Knowledge Management for Self-Organised Resource Allocation

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Introduction

Self-Governing Socio-technical Systems

- Self-governing socio-techincal systems:
  - rule-oriented systems
  - self-organising systems
  - value-sensitive systems
- These values may not even be explicitly referenced by the rules, but *values and rules should still be aligned*

Self-Governing Socio-technical Systems

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The Dilemma of the Rules

- on one hand, rules should be sufficiently unrestricted to allow 'freedom of (collective) action'
- on the other, sufficiently restricted to resist the 'iron law of oligarchy'

Common-Pool Resource (CPR) Management

- Resource allocation in open systems, common in socio-technical scenarios (smart-grids, cloud computing, sharing economy)
- Institutions, deal with challenges such as economy of scarcity, cooperation and regulation (Ostrom)
- Computational Justice, seek to achieve fair solutions, specially in exceptional situations (e.g. economy of scarcity)

Knowledge Management Processes

Knowledge Management in Classical Athens

- Openness, transparency and inclusivity
- Greater social benefits derived from higher levels of cooperation
- Capacity for resolving public collective action problems
- Participatory and deliberation model of self-governance

Knowledge Management Processes

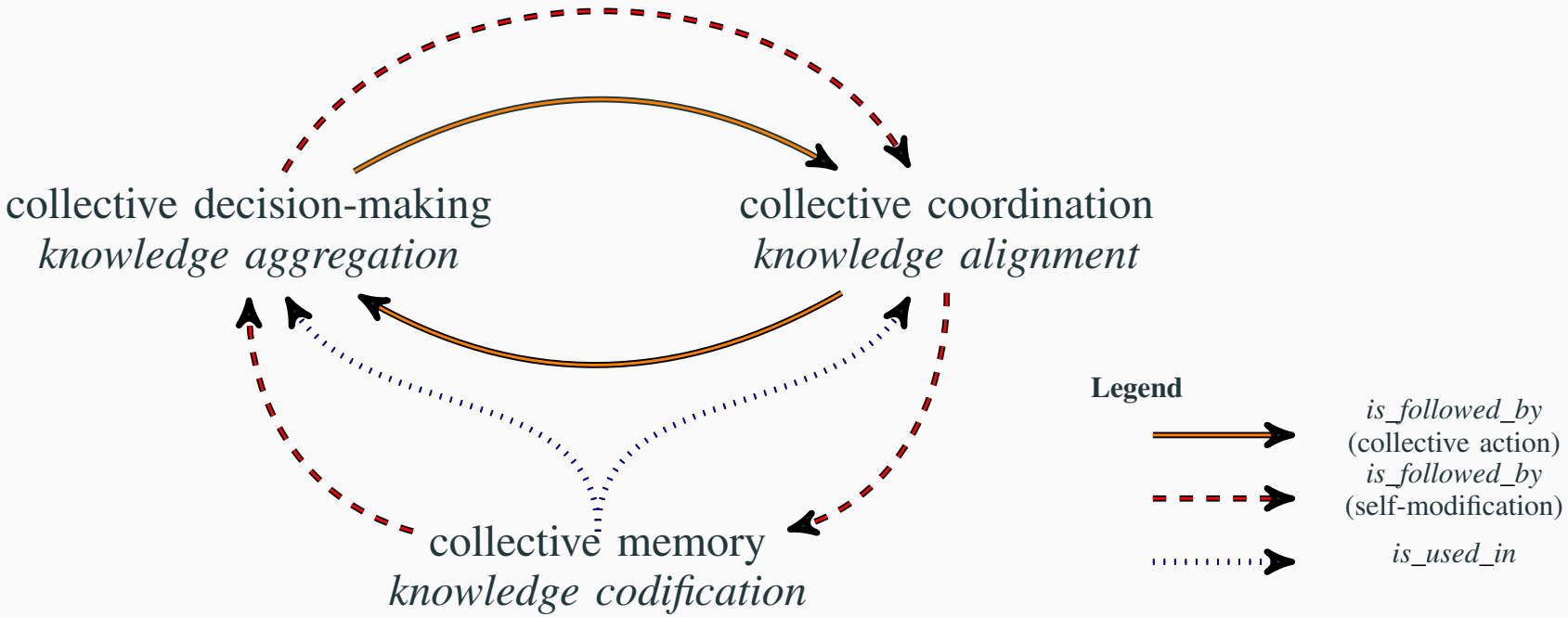
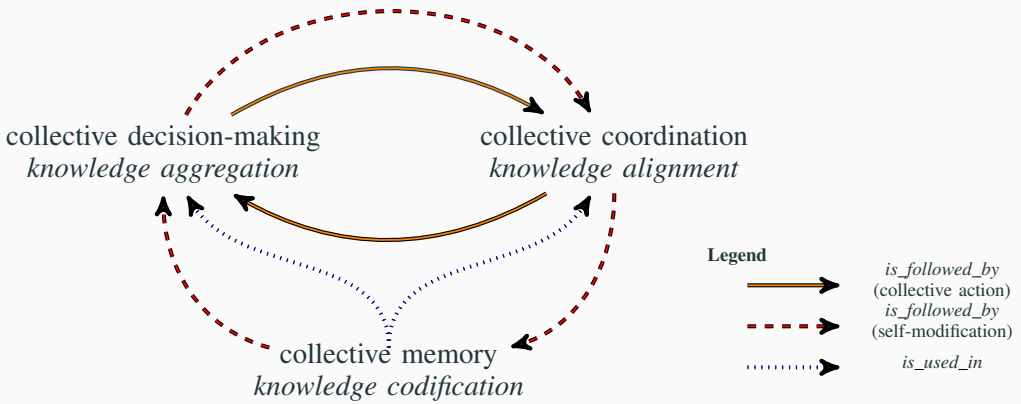


Figure 1: Athenian knowledge management processes (adapted from Ober)

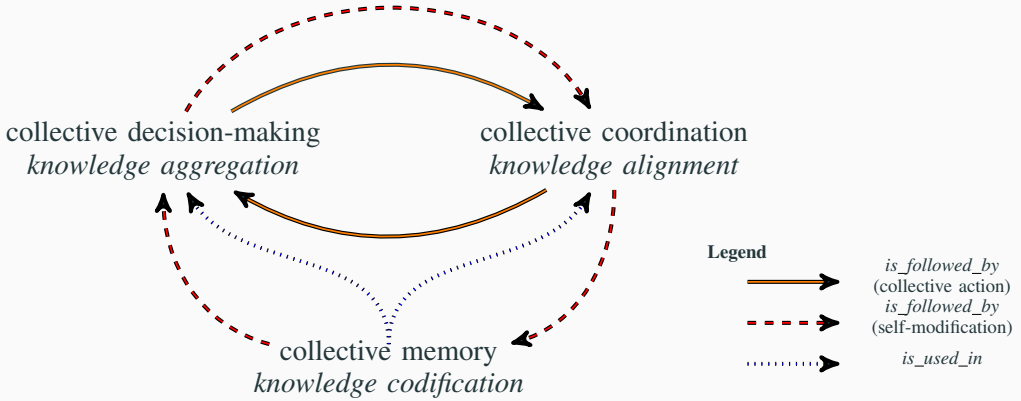
Knowledge Management Processes - Knowledge Aggregation



Knowledge Aggregation:

- Incentives for knowledgeable individuals to pool their knowledge for the benefit of the group
- Cost of communication sufficiently low to overcome the imposition of getting information from ”where it was” to ”where it needed to be”
- Sorting processes sifting false information from true and sifting useful and irrelevant information

