Incentivizing Crowd Networks for Rapid Geospatial Sensing

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[Joint work with Swaprava Nath, Pankaj Dayama, Y. Narahari, and James Zou]

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  - Participants recruiting their friends to expand the team.
  - Participants putting in serious efforts to accomplish the portion of the overall task.
- A properly designed incentive scheme can make the whole mission quite successful.
- However, designing a proper incentive scheme is somewhat non-trivial and challenging problem.

S. Nath, P. Dayama, Y. Narahari, and J. Zou, "Mechanism Design for Time Critical and Cost Critical Tasks Execution via Crowdsourcing", Workshop on Internet and Network Economics (WINE), 2012.

DARPA Network Challenge, 2009

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- Balloons are spread across the continental USA
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  - Time-critical competition
- Crowdsourcing with some help from modern technology is a natural approach

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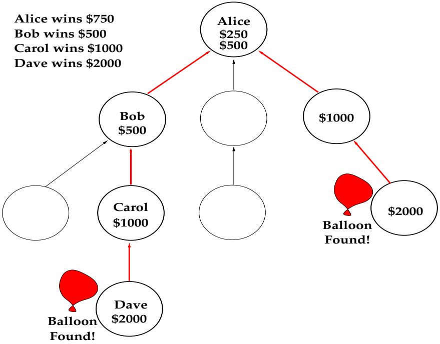


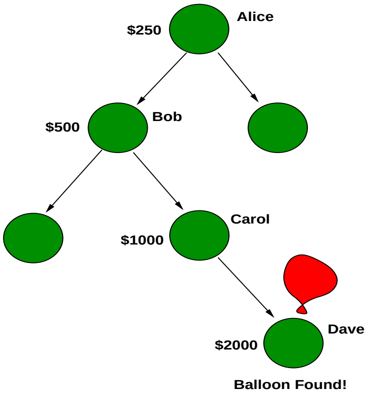
G. Pickard et. al., Time-Critical Social Mobilization. Science, 334(6055):509-512, October 2011

Design Challenges

- Human participants of the social network are strategic.
- Can manipulate the system in order to maximize their own payoff.
- Two major problems with any incentivizing mechanism for an atomic task over a social network:
  - Sybil Attack, and
  - Node Collapse Attack

Sybil Attack

- Nodes can multiply their identities by creating clones or fake nodes below themselves in the referral tree.
- Example: Carol can create two fake nodes to earn $750 more in the MIT scheme



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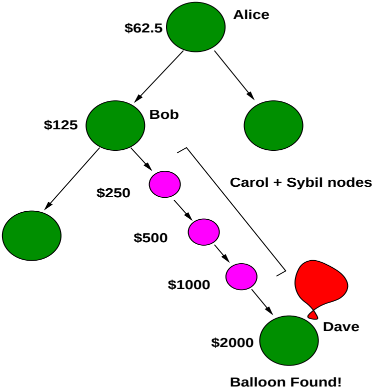
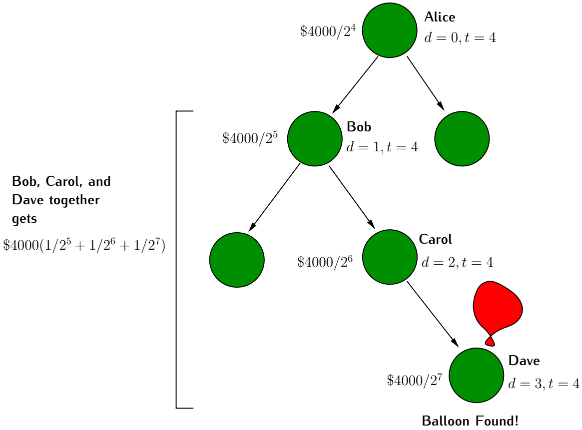


Sybil attack is undesirable because,

- 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

- To combat the sybil attack, one can think of a naïve reward scheme.
- TOP-DOWN: if the number of nodes in the winning chain (call this 'length') is t, node at depth d gets $\$4000/2^{d+t}$.
- This could lead to a different problem: node collapse problem



