Mechanism Design for Strategic Crowdsourcing

Swaprava Nath

PhD Candidate
Advisor: Prof. Y. Narahari
Department of Computer Science and Automation
Indian Institute of Science, Bangalore

PhD Thesis Defense

December 17, 2013

Outline of the Talk

1. Introduction to Crowdsourcing
2. Thesis Overview
3. Sybilproofness in Crowdsourcing Networks
   - Sybil Attacks and Node Collapse Attacks
   - Design Desiderata
   - Impossibility and Possibility Results
4. Summary and Path Ahead

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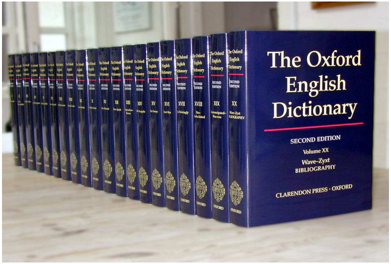
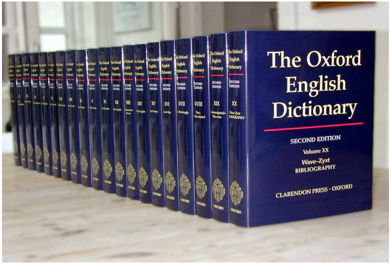
Crowdsourcing



[1]

[1] Project led by Prof. James Murray; **Book:** Simon Winchester. The Surgeon of Crowthorne: a tale of murder, madness and the Oxford English Dictionary. Penguin, 2002.

Crowdsourcing



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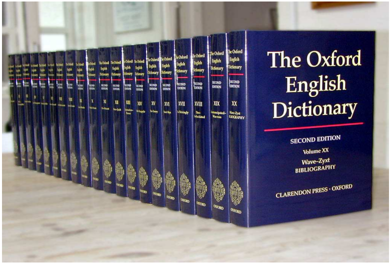

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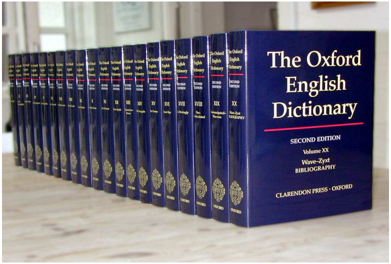
Crowdsourcing



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Commercial Crowdsourcing [1]

[1] Image courtesy: www.crowdsourcing.org

Crowdsourcing: A Definition

"Crowdsourcing is a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task."

From: Enrique Estellés-Arolas and Fernando González-Ladrón-de Guevara. Towards an integrated crowdsourcing definition. Journal of Information science, 38(2):189-200, 2012.

Crowdsourcing and Economics

- Goal: harness information, expertise, knowledge from a heterogeneous crowd

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Crowdsourcing

Crowdsourcing and Economics

- Goal: harness information, expertise, knowledge from a heterogeneous crowd
- Unleash the power of **social connectivity**

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Crowdsourcing over Networks

Crowdsourcing and Economics

- Human participants of the social network are **strategic**
- They choose actions that maximize their own **payoff**
- Requires a **game theoretic** analysis
- Goal: harness information, expertise, knowledge from a heterogeneous crowd
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Crowdsourcing over Networks

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Economics of Crowdsourcing over Networks

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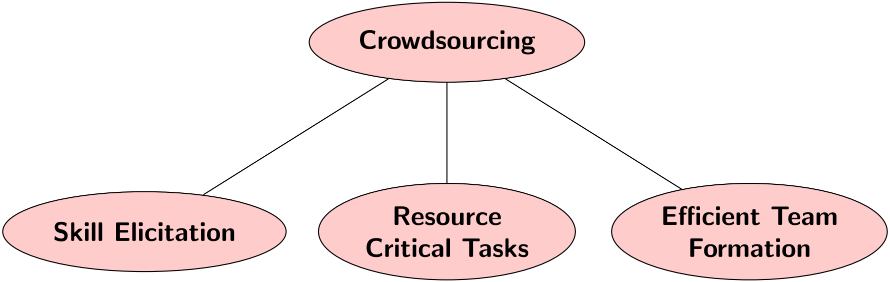