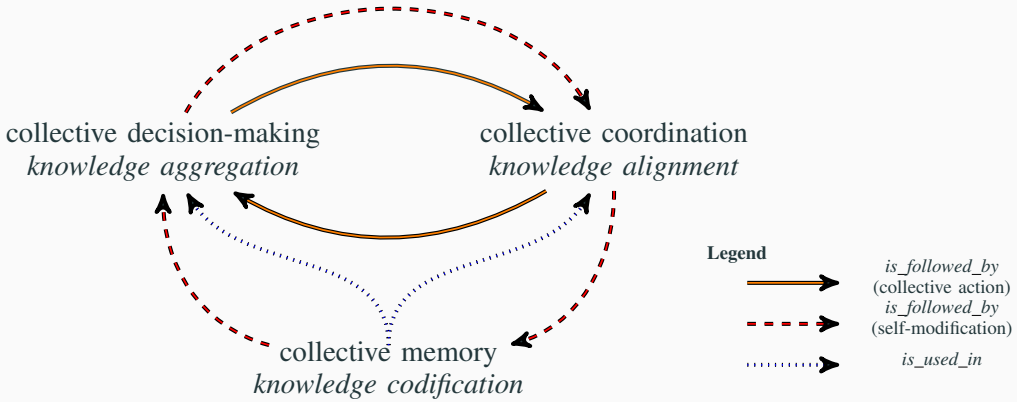
Knowledge Management Processes - Knowledge Alignment



Knowledge Alignment:

- Choice
- Informed Leader
- Commitment-following

Knowledge Management Processes - Knowledge Codification



Knowledge Codification:

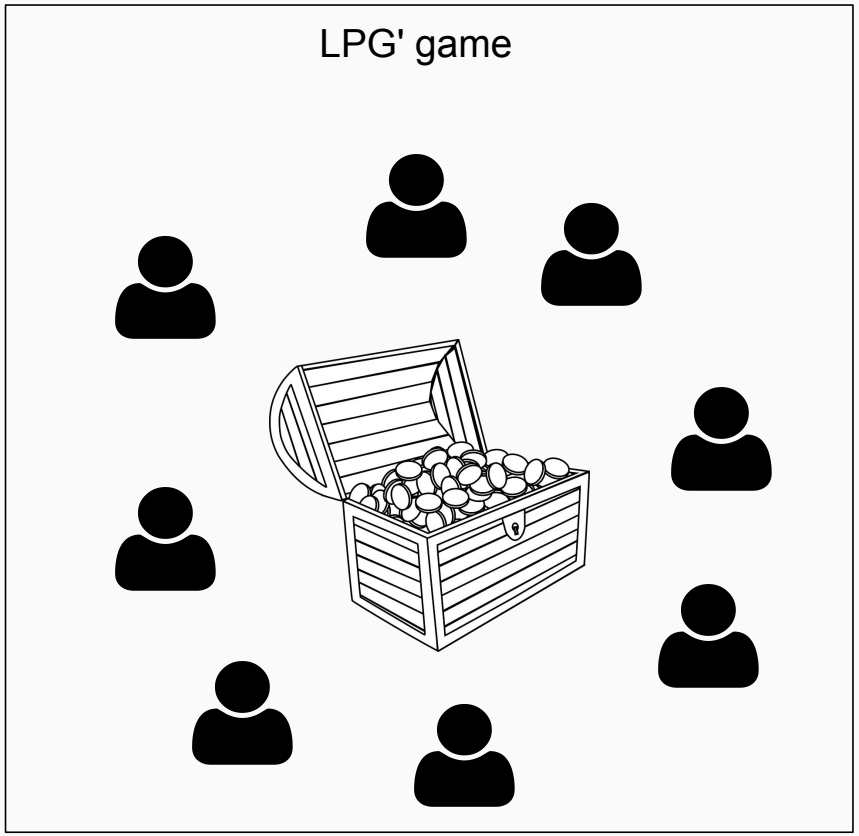
- Written laws or decrees
- Stable to allow confident planning, but also sufficiently fluid to avoid ossification and allow introspective improvement by amendment

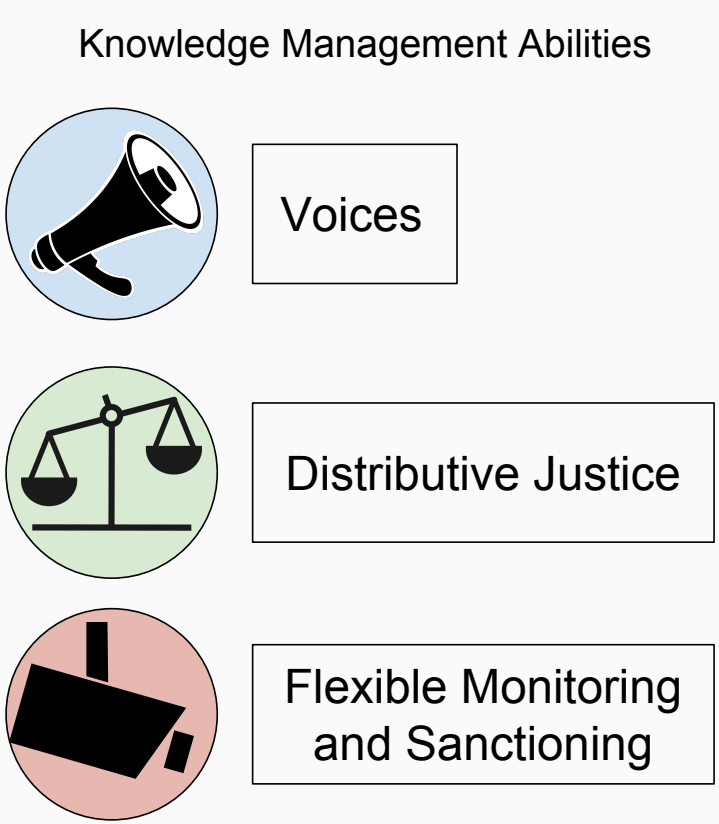
KM layer design principles

1. Clear boundaries (as per Ostrom) between who is a citizen/participant in knowledge aggregation and alignment processes, and who is not.
2. Processes generally aim to lower transaction costs, and increase aggregate value of social cooperation.
3. Agreement on certain matters on which decisions must be made as being of common interest (e.g. security, welfare of all within widest boundary).
4. Clear line between common interest questions and factional or partial goods questions. Appropriate procedural rules for decision-making in each domain.
5. Common knowledge by citizens of substantive rules and of procedural rules for making new rules and revising existing rules.
6. Epistemic diversity among citizens, along with distributed social knowledge of locus of expertise and reliability of experts.
7. Procedural rules ensure that valuable, diverse inputs are recognized as such and taken up as appropriate. Filtering process for assessing what (and whose) information input is (and is not) relevant to each specific sort of question.
8. Processes serve as focal points/bright lines for collective action by citizens against violations and specify a hierarchy of possible punishments depending on seriousness of violation.

Formal Model

Knowledge Management for Self-Organised Resource Allocation





- Voices: Opinion formulation and diffusion;
- Distributive Justice: Allocation policies definition;
- Flexible Monitoring and Sanctioning: Appropriate response for non-compliance;

LPG' Game

- Over time, players acknowledge resources need (q) and generation (g);
  - Economy of scarcity: $g_i < q_i$
- Through a common-pool of resources, agents contribute part of their resources (p_i) and disclose a demand (d_i);
- Resources are distributed to players (r), following allocation rules;
- Possibility of non-compliance: $p_i \leq g_i; d_i \geq q_i; r'_i \geq r_i$

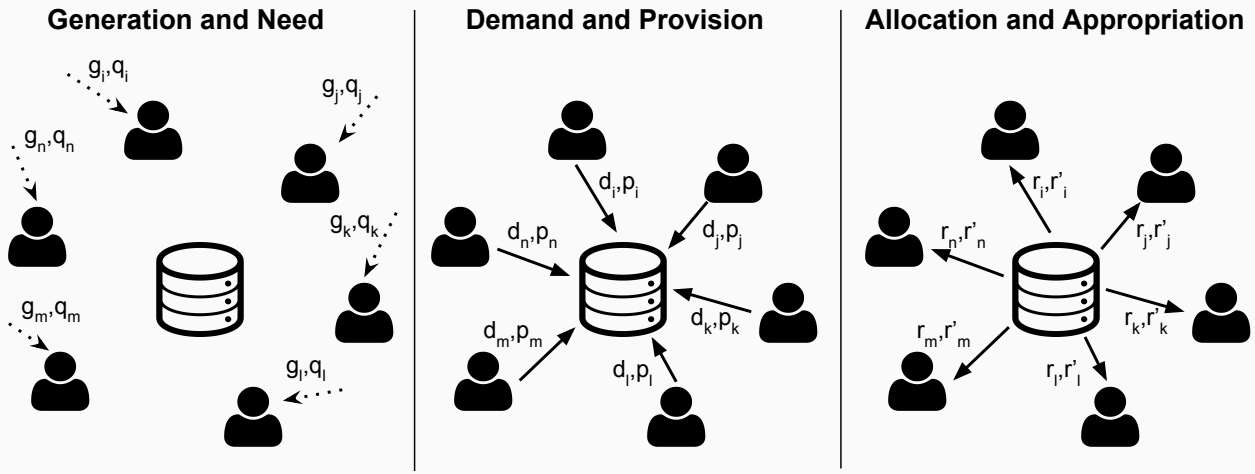


Figure 2: The LPG' Game

Results

Voices of Justice

Motivation

6. Epistemic diversity among citizens, along with distributed social knowledge of locus of expertise and reliability of experts.

