Countering Hidden-Action Attacks on Networked Systems

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Outline

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Motivation

- Asymmetric information inspires a class of hidden-action attacks: actions made attractive by a lack of observation
- Classic economics example: insurance companies cannot easily monitor their customer's behaviour so many behave recklessly
- Hidden-action in computer networks
  - Routers dropping selected packets
  - Nodes redirecting traffic to eavesdrop on conversations
  - Users in a file-sharing system "free-riding"

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Available Countermeasures

So what can be done to address hidden-action attacks?

- In economics, contracts are devised to compensate agents capable of hidden-action
  - Distributed algorithmic mechanism design
  - Side-payments often burdensome to implement
  - Accepts system attributes as unchangeable
- We instead turn to social capital theory to undermine the potential for hidden-action
  - Node interactions
  - Network topology
  - Enforcement mechanisms

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Contributions

- Define hidden-action attack category
- Identify hidden-action attacks in computer networks
- Demonstrate a contradiction between the environmental assumptions of peer-to-peer networks and the requirements for viable reputation systems
- Leverage results from social capital theory to improve network topology design and node interaction

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Why Social Capital?

Social capital analyses how human societies build institutions for facilitating credible transactions between mutually suspicious parties

1. Threat of punishment to deter misbehaviour
   - External or mutual enforcement
2. Resource allocation mechanism
   - Markets or communitarian institutions

Some institutions better suited to address hidden-action attacks

Increasing relevance to computer network design

- Nodes control behaviour but depend on interactions
- Computer scientists must build the institutions that define node interaction

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Enforcement Mechanisms

- External enforcement
  - Transactions translated into an independently verifiable contract
  - Enforcer does not participate in any transactions
  - Requires access to trusted, centralised mediator
- Mutual Enforcement
  - In many societies, members cannot rely upon an impartial third party
  - Transacting members punish misbehaviour
  - Scalable, decentralised approach—effective when environmental assumptions are met

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Market Failures and Communitarian Institutions

- Market institutions
  - Accommodates large populations with diverse interests
  - Low anticipation of future interactions
  - Repeated interaction with external enforcer, not each other, facilitate trust
  - Hidden-information during node selection
  - Hidden-action during node interaction
- Communitarian institutions
  - Grameen banks in Bangladesh
  - Small group size ensures repeated interactions
  - Low cost to monitor for (and punish) any misbehaviour
  - Undermines hidden-action attacks with mutual observation

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Hidden-Action Attacks Defined

Agent engaging in a transaction

- Can abide by (A) or break (B) the agreement
- Compare two operating environments
  - m: observation is difficult (e.g., market mechanism backed by external enforcement)
  - c: observation is easy (e.g., communitarian institution mutually enforced)

Expected utility for the agent

$$u_A = v_A - d_A$$

$$u_B = v_B - d_B - P(\text{detection}|B) * \text{penalty}$$

$$v : \text{value of action}, d : \text{disutility of action}$$

- Assume more costly to cooperate ($d_A > d_B$)
- More valuable individually to deviate ($v_B > v_A$)

Hidden-Action Attacks Defined (ctd.)

Definition An action B is considered a *hidden-action attack* whenever its benefits and costs to an agent satisfy the following inequalities:

$$P_m(\text{detect}|B) * \text{penalty}_m < (v_B - d_B) - (v_A - d_A) < P_c(\text{detect}|B) * \text{penalty}_c$$

- Hidden-action attacks may occur whenever the *net utility gain from deviating* lies between the expected penalty enforced when observation is unlikely and the penalty enforced when observation is likely
- Definition suggests that increasing observation along with a credible threat of punishment can obviate hidden-action attacks

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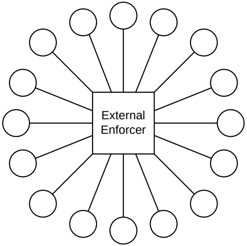
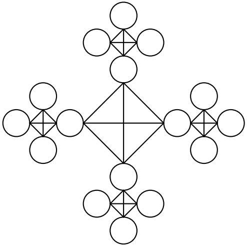
Exploiting Social Capital to Increase Observation



Market-style Institutions



Communitarian Institutions

- Network topology design
  - Small, densely-connected subgroups
  - Constrained connectivity
  - Fosters repeated interactions
  - Supports efficient observation
  - Comes at price of allocative inefficiency

Hidden-Action in Computer Networks

- Network interconnection enables hidden-action
  - Across the Internet, global interconnection is unavoidable
  - More specialised applications, however, are capable of constraining relevant attributes
- Attacks
  - Faked information aggregation in sensor networks
  - Selective forwarding in routing protocols
  - Redirecting traffic for eavesdropping
  - P2P free-riding

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Hidden-Action in Peer-to-Peer Systems

- Environmental assumptions of P2P file-sharing systems
  - Large member populations
  - Universal addressability
  - High turnover
  - Inexpensive/costless identities
- Proposed free-riding solutions use mutual enforcement
  - Direct contradiction of social capital research!
  - Mutual enforcement mechanisms require:
    1. Repeated interactions
    2. Far-sighted nodes
    3. Sufficient capability to punish deviation
  - Presently, P2P systems meet none of these requirements
  - Changes to network topology and interaction required

Countermeasures for Hidden-Action Attacks

- Resources available to the security engineer
  - Create monitoring threat
  - Change network structure and operation
- Build locality into network topology
  - Place interacting nodes in close proximity whenever possible
  - Arrange nodes in restricted neighbourhoods
- Incorporate mutual dependence between nodes to complete tasks

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Towards a Communitarian Institution for Enforcing Network Behaviour

- Neighbourhood topology
  - In many existing systems, node neighbours are selected based on random discovery (e.g., Gnutella) or random distribution (e.g., Chord)
  - Neighbour selection should connect nodes with similar interests
  - Critical for establishing repeated interactions and efficient observation
- Some requirements and open challenges
  - Node discovery mechanism
  - Network addressability restrictions
  - Efficient monitoring techniques
  - Effective punishment strategies

Discussion

- System attributes for mutual enforcement
  - Diversity vs. Solidarity of Interests
  - Instrumental vs. Expressive Actions
- Negative implications of communitarian institutions
  - Inefficient resource allocation
  - Tendency towards risk correlation
  - Privacy concerns
- Security maintenance costs often high in decentralised networks
  - Reputation systems and accounting mechanisms introduce high overhead
  - Minimising these costs is a fundamental challenge
  - Constructing network topologies and interactions to minimise hidden-action may reduce overhead

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Open questions

- Is mutual enforcement the only viable mechanism for deterring misbehaviour in decentralised networks?
- Can external enforcement be deployed without resorting to centralisation?
- How and when can network topologies be constrained without burdening or limiting users?

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Conclusions

- We have defined an economic category of hidden-action attacks
- We have turned to results from social capital theory to align incentives instead of relying on side payments
- We have found that many existing systems must change node topology and interactions for self-enforcement to work

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