# Network Economics
# --
# Lecture 2: Incentives in online systems I: free riding and effort elicitation

Patrick Loiseau
EURECOM

Fall 2016

# References

- Main:
  - N. Nisam, T. Roughgarden, E. Tardos and V. Vazirani (Eds). “Algorithmic Game Theory”, CUP 2007. Chapters 23 (see also 27).
    - Available online: http://www.cambridge.org/journals/nisan/downloads/Nisan_Non-printable.pdf
- Additional:
  - Yiling Chen and Arpita Gosh, “Social Computing and User Generated Content,” EC’13 tutorial
    - Slides at http://www.arpitaghosh.com/papers/ec13_tutorialSCUGC.pdf and http://yiling.seas.harvard.edu/wp-content/uploads/SCUGC_tutorial_2013_Chen.pdf
  - M. Chiang. “Networked Life, 20 Questions and Answers”, CUP 2012. Chapters 3-5.
    - See the videos on www.coursera.org

# Outline

1. Introduction
2. The P2P file sharing game
3. Free-riding and incentives for contribution
4. Hidden actions: the principal-agent model

# Outline

1. Introduction
2. The P2P file sharing game
3. Free-riding and incentives for contribution
4. Hidden actions: the principal-agent model

# Online systems

- Resources
  - P2P systems
- Information
  - Ratings
  - Opinion polls
- Content (user-generated content)
  - P2P systems
  - Reviews
  - Forums
  - Wikipedia
- Labor (crowdsourcing)
  - AMT

- In all these systems, there is a need for users contribution

# P2P networks

- First ones: Napster (1999), Gnutella (2000)
  - Free-riding problem
- Many users across the globe self-organizing to share files
  - Anonymity
  - One-shot interactions
  - →Difficult to sustain collaboration
- Exacerbated by
  - Hidden actions (nondetectable defection)
  - Cheap pseudonyms (multiple identities easy)

# Incentive mechanisms

- Good technology is not enough
- P2P networks need incentive mechanisms to incentivize users to contribute
  - Reputation (KaZaA)
  - Currency (called scrip)
  - Barter (BitTorrent) – direct reciprocity

# Extensions

- Other free-riding situations
  - E.g., mobile ad-hoc networks, P2P storage
- Rich strategy space
  - Share/not share
  - Amount of resources committed
  - Identity management
- Other applications of incentives / reputation systems
  - Online shopping, forums, etc.

# Outline

1. Introduction
2. The P2P file sharing game
3. Free-riding and incentives for contribution
4. Hidden actions: the principal-agent model

# The P2P file-sharing game

- Peer
  - Sometimes download → benefit
  - Sometimes upload → cost
- One interaction ~ prisoner's dilemma