- How to conciliate the different players' voices?
- How to weight different opinions
- "Not only must justice be done; it must also be seen to be done"
- How to deal with disagreement in the perception of fairness, e.g. a context might satisfy one part of a group, but infuriate the rest.

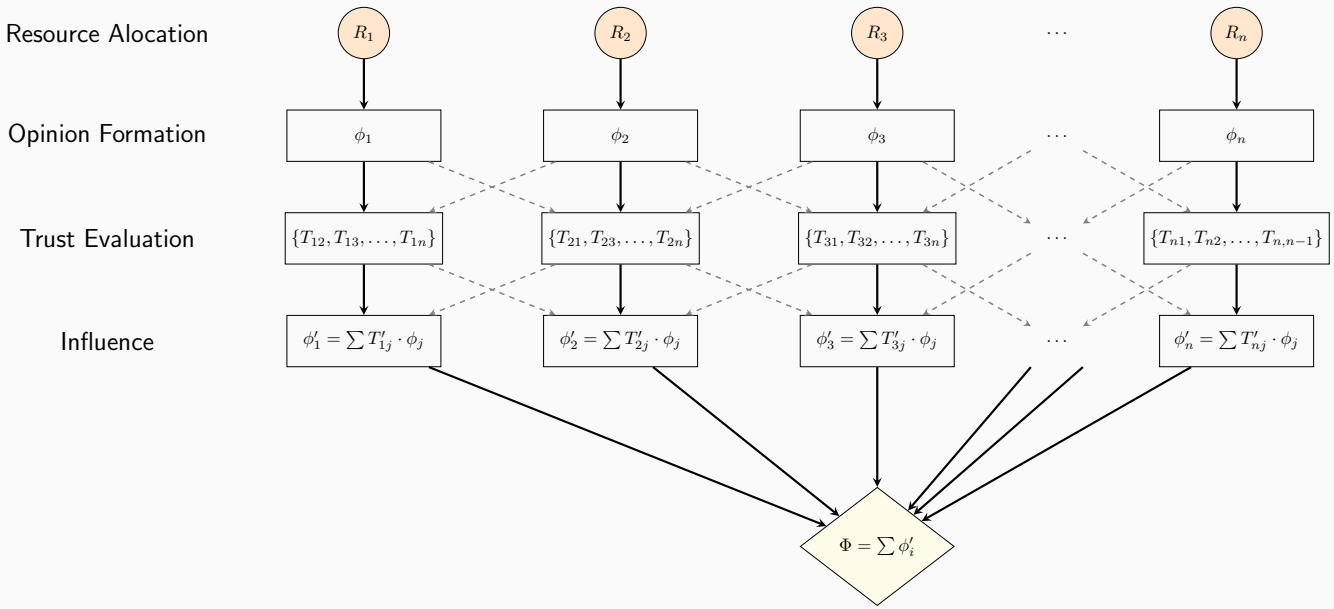
Motivation

6. Epistemic diversity among citizens, along with distributed social knowledge of locus of expertise and reliability of experts.

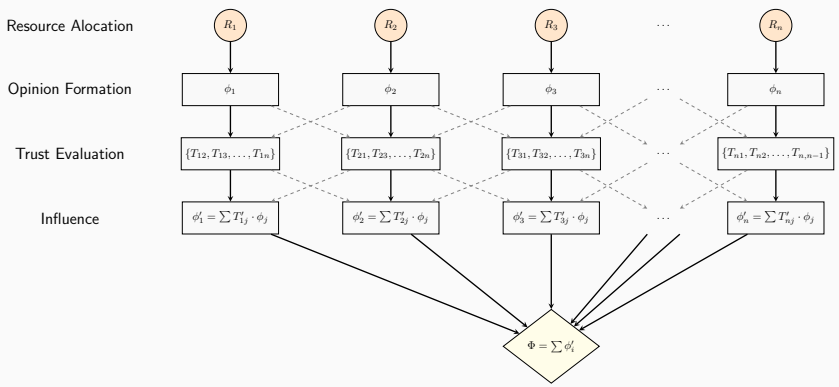
- Diversity → variety of behaviour and opinions
- Distributed social knowledge → information diffusion / convergence processes
- Locus of expertise → different network topologies, clustering
- Reliability of experts → Trust / affinity function guiding influence and information diffusion

Strategy

1. **Opinion Formation** - agent opinions are formulated, based on individual experience;
2. **Trust** - agents observe their environment and, through comparison, define its trusts;
3. **Influence** - agents communicate and diffuse opinions through their social influence.



Strategy



Trust:

1. Affinity

$$\tau_{ij}(t) = 1 - \frac{1}{1 + e^{-k(|\bar{\phi}_{N_i}(t) - \phi_j(t)| - \epsilon_0)}}$$

2. Memory

$$T_{ij}(t) = (1-\gamma) \cdot T_{ij}(t-1) + \gamma \cdot \tau_{ij}(t$$

Influence:

$$\phi_i(n) = \sum_{j \in \mathcal{N}_i} T_{ij} \phi_j(n-1)$$

Voices Results

1. *Coherence* - Can the solution identify and distinguish fair and unfair allocation schemes?
2. *Robustness* - Are there mechanisms able to avoid the influence of malicious agents trying to propagate false information?
3. *Resilience* - Does it work properly in different topologies and with topology changes?