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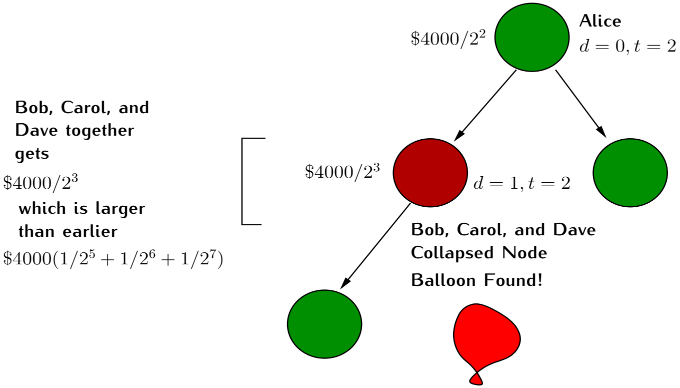
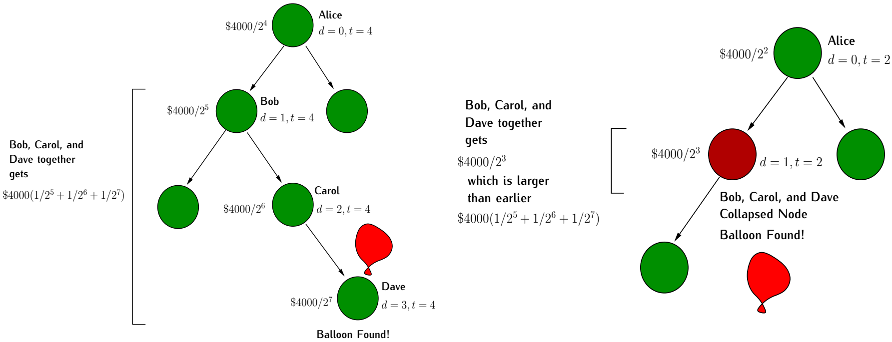


Node Collapse Attack (Contd.)



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.

Desirable Properties

Downstream Sybil-Proofness (DSP): Given the depth k of a node in a recruitment tree, a reward mechanism R is called *downstream sybilproof*, if the node cannot gain by adding fake nodes below itself in the current subtree. Formally,

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

Collapse-Proofness (CP): Given a depth k in a winning chain, 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. Mathematically,

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

Desirable Properties (Contd.)

Strict Contribution Rationality (SCR): This ensures a positive payoff to the nodes belonging to the winning chain. For all $t \geq 1$:

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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,

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

Impossibility and Possibility Results

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Possibility Result -I: For $t \geq 3$, a mechanism satisfies DSP, WCR, CP, and BB iff it is a *Winner Takes All* (WTA) mechanism.

WTA Mechanism: A reward mechanism R is called WTA if $R_{\text{max}} \geq R(t,t) > 0$, and $R(k,t) = 0,\ \forall k < t$.

Approximate Sybil-proofness

Potential way outs:

- **Relax the equilibrium**: Nash implementation[1]
- **Relax the properties**: equilibrium in dominant strategies (this talk)

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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,

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

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- $R(t,t) = (1-\delta).R_{max} \quad \forall t \;\text{ where }\; \delta \leq \frac{\epsilon}{1+\epsilon}$
- $R(k,t) = \delta.R(k+1,t) \;\; \forall \; k,t$

Quick Summary

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- **Possibility Result-II:** ϵ-DSP, CP, BB, and SCR is possible, for all $\epsilon > 0$

Incentive for Task Forwarding

- Not all mechanisms in the non-empty space would be interesting
- Leads us to define two additional fairness criteria.

Incentive for Task Forwarding

δ **- Strict Contribution Rationality (δ-SCR)** A node in the winning chain gets at least $\delta \in (0,1)$ fraction of her successor. Also the winner gets a positive reward. For all $t \geq 1$,

$R(k,t) \geq \delta R(k+1,t), \forall k \leq t-1,$ if t is the length of the winning chain.

$R(t,t) > 0,$ winner gets positive reward.

Winner's γ Security (γ-SEC): Payoff to the winning node is at least $\gamma \in (0,1)$ fraction of the total available budget.

$$R(t,t) \geq \gamma \cdot R_{\max}, \quad t \text{ is the length of the winning chain}$$

Cost Critical Setting

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

`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

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

A Characterization Theorem

Let us define, $\mathscr{E} = \{(\delta, \epsilon, \gamma) : \delta \leq \min\{1 - \gamma, \frac{\epsilon}{1+\epsilon}\}\}$, a technical condition on the parameters

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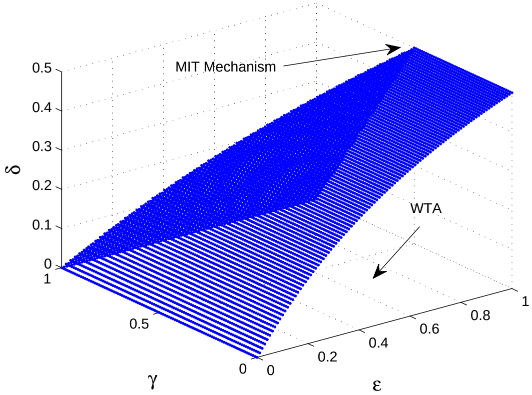
(γ, δ)-Geometric Mechanism ((γ, δ)-GEOM)

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,

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

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.

Summary and Future Directions

- Summary
  - Introducing the concept of Collapse-Proofness
  - Exhibiting the conflict among the desirable properties
  - Proposing an *approximate* Dominant Strategy Implementation
  - One can only hope to satisfy only an approximate versions of all the desirable properties under dominant strategy
  - Presenting a Cost critical Optimization technique
- Future Directions
  - Facilitating the learning from failure of one person in the crowd to enable succeed others
  - Investigating tightness of the characterization results
  - Approximating the CP property

Thank you!