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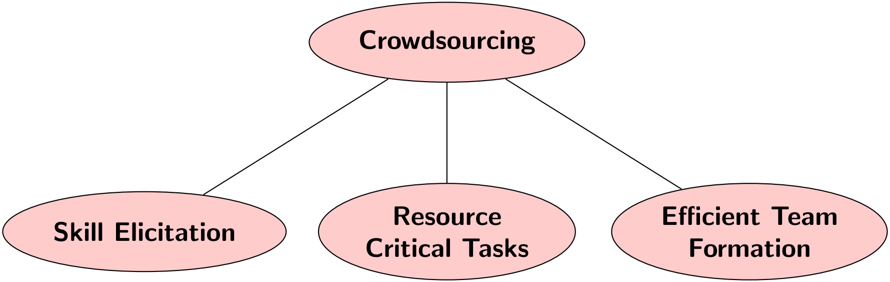
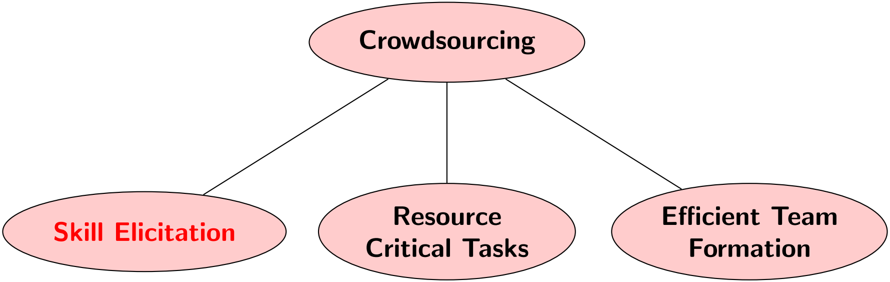


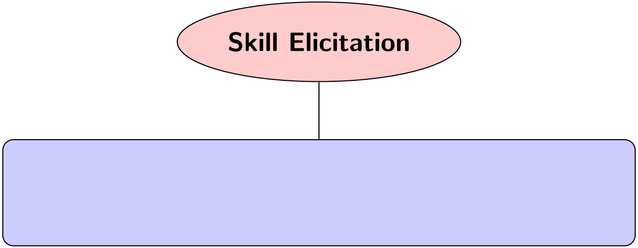
Analysis Tools: Game Theory and Mechanism Design

Thesis Overview



Analysis Tools: Game Theory and Mechanism Design

Skill Elicitation



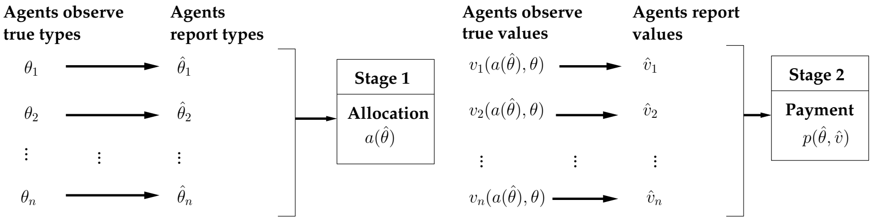
- Heterogeneity requires private **skills** to be honestly revealed
- The benefit is team dependent: **interdependent valuations**
- Ensuring efficiency and truthfulness is **impossible** by usual mechanisms [Jehiel and Moldovanu 2001]
- A two stage mechanism circumvents this problem [Mezzetti 2004]
- We improve it by making the second stage strictly truthful [a]

[a] S. Nath and O. Zoeter. A Strict Ex-post Incentive Compatible Mechanism for Interdependent Valuations. Economics Letters, 121(2):321-325, 2013.

Skill Elicitation

Skill Elicitation

- Static skills, interdependent values



Skill Elicitation

Skill Elicitation

- Static skills, interdependent values
- Stochastic skill transition, interdependent values

- We consider the **stochastic variation** of the skills
- Assumption: **Markov transitions**
- Show truthfulness, efficiency, and individual rationality [a]

[a] S. Nath, O. Zoeter, Y. Narahari, and C. Dance. Dynamic Mechanism Design for Markets with Strategic Resources. UAI, 2011.