Voices Results - Coherence

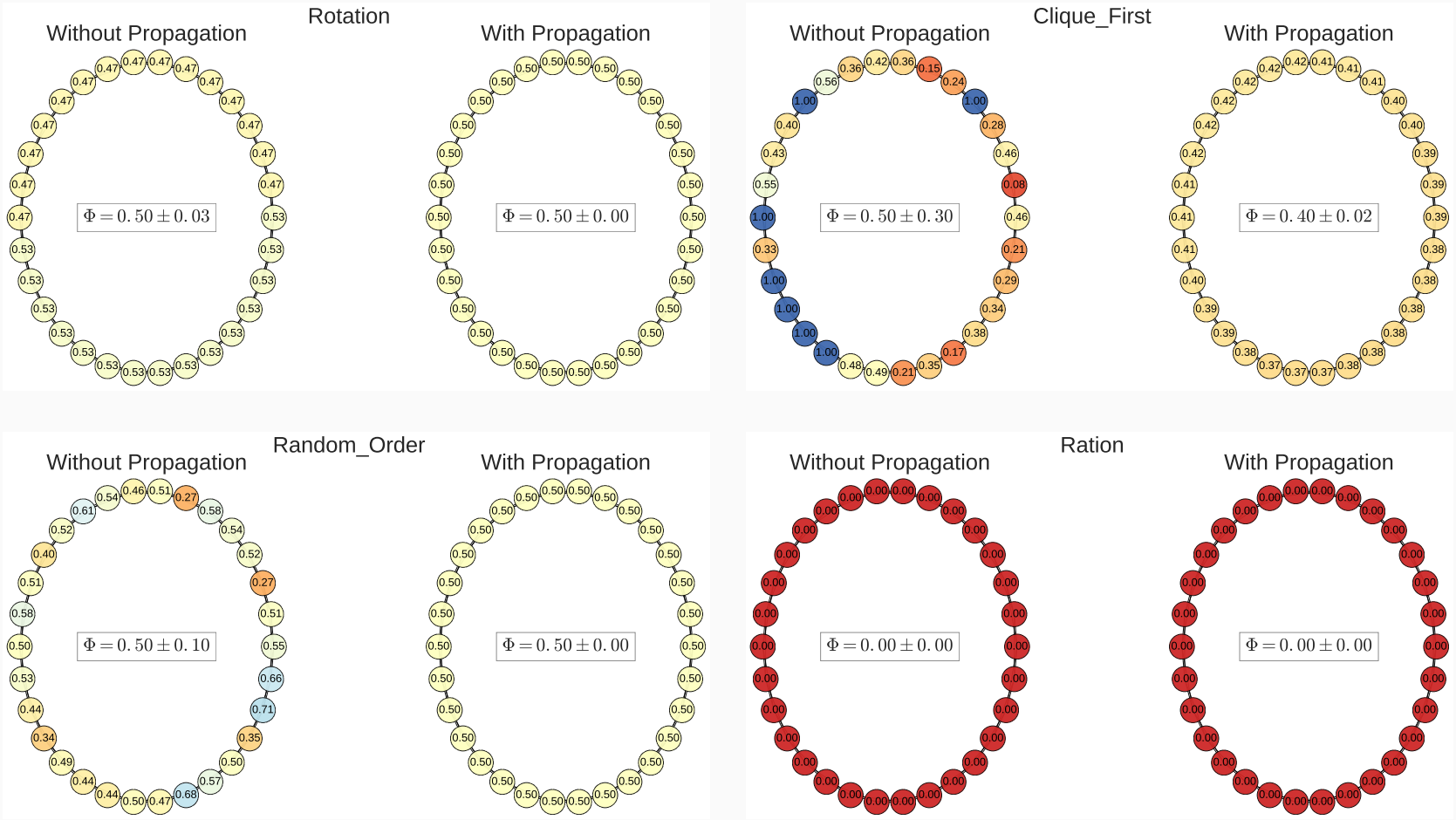
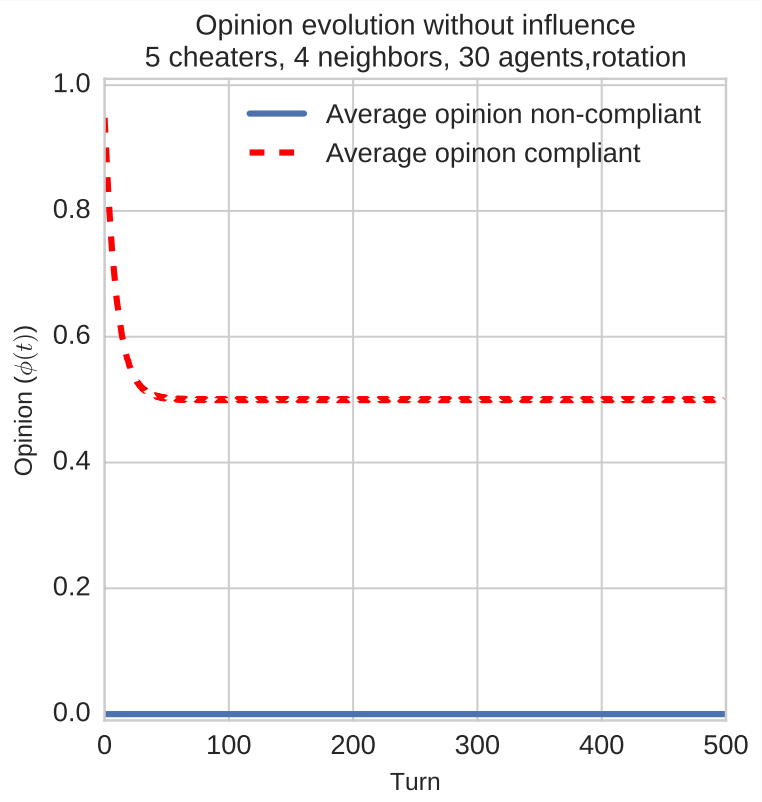
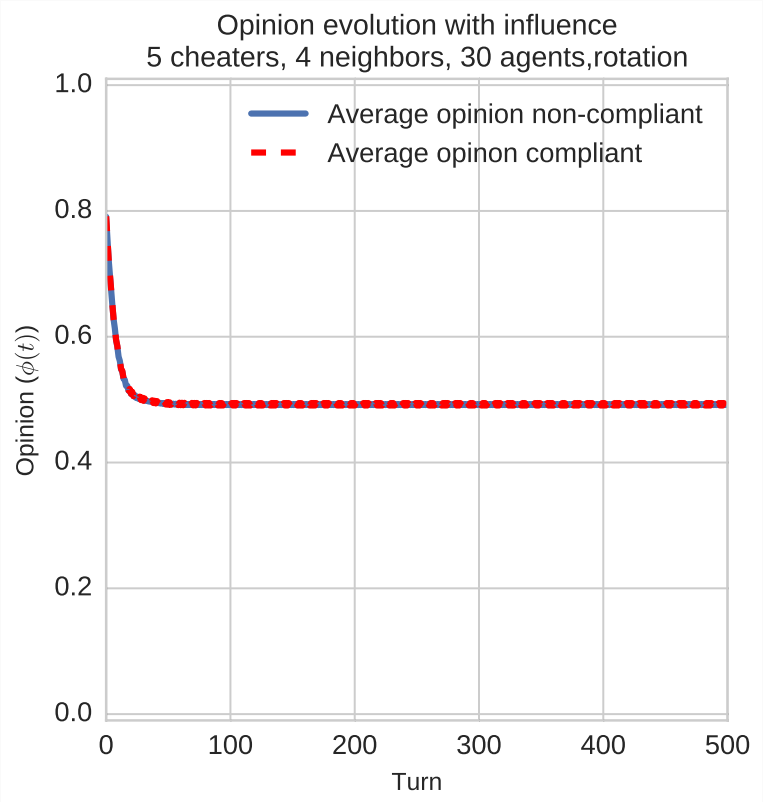


Figure 3: Mean opinon for different allocation methods. Propagation ensures more reliable and convergent final opinion.

Voices Results - Robustness





- Malicious agents try to undermine the public opinion by consistently propagating negative feedback.
- Trust and influence select the appropriate content

