  - cover the required skills of the task
  - total bid of which is the smallest
- Pay each selected worker her bid
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  - total bid of which is the smallest
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Properties

- Not computationally efficient ($O(2^n)$)
- Individually rational ($p_i = b_i$, $b_i \geq c_i$)
- Profitable
- Not truthful
The first Mechanism OPT

- choose the team from the $2^n - 1$ possible teams ($n$ is num. of workers)
  - cover the required skills of the task
  - total bid of which is the smallest
- Pay each selected worker her bid

Properties

- Not computationally efficient ($O(2^n)$)
- Individually rational ($p_i = b_i$, $b_i \geq c_i$)
- Profitable
- Not truthful
The second mechanism GREEDY

- Small bids (per “skill contribution”) first
- Pay each selected worker her bid
GREEDY-Example

b1 = 4

W1

b2 = 12

W2

b3 = 6

W3

b4 = 15

W4

V = 50
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

GREEDY

GREEDY-Example

\[ b_1 = 4 \]
\[ b_2 = 12 \]
\[ b_3 = 6 \]
\[ b_4 = 15 \]

\[ W_1 \]
\[ W_2 \]
\[ W_3 \]
\[ W_4 \]

\[ V = 50 \]
GREEDY-Example

- $b_1 = 4$
- $b_2 = 12$
- $b_3 = 6$
- $b_4 = 15$

- $W_1$
  - $4/1 = 4$

- $W_2$
  - $12/2 = 6$

- $W_3$
  - $6/2 = 3$

- $W_4$
  - $15/3 = 5$

- $V = 50$
GREEDY-Example

\[ b_1 = 4 \]

\[ \begin{array}{c}
1 \\
W_1
\end{array} \]

\[ b_2 = 12 \]

\[ \begin{array}{ccc}
1 & 2 & 3 \\
W_2
\end{array} \]

\[ b_3 = 6 \]

\[ \begin{array}{cc}
1 & 2 \\
W_3
\end{array} \]

\[ b_4 = 15 \]

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\[ V = 50 \]
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Mechanisms

GREEDY

GREEDY-Example

\[ V = 50 \]

\[
\begin{align*}
W_1 & : \frac{4}{0} = \infty \\
W_2 & : \frac{12}{1} = 12 \\
W_3 & : \text{Selected} \\
W_4 & : \frac{15}{1} = 15
\end{align*}
\]

\[
\begin{align*}
b_1 & = 4 \\
b_2 & = 12 \\
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Mechanisms

GREEDY

GREEDY-Example

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\[ \frac{4}{0} = \infty \]
\[ \frac{12}{1} = 12 \]
\[ \frac{15}{1} = 15 \]

\[ V = 50 \]
GREEDY-Example

\[ \begin{align*}
W_1 & : b_1 = 4 \\
W_2 & : b_2 = 12 \\
W_3 & : b_3 = 6 \\
W_4 & : b_4 = 15
\end{align*} \]

\[ \begin{align*}
P_2 & = 12 \\
P_3 & = 6
\end{align*} \]

\[ V = 50 \]
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Mechanisms

GREEDY

GREEDY-Properties

- Properties
  - Computationally efficient \((O(n^2))\)
  - Individually rational \((p_i = b_i, b_i \geq c_i)\)
  - Profitable
  - Not truthful (same as OPT)
VCG

The third mechanism VCG (Vickrey-Clarke-Groves auction)

- Selection rule: select the team that cover the required skills and the total cost of which is the smallest

\[ S = \arg \min_T \sum_{w_i \in T} c_i \]  

Payment rule

\[ p_i = \min_T \left( \sum_{w_j \in T \wedge w_i \notin T} c_j - \sum_{w_j \in S \wedge j \neq i} c_j \right) \]
VCG-Example

\[ b_1 = 4 \]
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\[ W_1 \]
\[ W_2 \]
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\[ W_4 \]

\[ V = 50 \]
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VCG

VCG-Example

\[ b_1 = 4 \quad b_2 = 12 \quad b_3 = 6 \quad b_4 = 15 \]

\[ S = \{ W_4 \} \]

\[ V = 50 \]
VCG-Example

\[ b_1 = 4 \quad b_2 = 12 \quad b_3 = 6 \quad b_4 = 15 \]

\[ S = \{ W_4 \} \]

\[ T = \{ W_1, W_2 \} \]

\[ V = 50 \]
VCG-Example

\[ \begin{align*}
\text{b}_1 &= 4 \\
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\end{align*} \]

\[ \begin{align*}
1 & \quad \quad \quad \quad \quad \\
2 & \quad \quad \quad \quad 3 \\
1 & \quad \quad 2 \\
1 & \quad 2 & \quad 3
\end{align*} \]

\[ S = \{ W_4 \} \]

\[ T = \{ W_1, W_2 \} \]

\[ P_4 = 4 + 12 - 0 = 16 \]

\[ V = 50 \]
VCG-Properties

- Properties
  - Not Computationally efficient ($O(n2^n)$)
  - Individually rational ($p_i \geq b_i$, $b_i = c_i$)
  - Profitable
  - Truthful

\[
u'_i = p'_i - c_i
\]
\[
= \min_T \sum_{w_j \in T \land w_i \notin T} c_j - \sum_{w_j \in S' \land j \neq i} c_j - c_i
\]
\[
= \min_T \sum_{w_j \in T \land w_i \notin T} c_j - \sum_{w_j \in S'} c_j
\]
\[
\leq u_i
\]
The forth mechanism TruTeam