| | C | D |
|---|---|---|
| C | 2, 2 | -1, 3 |
| D | 3, -1 | 0, 0 |

# Prisoner's dilemma

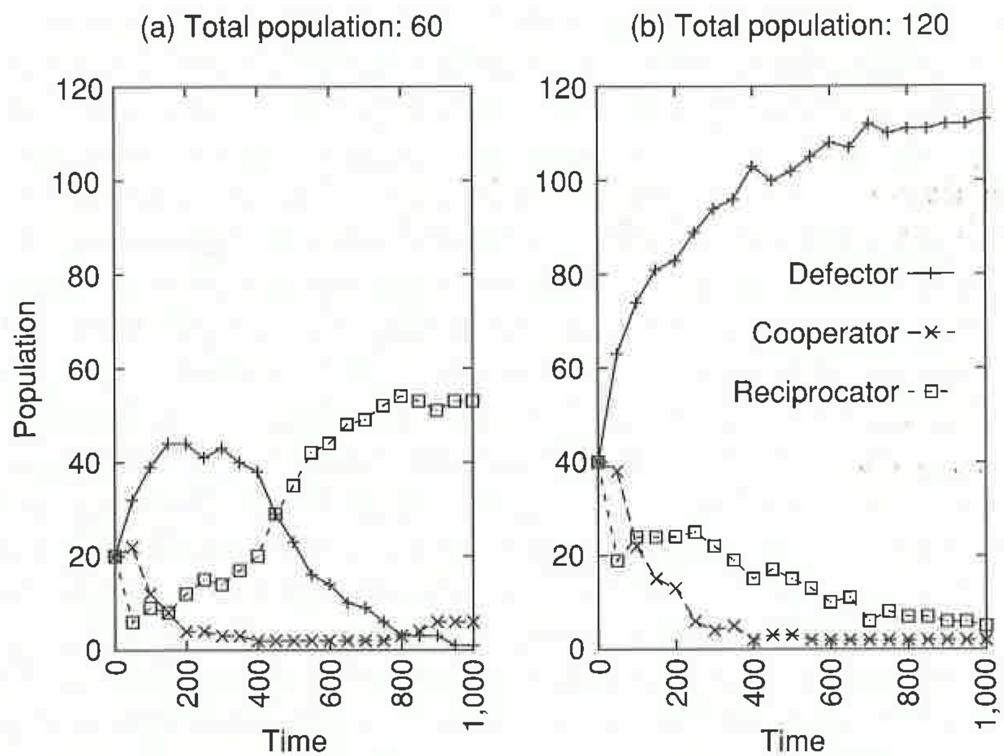
- Dominant strategy: D
- Socially optimal (C, C)

- Single shot leads to (D, D)
  – Socially undesirable
- Iterated prisoner's dilemma
  – Tit-for-tat yields socially optimal outcome

| | C | D |
|---|---|---|
| C | 2, 2 | -1, 3 |
| D | 3, -1 | 0, 0 |

# P2P

- Many users, random interactions




Feldman et al. 2004

- Direct reciprocity does not scale

# P2P

- Direct reciprocity
  - Enforced by Bittorrent at the scale of one file but not over several files
- Indirect reciprocity
  - Reputation system
  - Currency system

# How to treat new comers

- P2P has high turnover
- Often interact with stranger with no history

- TFT strategy with C with new comers
  - Encourage new comers
  - BUT Facilitates whitewashing

# Outline

1. Introduction
2. The P2P file sharing game
3. Free-riding and incentives for contribution
4. Hidden actions: the principal-agent model

# Reputation

- Long history of facilitating cooperation (e.g. eBay)
- In general coupled with service differentiation
  - Good reputation = good service
  - Bad reputation = bad service

- Ex: KaZaA

# Trust

- EigenTrust (Sep Kamvar, Mario Schlosser, and Hector Garcia-Molina, 2003)
  – Computes a global trust value of each peer based on the local trust values

- Used to limit malicious/inauthentic files
  – Defense against pollution attacks

# Attacks against pollution systems

- Whitewashing
- Sybil attacks
- Collusion
- Dishonest feedback

- See next lecture…
- This lecture: how reputation helps in eliciting effort

# A minimalist P2P model

- Large number of peers (players)
- Peer i has type $\theta_i$ (~ "generosity")
- Action space: contribute or free-ride
- x: fraction of contributing peers

→1/x: cost of contributing

- Rational peer:
  - Contribute if $\theta_i > 1/x$
  - Free-ride otherwise

# Contributions with no incentive mechanism

- Assume uniform distribution of types

# Contributions with no incentive mechanism (2)

- Equilibria stability

# Contributions with no incentive mechanism (3)

- Equilibria computation

# Contributions with no incentive mechanism (4)

- Result: The highest stable equilibrium contribution level $x_1$ increases with $\theta_m$ and converges to one as goes $\theta_m$ to infinity but falls to zero if $\theta_m < 4$

- Remark: if the distribution is not uniform: the graphical method still applies

# Overall system performance

- $W = ax-(1/x)x = ax-1$

- Even if participation provides high benefits, the system may collapse

# Reputation and service differentiation in P2P

- Consider a reputation system that can catch free-riders with probability p and exclude them
  - Alternatively: catch all free-riders and give them service altered by (1-p)