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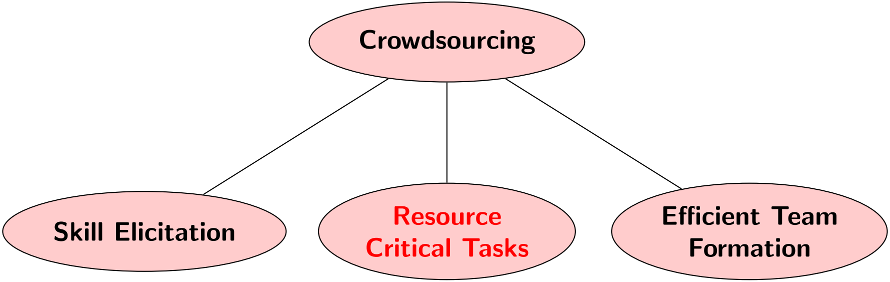
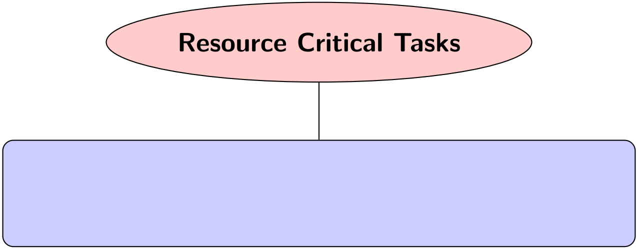


Analysis Tools: Game Theory and Mechanism Design

Resource Critical Task Execution



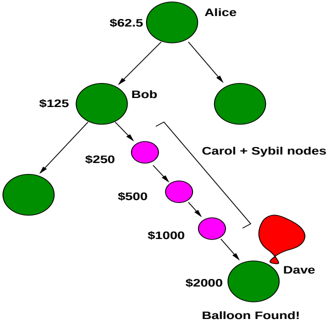
- Crowdsourcing introduces structural manipulation
- Fake node creation: **sybil attack**
- We show a limit of achievability
- Characterize the space of approximate sybilproof mechanisms [a]

[a] S. Nath, P. Dayama, D. Garg, Y. Narahari, and J. Zou. Mechanism Design for Time Critical and Cost Critical Task Execution via Crowdsourcing. WINE 2012.

Resource Critical Task Execution

Resource Critical Tasks

- *Sybilproofness*, rewarding only the winning chain



Resource Critical Task Execution

Resource Critical Tasks

- *Sybilproofness*, rewarding only the winning chain
- Rewarding all contributors

- Partial information is also rewarded
- Approach: integrating **prediction markets** with crowdsourcing [a]
- Challenge: **information manipulation**

[a] S. Nath, P. Dayama, R. D. Vallam, D. Garg, and Y. Narahari. Synergistic Crowdsourcing. Working Paper, 2013.

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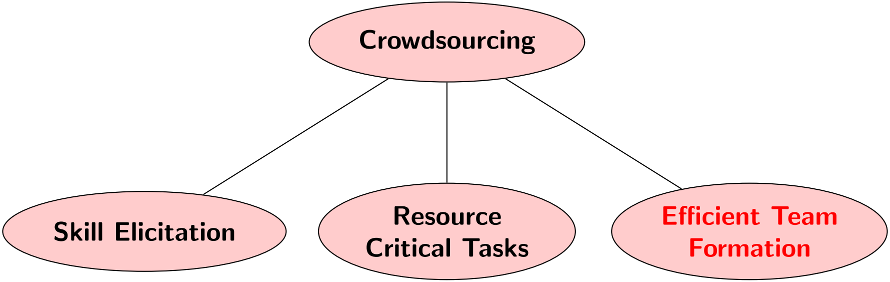
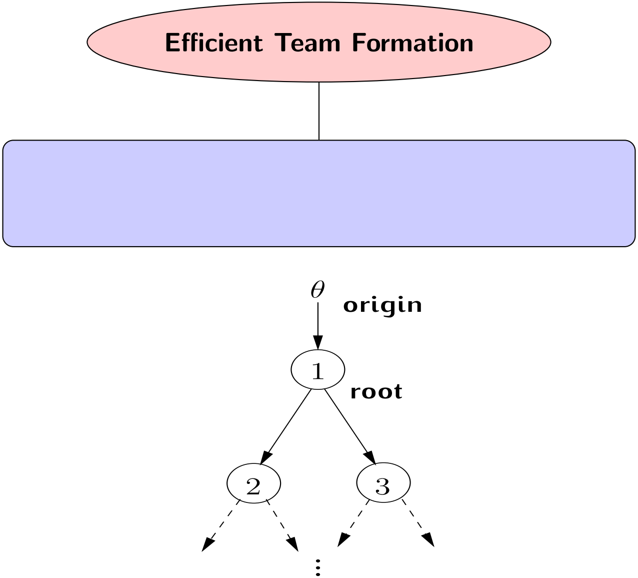


