Incentive Compatibility

- A multi-agent system is incentive compatible if selfish agents interact truthfully.
- Incentive compatible systems are more trusted by agents.

**Example: Auction Systems**

<table>
<thead>
<tr>
<th>Action</th>
<th>(s,r)</th>
<th>(s,s)</th>
<th>(r,s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Utility</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

Highest bidder wins the bid.

**Problem**

All agents in a multi-agent system M are selfish. Is multi-agent system M incentive compatible?

**Prior Work**

Analysis of selfish agents extensively studied

- No unifying framework for analysis of systems of selfish agents
- No automated approaches for analysis of selfish agents

**Framework: Weighted Regular Games**

- Quantitative abstraction of systems of selfish agents
- Quantitative utilities indicate agent motives
- Finite state model
- Executions in model correspond to collective behavior of agents
- Action tuples correspond to collective action of agents
- Weight tuples correspond to collective utility of agents
- Weight sequence is a utility function over states
- Utility of agent A with weight sequence A is

\[ u(A) = \sum_{d=1}^{\infty} \frac{a_d}{\delta^d} \]  for discount factor \( \delta > 1 \).

**Nash Equilibria: Analysis in WRG**

- An execution is in Nash equilibrium if no agent can receive greater utility by unilaterally deviating from the execution
- A notion of collective selfish behavior of all agents
- Many other notions exist

**Our Contribution**

- A unifying framework for modeling systems of selfish agents
- Quantitative abstraction of these systems
- ComputeNash: An algorithm to compute all Nash equilibria in weighted regular games

**Case Study: Bitcoin Protocol is not Incentive Compatible**

Srir and Fyal (2013) proved via manual rigorous analysis that the Bitcoin protocol is not incentive compatible.

**Bitcoin Protocol Model**

- Agent A1 and A2 actions:
  - Action 1: Searching for a bitcoin.
  - Action 2: Releases bitcoin finding one.
  - Dishonest agent A1, Action 1: May hide bitcoin after finding it.
  - Dishonest agent A1, Action 2: May hide bitcoin after finding it.

**Analysis of utilities of sequences**

**Core Insights**

- \( u(A) > u(B) \) if there exists \( C \) s.t.
  
  \[ u(A) = u(B) + u(C) \]  and \( u(C) > 0 \)

- \( C \) can be guessed non-deterministically using properties of arithmetic in base \( d \).

**ComputeNash**

- Computes all Nash equilibria in a WRG
- Complexity: Exponential in size of input WRG
- Observation: All Nash equilibria forms a regular language

**Conclusion**

- Presented a unifying framework for analyzing systems of selfish agents
- Analyzed these systems under Nash equilibria

**Future Work**

- Extension of framework to
  - Probabilistic systems
  - Infinite state models
- Extension to similar results under other notions of rationality
- Adoption of such algorithms to more real world applications.

**Collaborators**

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