- Two effects
  - Load reduced, hence cost reduced
  - Penalty introduces a threat

# Equilibrium with reputation

- Q: individual benefit
- R: reduced contribution
- T: threat

# Equilibrium with reputation (2)

# System performance with reputation

- $W = x(Q-R)+(1-x)(Q-T) = (ax-1)(x+(1-x)(1-p))$

- Trade-off: Penalty on free riders increases x but entails social cost

- If $p>1/a$, the threat is larger than the cost

→ No free rider, optimal system performance $a-1$

# FOX (Fair Optimal eXchange)

- Theoretical approach
- Assumes all peer are homogeneous, with capacity to serve k requests in parallel and seek to minimize completion time
- FOX: distributed synchronized protocol giving the optimum
  - i.e., all peers can achieve optimum if they comply
- “grim trigger” strategy: each peer can collapse the system if he finds a deviating neighbor

# FOX equilibrium

# Outline

1. Introduction
2. The P2P file sharing game
3. Free-riding and incentives for contribution
4. Hidden actions: the principal-agent model

# Hidden actions

- In P2P, many strategic actions are not directly observable
  - Arrival/departure
  - Message forwarding

- Same with many other contexts
  - Packet forwarding in ad-hoc networks
  - Worker's effort

- Moral hazard: situation in which a party is more willing to take a risk knowing that the cost will be supported (at least in part) by others
  - E.g., insurance

# Principal-agent model

- A principal employs a set of n agents: $N = \{1, \dots, n\}$
- Action set $A_i = \{0, 1\}$
- Cost $c(0)=0$, $c(1)=c>0$
- The actions of agents determine (probabilistically) an outcome o in $\{0, 1\}$
- Principal valuation of success: $v>0$ (no gain in case of failure)
- Technology (or success function) $t(a_1, \dots, a_n)$: probability of success

- Remark: many different models exist
  - One agent, different action sets
  - Etc.

# Read-once networks

- One graph with 2 special nodes: source and sink
- Each agent controls 1 link
- Agents action:
  - low effort → succeed with probability $\gamma$ in (0, 1/2)
  - High effort → succeed with probability $1-\gamma$ in (1/2, 1)
- The project succeeds if there is a successful source-sink path

# Example

- AND technology

- OR technology

# Contract

- The principal agent can design a "contract"
  - Payment of $p_i \geq 0$ upon success
  - Nothing upon failure
- The agents are in a game:

$$u_i(a) = p_i t(a) - c(a_i)$$

- The principal wants to design a contract such that his expected profit is maximized

$$u(a,v) = t(a) \cdot \left( v - \sum_{i \in N} p_i \right)$$

# Definitions and assumptions

- Assumptions:
  - $t(1, a_{-i}) > t(0, a_{-i})$ for all $a_{-i}$
  - $t(a) > 0$ for all a
- Definition: the marginal contribution of agent i given $a_{-i}$ is

$$\Delta_i(a_{-i}) = t(1, a_{-i}) - t(0, a_{-i})$$

- Increase in success probability due to i's effort

# Individual best response

- Given $a_{-i}$, agent's i best strategy is

$$a_i = 1 \quad \text{if} \quad p_i \geq \frac{c}{\Delta_i(a_{-i})}$$

$$a_i = 0 \quad \text{if} \quad p_i \leq \frac{c}{\Delta_i(a_{-i})}$$

# Best contract inducing *a*

- The best contract for the principal that induces *a* as an equilibrium consists in
  - $p_i = 0$ for the agents choosing $a_i$=0
  - $p_i = \dfrac{c}{\Delta_i(a_{-i})}$ for the agents choosing $a_i$=1

# Best contract inducing *a* (2)

- With this best contract, expected utilities are
  - $u_i = 0$ for the agents choosing $a_i$=0
  - $u_i = c \cdot \left( \frac{t(1, a_{-i})}{\Delta_i(a_{-i})} - 1 \right)$ for the agents choosing $a_i$=1
  - $u(a, v) = t(a) \cdot \left( v - \sum_{i:a_i=1} \frac{c}{\Delta_i(a_{-i})} \right)$ for the principal