Analysis Tools: Game Theory and Mechanism Design

Efficient Team Formation



Efficient Team Formation

Efficient Team Formation

- Through incentive design

- We consider efforts in crowdsourcing networks
- Individuals trade-off their work and management efforts
- What happens in the **equilibrium**
- How can we maximize the **net productive output** [a]

[a] S. Nath, B. Narayanaswamy. Productive Output in Hierarchical Crowdsourcing, submitted to AAMAS 2014.

Efficient Team Formation

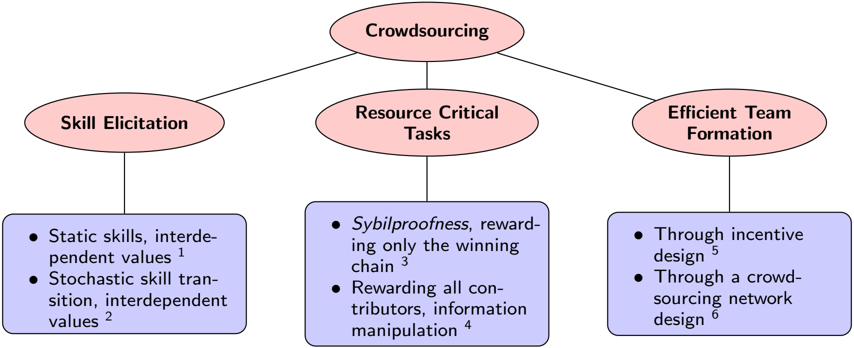
Efficient Team Formation

- Through incentive design
- Through network design

- Network design also improves the **productive output**
- Queuing model, **risk** minimization [a]

[a] S. Nath, B. Narayanaswamy, K. Kandhway, B. Kotnis, and D. C. Parkes. On Profit Sharing and Hierarchies in Organizations. AMES 2012.

Thesis Overview (Consolidated)



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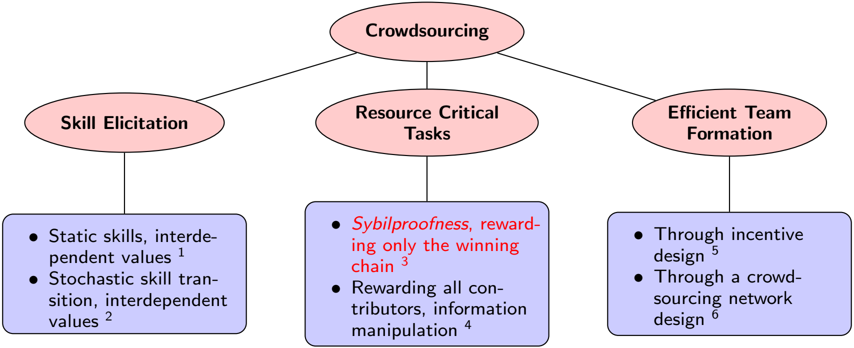

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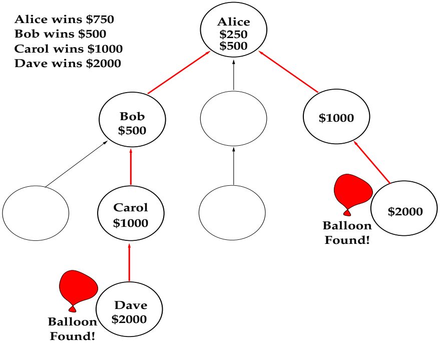
DARPA Network Challenge, 2009

- The challenge is to identify the locations of 10 balloons
- Whoever locates all of them in the shortest time will get a reward of $40,000
- Balloons are spread across the continental USA
  - Impossible for any individual to travel to all the places
  - Time-critical competition
- **Crowdsourcing** is a natural approach