Voices Results - Resilience

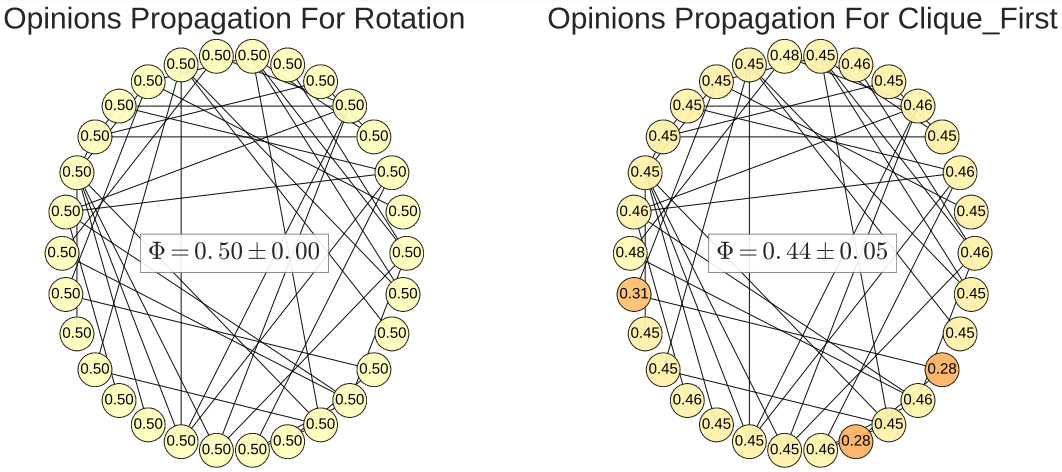


Figure 4: Random (Erdos Renyi) Network

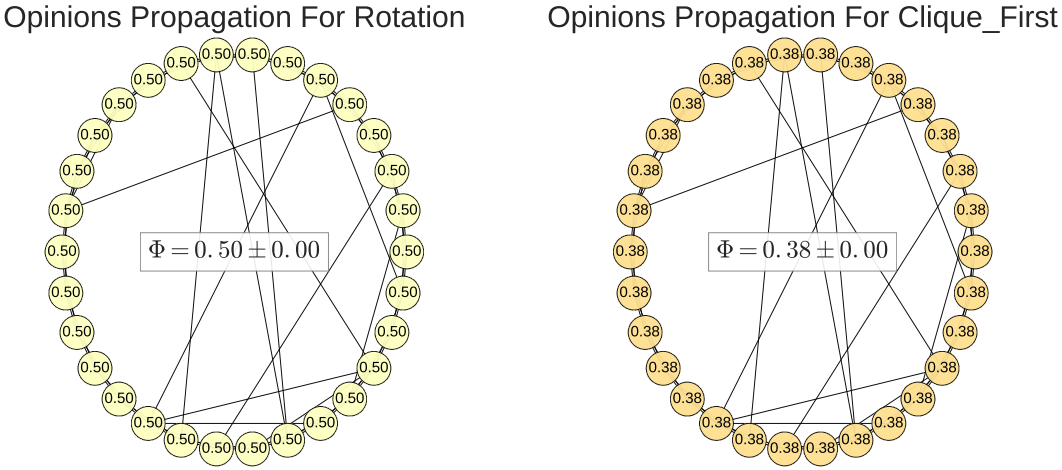


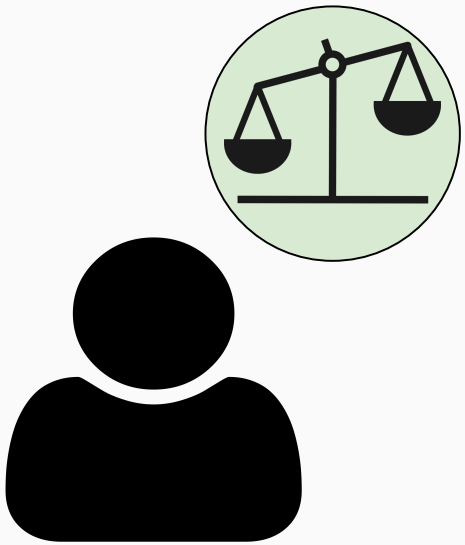
Figure 5: Small-World Network

Despite same number of connections, small-world network enables locus of information, creating overall better knowledge of the system's state.

Distributed Distributive Justice

Motivation

7. Procedural rules ensure that valuable, diverse inputs are recognized as such and taken up as appropriate. Filtering process for assessing what (and whose) information input is (and is not) relevant to each specific sort of question.



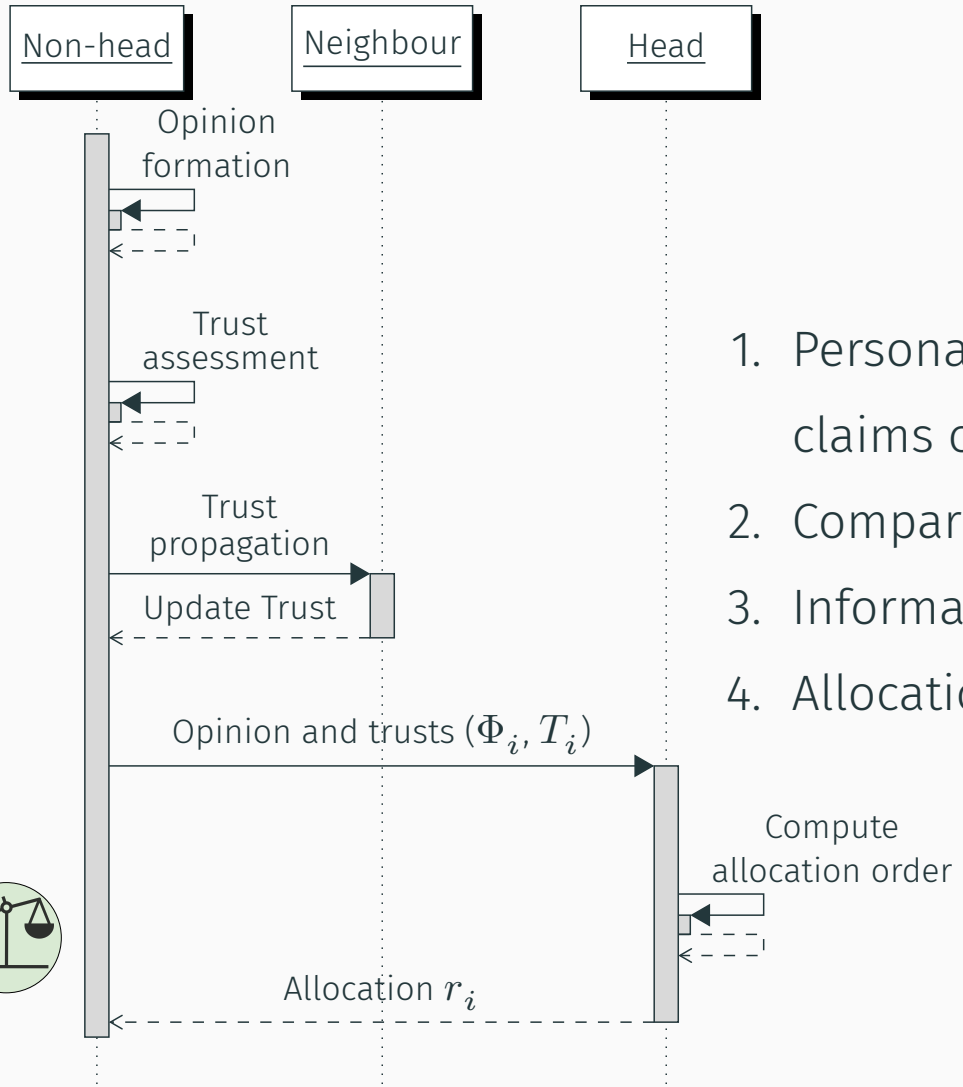
- How to evaluate multiple inputs to legislate a resource allocation policy?
- How to discern between relevant and irrelevant inputs in the decision making?
- How to achieve fairness in resource allocation policies?

Motivation

7. Procedural rules ensure that valuable, diverse inputs are recognized as such and taken up as appropriate. Filtering process for assessing what (and whose) information input is (and is not) relevant to each specific sort of question.

- Procedural rules → resource allocation policy making, claim and responses for resources
- Valuable, diverse input recognised as such → Rescher's legitimate claims
- Filtering process assessing (ir)relevant information → Trust, reputation, affinity