# Principal's objective

- Choosing the actions profile $a^*$ that maximizes his utility u($a$,v)
- Equivalent to choosing the set $S^*$ of agents with $a_i$=1
- Depends on v → $S^*(v)$

- We say that the principal contracts with i if $a_i$=1

# Hidden vs observable actions

- Hidden actions: $$u(a,v) = t(a)\cdot\left(v - \sum_{i:a_i=1}\frac{c}{\Delta_i(a_{-i})}\right)$$

$$u_i = c\cdot\left(\frac{t(1,a_{-i})}{\Delta_i(a_{-i})} - 1\right)$$ if $a_i$=1 and 0 otherwise

- If actions were observable
  – Give $p_i$=c to high-effort agents regardless of success
  – Yields for the principal a utility equal to social welfare

$$u(a,v) = t(a)\cdot v - \sum_{i:a_i=1} c$$

→ Choose *a* to maximize social welfare

# (POU) Price of Unaccountability

- $S^*(v)$: optimal contract in hidden case
- $S_0^*(v)$: optimal contract in observable case

- Definition: the POU(t) of a technology t is defined as the worst-case ratio over v of the principal's utility in the observable and hidden actions cases

$$POU(t) = \sup_{v>0} \frac{t(S_0^*(v)) \cdot v - \sum_{i \in S_0^*(v)} c}{t(S^*(v)) \cdot \left( v - \sum_{i \in S^*(v)} \frac{c}{t(S^*(v)) - t(S^*(v) \setminus \{i\})} \right)}$$

# Remark

- POU(t)>1

# Optimal contract

- We want to answer the questions:

- How to select the optimal contract (i.e., the optimal set of contracting agents)?
- How does it change with the principal's valuation v?

# Monotonicity

- The optimal contracts weakly improves when v increases:
  - For any technology, in both the hidden- and observable-actions cases, the expected utility of the principal, the success probability and the expected payment of the optimal contract are all non-decreasing when v increases

# Proof

# Proof (2)

# Consequences

- Anonymous technology: the success probability is symmetric in the players
- For technologies for which the success probability depends only on the number of contracted agents (e.g. AND, OR), the number of contracted agents is non-decreasing when v increases

# Optimal contract for the AND technology

- Theorem: For any anonymous AND technology with $\gamma = \gamma_i = 1\text{-}\delta_i$ for all i
  - There exists a valuation finite $v_*$ such that for any $v<v_*$, it is optimal to contract with no agent and for any $v>v_*$, it is optimal to contract with all agents (for $v=v_*$, both contracts are optimal)
  - The price of unaccountability is

$$POU = \left(\frac{1}{\gamma} - 1\right)^{n-1} + \left(1 - \frac{\gamma}{1-\gamma}\right)$$

# Remarks

- Proof in M. Babaioff, M. Feldman and N. Nisan, “Combinatorial Agency”, in Proceedings of EC 2006.
- POU is not bounded!
  - Monitoring can be beneficial, even if costly

# Example

- $n=2$, $c=1$, $\gamma=1/4$
- Compute for all number of agents
  - t
  - Δ
  - Utility of principal

# Optimal contract for the OR technology

- Theorem: For any anonymous OR technology with $\gamma = \gamma_i = 1\text{-}\delta_i$ for all i
  - There exist finite positive values $v_1, \ldots, v_n$ such that for any v in $(v_k, v_{k+1})$, it is optimal to contract k agent. (For $v<v_0$, it is optimal to contract 0 agent, for $v>v_n$, it is optimal to contract n agent and for $v=v_k$, the principal is indifferent between contracting k-1 or k agents.)
  - The price of unaccountability is upper bounded by 5/2

# Example

- $n=2$, $c=1$, $\gamma=1/4$
- Compute for all number of agents
  - t
  - Δ
  - Utility of principal

# Illustration

- Number of contracted agents