Red Balloon Challenge: Winning Solution by MIT

- Winning solution: MIT Media Lab [2]
- "Find yourself and/or spread the message"
- **Atomic Tasks**: accomplished by a single individual



A *geometric* reward mechanism

[2] G. Pickard, W. Pan, I. Rahwan, M. Cebrian, R. Crane, A. Madan, and A. Pentland. Time-Critical Social Mobilization. Science, 334(6055):509-512, October 2011

Outline of the Talk

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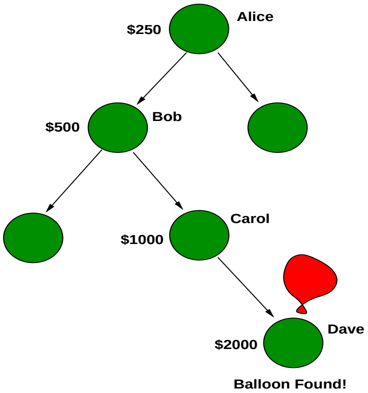
Sybil Attack



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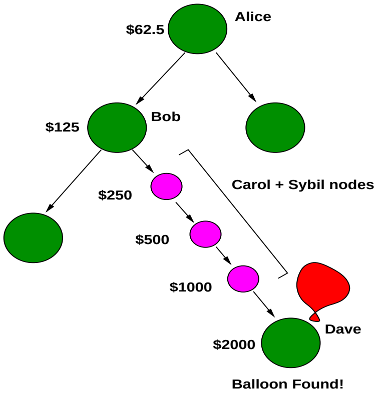
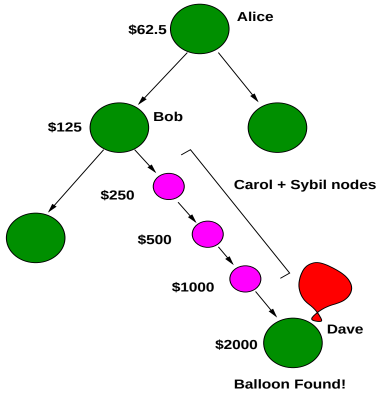


Carol can create two fake nodes to earn $750 more in the MIT scheme

Sybil Attack

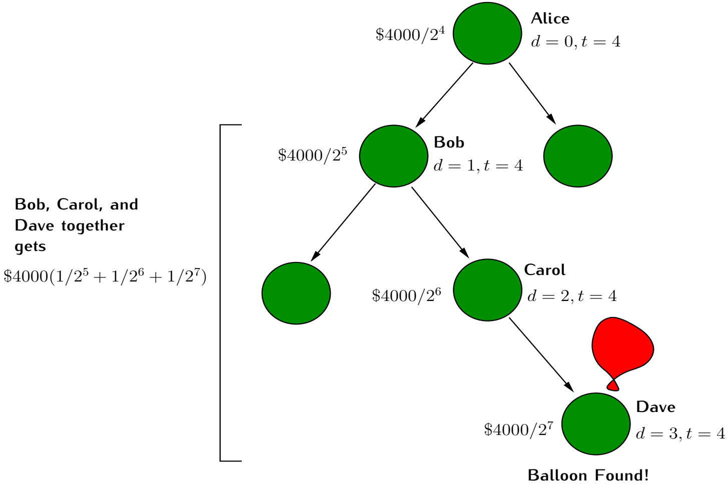


Sybil attack is undesirable because,

- Increases the expenditure of the task owner, as the sybils are getting paid.
- Reduces the reward of the ancestors of the sybil-creating nodes.

Node Collapse Attack

- **Alternative:** a naïve reward scheme.
- TOP-DOWN: node at depth d of a winning chain of length t gets \$4000/2^{d+t}.