Strategy



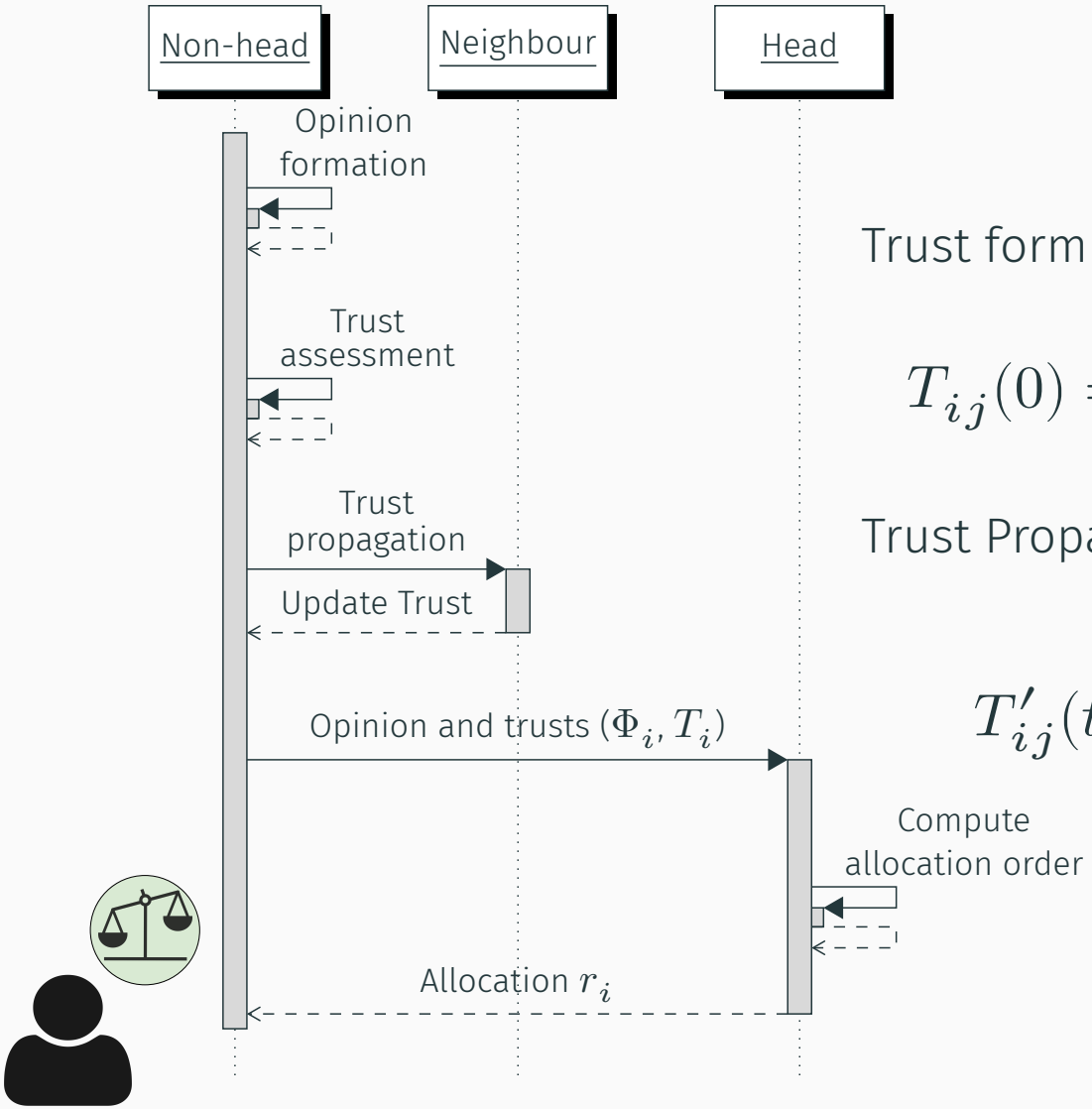
1. Personal opinion formation (legitimate claims of justice)
2. Comparison to the environment (trust)
3. Information exchange and trust update
4. Allocation guided by reputation

Strategy - Personal Opinion Formation (legitimate claims of justice)

Legitimate Claims of Justice:

Canons of equality	$\phi_i^1(S) = \frac{\sum_{t=0}^{S} r_i(t)}{S}$
	$\phi_i^2(S) = \frac{\sum_{t=0}^{S} (r_i(t)>0)}{S}$
	$\phi_i^3(S) = \begin{cases} (1-\alpha)\cdot\phi_i^3(S-1)+\alpha & \text{if } r_i(S) \geq d_i(S) \\ (1-\beta)\cdot\phi_i^3(S-1) & \text{if } r_i(S) < d_i(S) \end{cases}$
Canon of needs	$\phi_i^4(S) = \frac{\sum_{t=0}^{S} d_i(t)}{S}$
Canon of productivity	$\phi_i^5(S) = \frac{\sum_{t=0}^{S} p_i(t)}{S}$
Canon of effort	$\phi_i^6(S) = S$
Canon of social utility	$\phi_i^7(S) = \frac{\sum_{t=0}^{S} \mathbb{I}(head(t)=i)}{S}$
Canon of supply and demand	$\phi_i^8(S) = \frac{\sum_{t=0}^{S} \mathbb{I}(p_i(t)=g_i(t) \wedge d_i(t)=q_i(t) \wedge r_i'(t)=r_i(t))}{S}$

Strategy - Trust Assessment and Propagation



Trust formulation:

$$T_{ij}(0) = f(\text{affinity}(i,j), \text{memory}(i,j))$$

Trust Propagation:

$$T'_{ij}(t) = \frac{\sum_{k \in N_{ij}} T_{ik}(t) T_{kj}(t)}{\sum_{k \in N_{ij}} T_{ik}(t)}$$

Distributed Justice Results

1. *Efficiency* - can the solution efficiently distribute resources under full compliance?
2. *Fairness* - does the solution guarantee fair allocations in case of non-compliance?
3. *Robustness* - what is the effect of changing network topology and behaviour?

Distributive Justice Results - Efficiency

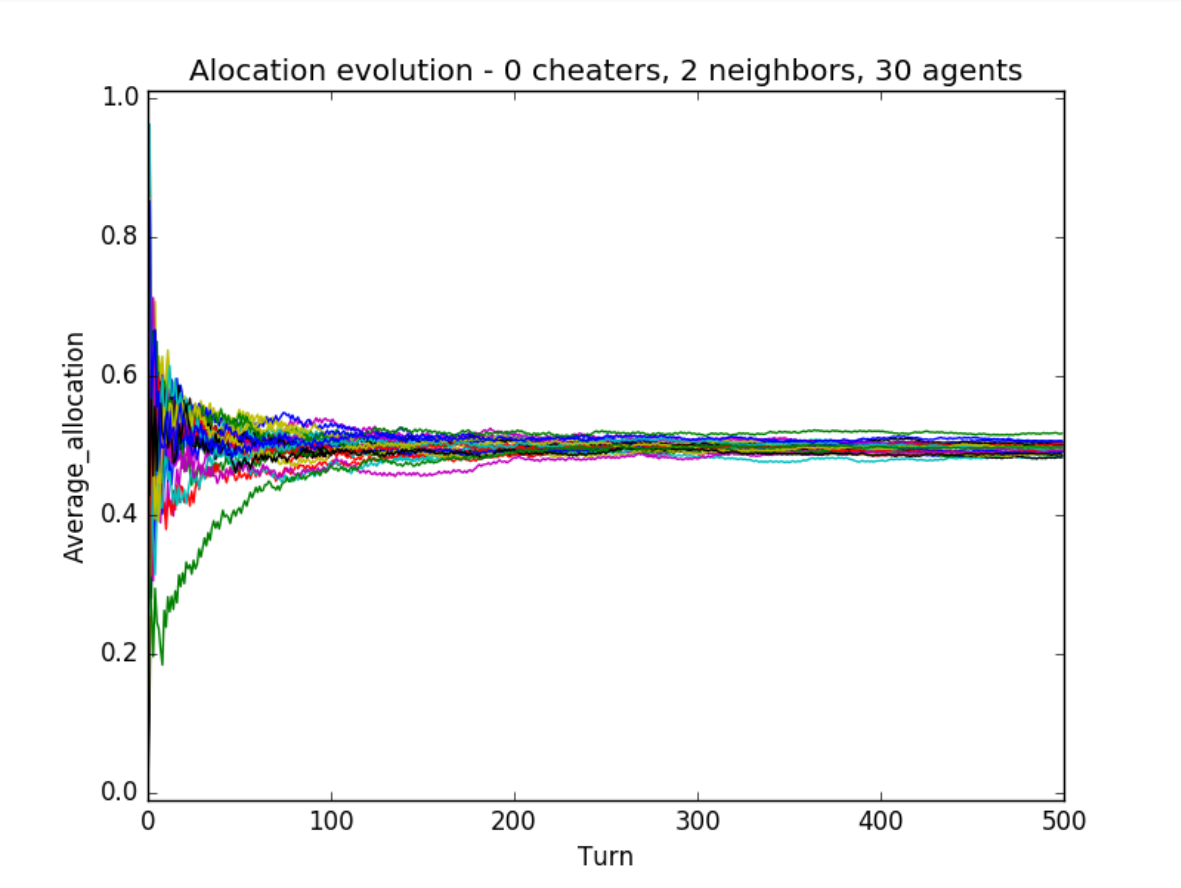


Figure 6: Allocation in scenario without non-compliant agents. Each coloured line represents a different agent.

- Agents more in need are prioritized, resulting in a stable and egalitarian distribution.