- Selection rule: Small bids (per “skill contribution”) first, same as GREEDY
- Payment rule: Pay each selected worker the highest bid that she can report and still be selected
TruTeam-Example

\[ V = 50 \]

\[ b_1 = 4 \]
\[ b_2 = 12 \]
\[ b_3 = 6 \]
\[ b_4 = 15 \]

\[
\begin{array}{c}
W_1 \\
4/1 = 4 \\
\end{array}
\]
\[
\begin{array}{ccc}
W_2 \\
12/2 = 6 \\
\end{array}
\]
\[
\begin{array}{c}
W_3 \\
6/2 = 3 \\
\end{array}
\]
\[
\begin{array}{ccc}
W_4 \\
15/3 = 5 \\
\end{array}
\]
If W3 want to be the first selected worker, then 
\( \frac{b_3}{2} \leq \frac{b_1}{1} \Rightarrow \frac{b_3}{2} \leq \frac{4}{1} \times 2 = 8 \)
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

TruTeam

TruTeam-Example

If \( W_3 \) want to be the first selected worker, then
\[
\frac{b_3}{1} \leq \frac{b_1}{1} \Rightarrow b_3 \leq 4/1 \times 2 = 8
\]

If \( W_3 \) want to be the second selected worker, then
\[
\frac{b_3}{1} \leq \frac{b_2}{2} \Rightarrow b_3 \leq 12/2 \times 1 = 6
\]
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

TruTeam

TruTeam-Example

If $W_3$ want to be the first selected worker, then
\[
b_3/1 \leq b_1/1 \Rightarrow b_3 \leq 4/1 \times 2 = 8
\]

If $W_3$ want to be the second selected worker, then
\[
b_3/1 \leq b_2/2 \Rightarrow b_3 \leq 12/2 \times 1 = 6
\]
TruTeam-Example

If \( W_3 \) want to be the first selected worker, then
\[
\frac{b_3}{2} \leq \frac{b_1}{1} \quad \Rightarrow \quad b_3 \leq \frac{12}{2} \times \frac{1}{1} = 8
\]

If \( W_3 \) want to be the second selected worker, then
\[
\frac{b_3}{1} \leq \frac{b_2}{2} \quad \Rightarrow \quad b_3 \leq \frac{15}{2} \times 1 = 6
\]

\[
\frac{V}{b_1} = \frac{50}{4} = 12.5, \quad \frac{V}{b_2} = \frac{50}{12} = 4.17, \quad \frac{V}{b_3} = \frac{50}{6} = 8.33, \quad \frac{V}{b_4} = \frac{50}{15} = 3.33
\]
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

TruTeam

TruTeam-Example

\[ W_1 \]
\[ W_2 \]
\[ W_3 \]
\[ W_4 \]

\[ V = 50 \]

\[ b_1 = 4 \]
\[ b_2 = 12 \]
\[ b_3 = 6 \]
\[ b_4 = 15 \]
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

TruTeam

TruTeam-Example

\[ b_1 = 4 \]
\[ b_2 = 12 \]
\[ b_3 = 6 \]
\[ b_4 = 15 \]

\[ \frac{4}{0} = \infty \]
\[ \frac{12}{1} = 12 \]
\[ \frac{15}{1} = 15 \]

\[ V = 50 \]
TruTeam-Example

- $b_1 = 4$
- $b_2 = 12$
- $b_3 = 6$
- $b_4 = 15$

- $W_1$: $4/0 = \infty$
- $W_2$: $12/1 = 12$
- $W_3$: $15/1 = 15$

- $V = 50$
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

TruTeam

TruTeam-Example

If $W_2$ want to be the second selected worker, then $b_2/1 \leq b_4/1 \Rightarrow b_2 \leq 15/1 \times 1 = 15$
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

TruTeam

TruTeam-Example

If W2 wants to be the second selected worker, then $b_2/1 \leq b_4/1 \Rightarrow b_2 \leq 15/1 \times 1 = 15$
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Mechanisms