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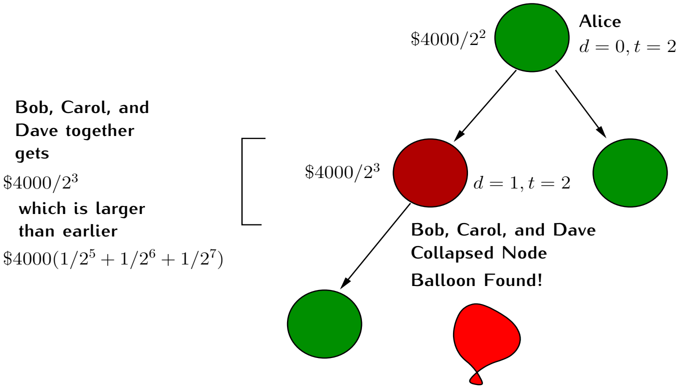
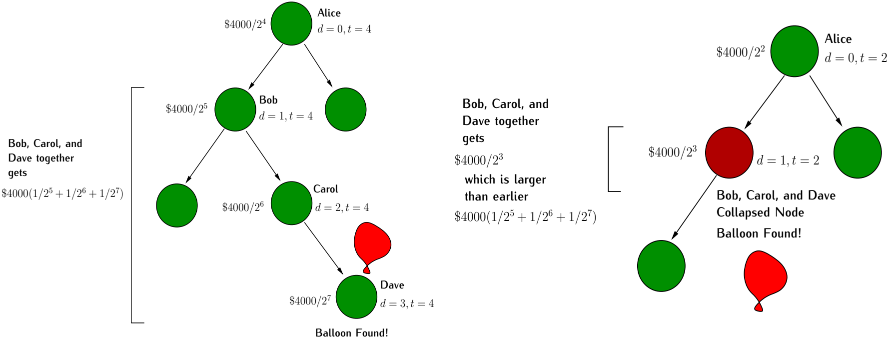


Node Collapse Attack (Contd.)



Node collapse is undesirable:

- Costs more to the social planner
- Sharing of this surplus could lead to bargaining among the agents
- Hides the structure of the actual network, which could otherwise be used for different purposes.

Outline of the Talk

Design Desiderata

Definition (Downstream Sybil-Proofness (DSP))

A reward mechanism R is called *downstream sybilproof*, if the node cannot gain by adding fake nodes below itself in the current subtree. Formally,

$$R(k,t) \geqslant \sum_{i=0}^{n} R(k+i, t+n) \quad \forall k \leqslant t, \forall t, n.$$

Definition (Collapse-Proofness (CP))

A reward mechanism R is called *collapse-proof*, if the user in the subchain of length p lying beneath k collectively cannot gain by collapsing to depth k. Formally,

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- **This asks for a Dominant Strategy implementation**

Design Desiderata (Contd.)

Definition (Strict Contribution Rationality (SCR))

This ensures a positive payoff to the nodes belonging to the winning chain. For all $t \geqslant 1$:

$$R(k, t) > 0, \quad \forall k \leqslant t, \text{ if } t \text{ is the length of the winning chain.}$$

Definition (Weak Contribution Rationality (WCR))

This ensures a non-negative payoff to the nodes in the winning chain. For all $t \geqslant 1$:

$$R(k, t) \geqslant 0, \quad \forall k \leqslant t - 1, \text{ if } t \text{ is the length of the winning chain.}$$
$$R(t, t) > 0, \qquad \text{winner gets positive reward.}$$

Design Desiderata (Contd.)

Definition (Budget Balance (BB))

Suppose the maximum budget allocated by the planner for executing a task is R_{max}. Then, a mechanism R is budget balanced if,

$$\sum_{k=1}^{t} R(k,t) \leqslant R_{max}, \quad \forall t.$$

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Impossibility and Possibility Results

Question: Can we satisfy all these properties simultaneously?

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Answer: No!

Theorem (Impossibility Result)

For $t \geqslant 3$, no reward mechanism can simultaneously satisfy DSP, SCR, and CP.

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Theorem (Impossibility Result)

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Theorem (Possibility Result A)

For $t \geqslant 3$, a mechanism satisfies DSP, WCR, CP, and BB iff it is a Winner Takes All *(WTA) mechanism. A reward mechanism R is called WTA if* $R_{max} \geqslant R(t,t) > 0$, *and* $R(k,t) = 0, \ \forall k < t$.

Approximate Sybil-proofness

Potential way outs:

- **Relax the equilibrium**: Nash implementation [3]
- **Relax the properties**: equilibrium in dominant strategies (this talk)

[3] M. Babaioff, S. Dobzinski, S. Oren, and A. Zohar. On Bitcoin and Red Balloons. In Proceedings of ACM Electronic Commerce (EC), 2012.