Distributive Justice Results - Fairness

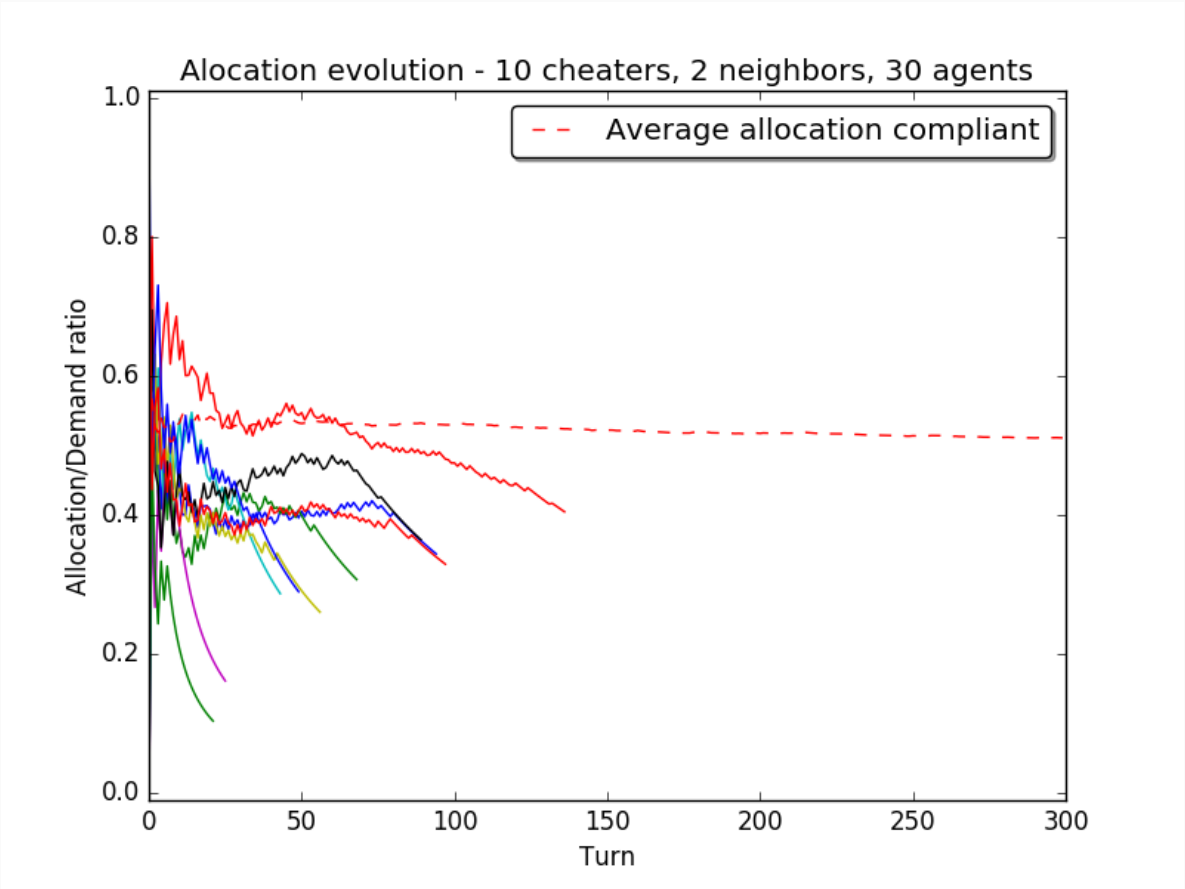


Figure 7: Individual allocations for non-compliant agents (solid lines) compared to compliant average (dashed).

- Non-compliant agents are not trusted, therefore do not receive resources and eventually leave the cluster.

Distributive Justice Results - Robustness

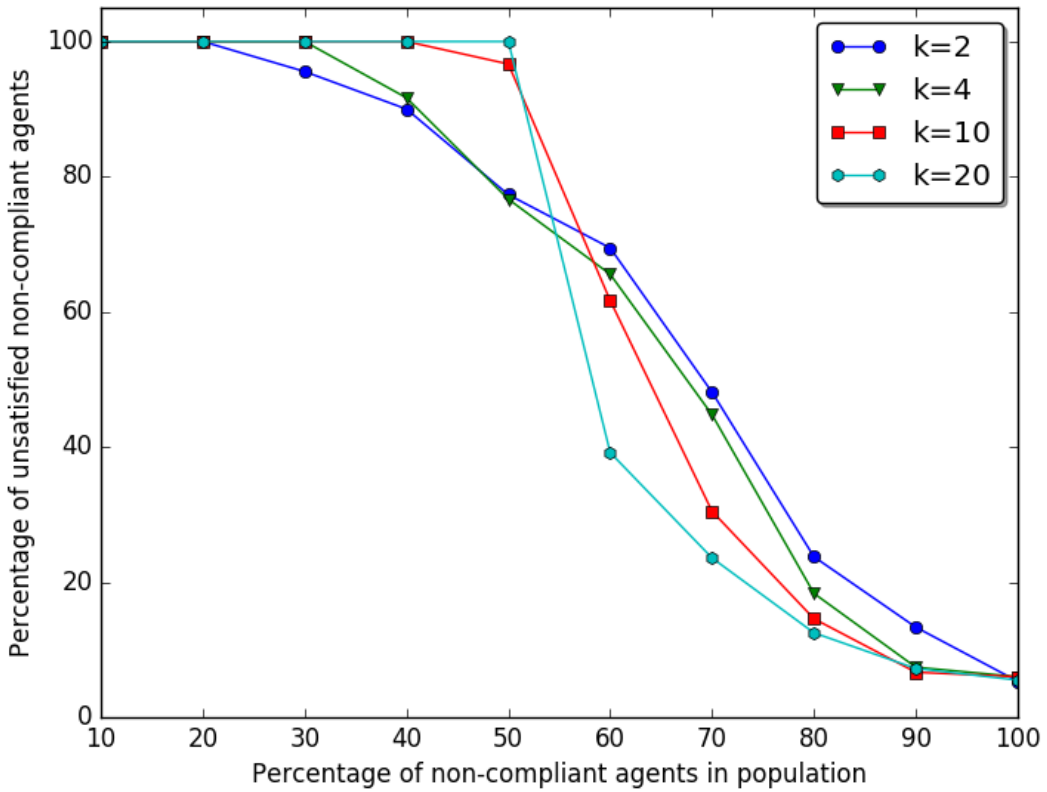


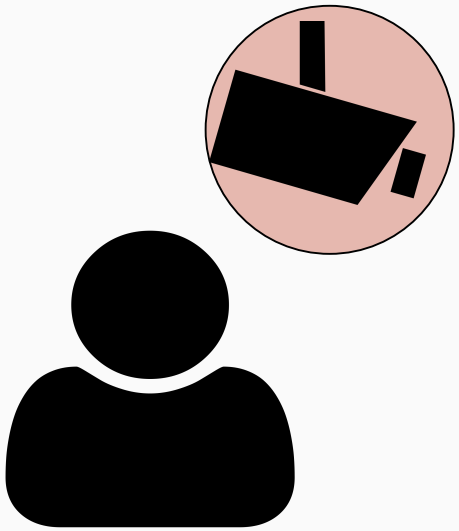
Figure 8: Ability of non-compliant behaviour detection, by size of neighbourhood (k).

- Below 50%: non-compliancy is opposed even with few connections;
- Above 50%: non-compliancy becomes the 'rule', but can not produce an enduring allocarion to all agents.

Flexible Monitoring and Sanctioning

Motivation

8. Processes serve as focal points/bright lines for collective action by citizens against violations and specify a hierarchy of possible punishments depending on seriousness of violation.

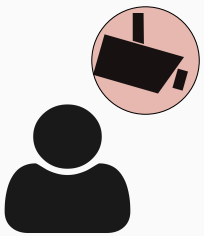


- How to respond to transgressions?
- What is the best procedure to deal with non-compliance?
- How to ensure diversity and flexibility in open systems?