TruTeam

TruTeam-Example

If W2 want to be the second selected worker, then
\[ \frac{b_2}{1} \leq \frac{b_4}{1} \rightarrow b_2 \leq \frac{15}{1} \times 1 = 15 \]

\[ P_2 = \max\{15\} = 15 \]
TruTeam-Example

- $b_1 = 4$
- $b_2 = 12$
- $b_3 = 6$
- $b_4 = 15$

- $V = 50$
- $P_2 = 15$
- $P_3 = 8$
TruTeam-Properties

- Properties
  - Computationally efficient \( O(n^2l) \)
  - Individually rational \( p_i \geq b_i, b_i = c_i \)
  - Profitable
  - Truthful
    - If \( w_i \) is selected by bidding truthfully, overbid or underbid will not bring higher utility
    - If \( w_i \) is not selected by bidding truthfully, is selected by underbidding, utility will be negative
Evaluation-Metrics

- Running Time.
- Requester’s Utility
- Social Welfare [Nisan et al., 2007], which is defined as the sum of all the players’ utility in game theory.

\[
\text{social welfare} = U_R + \sum_{w_i \in W} u_i \\
= v - \sum_{w_i \in S} p_i + \sum_{w_i \in S} (p_i - c_i) \\
= v - \sum_{w_i \in S} c_i
\]  

- Truthfulness
Simulation Setup

- $v = 500$
- $c_i \sim u[x, y]$
- bidding
  - Truthful bidding, $b_i = c_i$
  - Overbidding, randomly select $k \in [1, n]$ workers, each over bid a random value $r_i \in [1, v]$, $b_i = c_i + r_i$.
- skills: randomly assign $x_i \sim N(u, \sigma)$ skills for $w_i$
Simulation Setup

- Two datasets: “Small” and “Large”

<table>
<thead>
<tr>
<th></th>
<th>Evaluate $n$</th>
<th>Evaluate $l$</th>
<th>$(u, \sigma)$</th>
<th>$[x, y]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>small</td>
<td>$n = 10 \sim 25$, fixing $l = 5$</td>
<td>$l = 1 \sim 10$, fixing $n = 20$</td>
<td>$(l/3, 0.4)$</td>
<td>$[1, v/5]$</td>
</tr>
<tr>
<td>large</td>
<td>$n = 10 \sim 3000$, fixing $l = 50$</td>
<td>$l = 1 \sim 100$, fixing $n = 1000$</td>
<td>$(l/5, 0.4)$</td>
<td>$[1, v]$</td>
</tr>
</tbody>
</table>
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Evaluation

Results - Running Time

(a) fix $l = 5$

(b) fix $l = 5$

(c) fix $n = 20$

(d) fix $n = 20$
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Evaluation

Results - Running Time

(e) fix $l = 50$

(f) fix $l = 50$

(g) fix $n = 1000$

(h) fix $n = 1000$
- No. of workers(skills) increase, running time increases
- OPT and VCG are not efficient
- GREEDY performs better than TruTeam
- TruTeam is efficient (0.6sec)
Evaluation

Results - Requester's Utility

(i) $\text{fix } l = 5$

(j) $\text{fix } l = 5$

(k) $\text{fix } n = 20$

(l) $\text{fix } n = 20$
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Evaluation

Results-Requester’s Utility

Graphs showing the utility of the requester for different scenarios:

- **(m) fix \(l = 50\)**
- **(n) fix \(l = 50\)**
- **(o) fix \(n = 1000\)**
- **(p) fix \(n = 1000\)**
Evaluation

Results-Requester’s Utility

- Requester’s utility increases (decreases) as the no. of workers (skills) increases
- Truthful bid
  - OPT and GREEDY yield higher utility than VCG and TruTeam
  - Difference becomes smaller as no. of workers increases
- Over bid
  - As no. workers (skills) increases, VCG and TruTeam outperform OPT and GREEDY.
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Results-Social Welfare

(q) fix $l = 5$

(r) fix $l = 5$

(s) fix $n = 20$

(t) fix $n = 20$
An Efficient and Truthful Pricing Mechanism for Team Formation in Crowdsourcing Markets

Evaluation

Results-Social Welfare

(u) \( f(x) = 50 \)

(v) \( f(x) = 50 \)

(w) \( f(x) = 1000 \)

(x) \( f(x) = 1000 \)
OPT and VCG, GREEDY and TruTeam are supposed to selected the same team of workers, so they are supposed to have same social welfare, respectively.

In case of over bidding, VCG and TruTeam outperform OPT and GREEDY
▶ set $n = 1000, l = 50$
▶ randomly select $w_{637}, w_{219}$

(y) Utility of Worker $w_{637}$

(z) Utility of Worker $w_{219}$
### Conclusion and Future Work

<table>
<thead>
<tr>
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<th>Computationally Efficient</th>
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- In this work, we help the requester select a team of worker to perform a complex task and decide the payment to each selected worker.
Conclusion and Future Work

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</table>

- In this work, we help the requester select a team of workers to perform a complex task and decide the payment to each selected worker.
- In the future, we may take quality of workers and answers into consideration when selecting workers.
Thank you! Questions?
References


References II

On-line load balancing.

Determining expert profiles (with an application to expert finding).
In *International Joint Conferences on Artificial Intelligence (IJCAI)*, volume 7, pages 2657–2662.

Knowledge market design: A field experiment at google answers.
References III


References VI


References VII