Approximate Sybil-proofness

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Definition (ϵ-Downstream Sybil-Proofness (ϵ-DSP))

A reward mechanism R is called ϵ - *DSP*, if no node can gain by more than a factor of $(1+\epsilon)$ by adding fake nodes below herself in the current subtree. Mathematically,

$$(1+\epsilon) \cdot R(k,t) \geqslant \sum_{i=0}^{n} R(k+i, t+n) \quad \forall k \leqslant t, \forall t, n.$$

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A Possibility Result

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For all $\epsilon > 0$, there exists a mechanism that is ϵ-DSP, CP, BB, and SCR.

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Not enough to guarantee fairness to the participants

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- **Incentive for Task Forwarding**
  Each agent gets at least $\delta \in (0, 1)$ fraction of her successor
  Call this δ - Strict Contribution Rationality, δ-SCR

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  The leaf node gets at least γ fraction $(0 < \gamma < 1)$ of the total budget R_{max}
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Theorem (Characterization of Cost Minimal Mechanisms)

If $(\delta, \epsilon, \gamma) \in \mathscr{E}$, *a* cost minimal *mechanism satisfying* ϵ*-DSP,* δ*-SCR,* γ*-SEC, and BB* $\Leftrightarrow$ (γ, δ)*-GEOM*

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(γ, δ)-**GEOM:**
$$\begin{cases} R(t, t) & = \gamma \cdot R_{max} \\ R(k, t) & = \delta \cdot R(k + 1, t), \ k \leqslant t - 1 \end{cases}$$

$$\mathscr{E} = \{(\delta, \epsilon, \gamma) : \delta \leqslant \min\{1 - \gamma, \epsilon/(1 + \epsilon)\}\}$$

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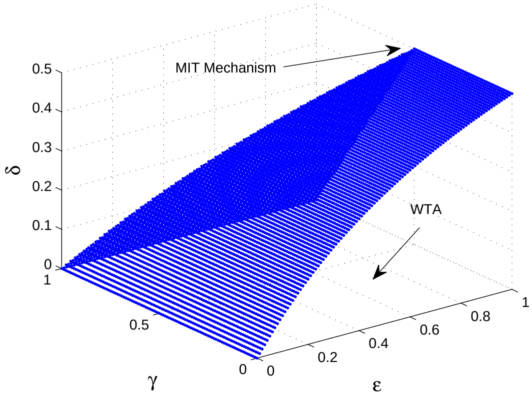
In addition:

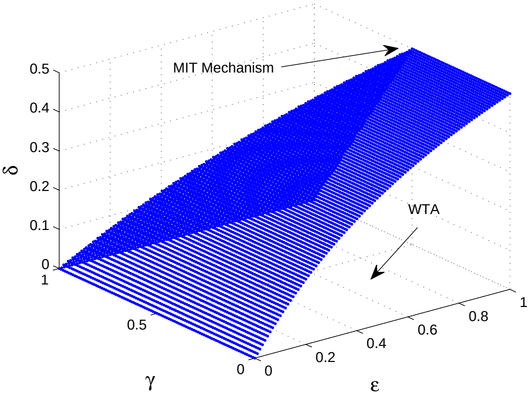
- **(γ, δ)-GEOM is CP**

Graphical Illustration



The set of $(\delta, \epsilon, \gamma)$ tuples, given by $\mathscr{E}$, for which the *MINCOST* mechanism is the (γ, δ)-GEOM mechanism, is the space below the shaded region. MIT mechanism ($\epsilon = 1, \delta = 0.5, \gamma = 0.5$) and the WTA mechanism ($\delta = 0$, the floor of the space in the figure above) are special cases.

Graphical Illustration

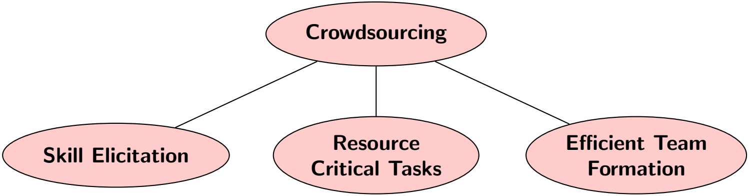


To probe further: S. Nath, P. Dayama, D. Garg, Y. Narahari, and J. Zou. Mechanism Design for Time Critical and Cost Critical Task Execution via Crowdsourcing. In proceedings, Conference on Web and INternet Economics (WINE) 2012.

Outline of the Talk

Summary

- This thesis considers the **network** aspect of *crowdsourcing*
- Models the crowd as **rational** and **intelligent** agents
- Addresses three **game theoretic** problems in crowdsourcing



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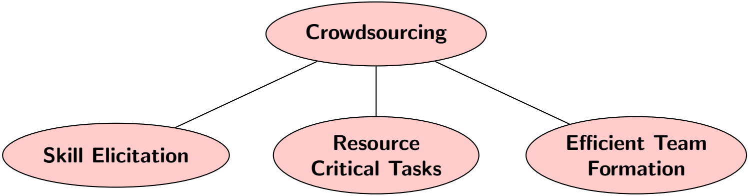

- And provides **mechanism design** solutions

"A game theoretic analysis on the network of strategic agents yields an efficient and robust design of the crowdsourcing mechanisms"

Scope of Future Research

Open questions:

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  - can be a complementary problem to the incentive compatibility
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- **Network Stability Analysis in Crowdsourcing**
  - *Stable network*: nodes do not *make* or *break* connections
  - Reward sharing **contracts** can make a network stable


Internet Economics
Crowdsourcing
Resource Critical Tasks
Skill Elicitation
Efficient Team Formation
Matching
Webpage to Viewer
House Allocation
College Admission
Online Advertising
Search Auctions
Recommender Systems
User Review Forums
Resource Allocation
Cloud Computing
Bandwidth Allocation

Thank you!

✉ swaprava@gmail.com

http://swaprava.byethost7.com

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Cost Critical Setting

Goal: Accomplishing the task at minimum cost
Note: γ-SEC property is essential, otherwise the solution would be all-zero.

Definition (MINCOST over $\mathscr{C}$)

A reward mechanism R is called *MINCOST* over a class of mechanisms $\mathscr{C}$, if it minimizes the total reward distributed to the participants in the winning chain. That is, R is *MINCOST* over $\mathscr{C}$, if

$$R \in \arg\min_{R' \in \mathscr{C}} \sum_{k=1}^{t} R'(k,t), \quad \forall t.$$

A Characterization Theorem

Define: $\mathscr{E} = \{(\delta, \epsilon, \gamma) : \delta \leqslant \min\{1-\gamma, \epsilon/(1+\epsilon)\}\}$

Theorem (Characterization of Cost Critical Setting)

If $(\delta, \epsilon, \gamma) \in \mathscr{E}$, a mechanism is `MINCOST` over the class of mechanisms satisfying ϵ-DSP, δ-SCR, γ-SEC, and BB iff it is (γ, δ)-GEOM.

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(γ, δ)-Geometric Mechanism ((γ, δ)-GEOM)

This mechanism gives γ fraction of the total reward to the winner and geometrically decreases the rewards from leaf towards root by a factor δ. For all t,

$$R(t, t) = \gamma \cdot R_{\max}$$
$$R(k, t) = \delta^{t-k} \cdot \gamma R_{\max}, \; k \leqslant t - 1$$

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In addition:

- **(γ, δ)-GEOM is CP**

Time Critical Setting

Goal: Accomplishing the task at the minimum time. So, the entire budget R_{max} can be exhausted to encourage faster *task execution* and *propagation*.

Definition (MAXLEAF over $\mathscr{C}$)

A reward mechanism R is called *MAXLEAF* over a class of mechanisms $\mathscr{C}$, if it maximizes the reward of the leaf node in the winning chain. That is, R is *MAXLEAF* over $\mathscr{C}$, if

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Theorem (A Characterization for Time Critical Setting)

If $\delta \leqslant \frac{\epsilon}{1+\epsilon}$, a mechanism is `MAXLEAF` over the class of mechanisms satisfying ϵ-DSP, δ-SCR, and BB iff it is δ-GEOM mechanism.

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δ-Geometric mechanism (δ-GEOM)

This mechanism gives $\frac{1-\delta}{1-\delta^t}$ fraction of the total reward to the winner and geometrically decreases the rewards towards root with the factor δ; t is the length of the winning chain.

$$R(t,t) = \frac{1-\delta}{1-\delta^t} \cdot R_{\max}$$
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