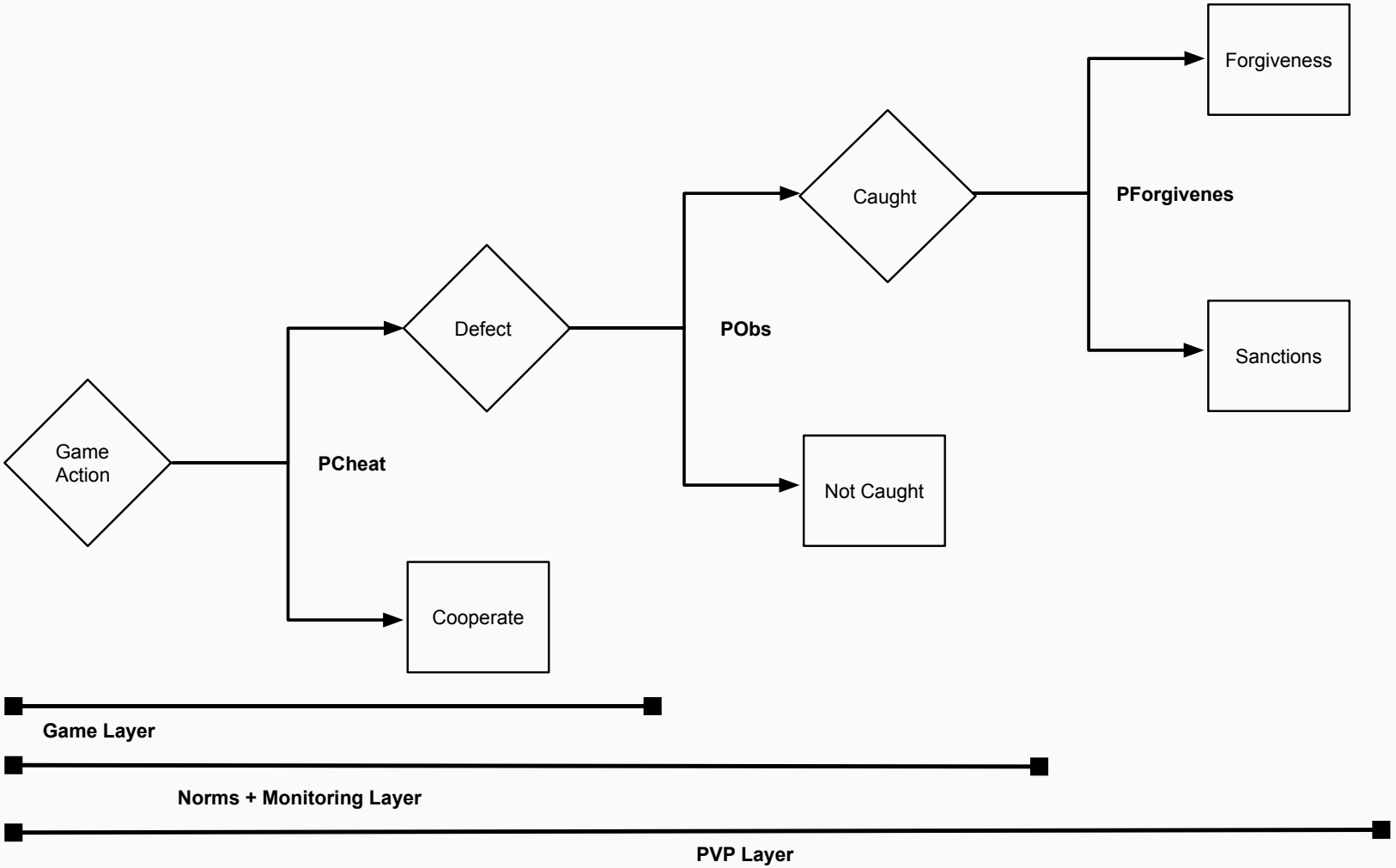
Motivation

8. Processes serve as focal points/bright lines for collective action by citizens against violations and specify a hierarchy of possible punishments depending on seriousness of violation.

- Processes against violations → Monitoring and sanctioning mechanisms
- Hierarchy of punishments depending on seriousness of violation
  → Principled Violation of Policy

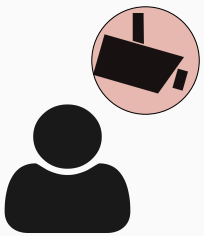


Strategy


Forgiveness
Caught
PForgivenes
Defect
PObs
Sanctions
Game
Action
PCheat
Not Caught
Cooperate
Game Layer
Norms + Monitoring Layer
PVP Layer

Flexible Monitoring and Sanctioning Results

1. Cost-effective monitoring
2. Hierarchy of punishments
3. Flexible monitoring and sanctioning
4. Justice perception and policy justification



Flexible Monitoring and Sanctioning Results - Cost-effective Monitoring

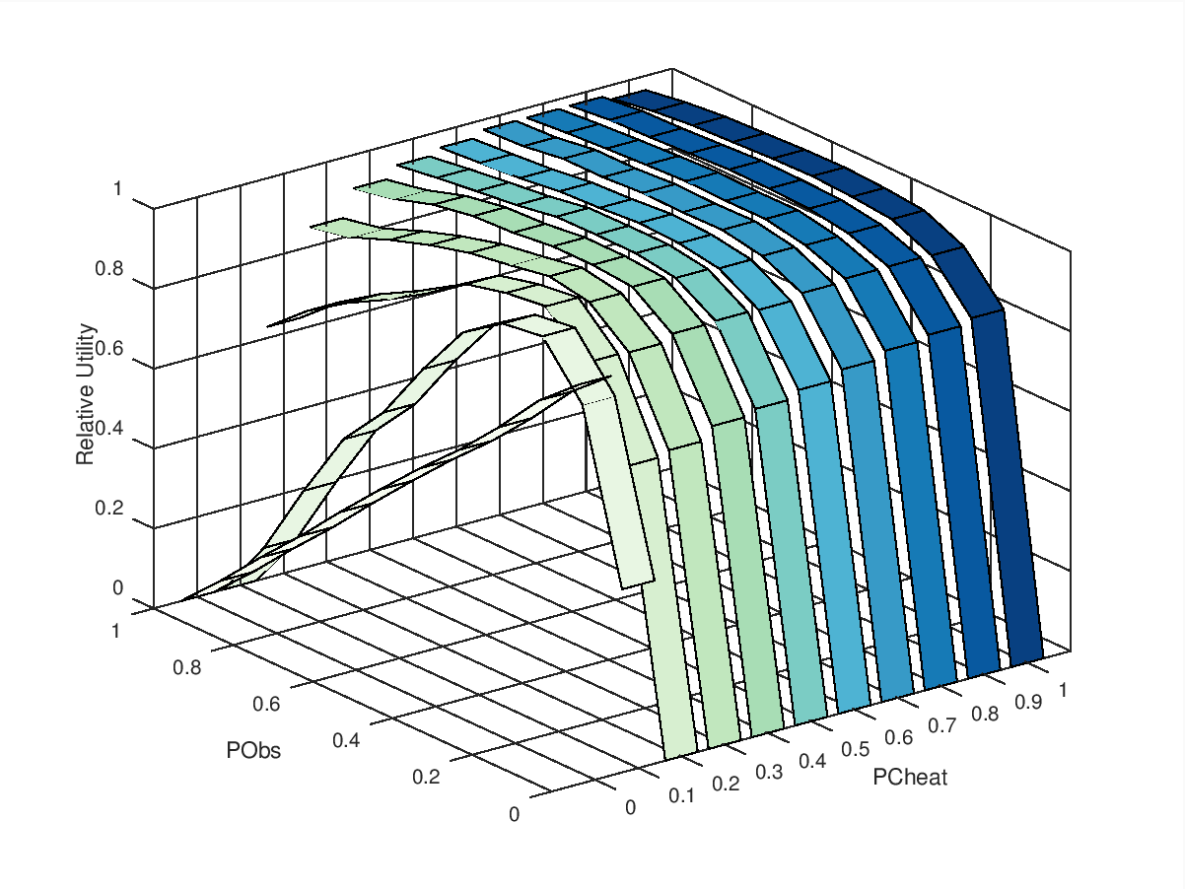


Figure 9: Relative utility of compliant agents for different combinations of $PObs$ and $PCheat$

If monitoring has costs, depending on the levels of non-compliance ($PCheat$), increasing the monitoring frequency ($PObs$) has small or negative effect on general utility.

Flexible Monitoring and Sanctioning Results - Hierarchy of Punishments

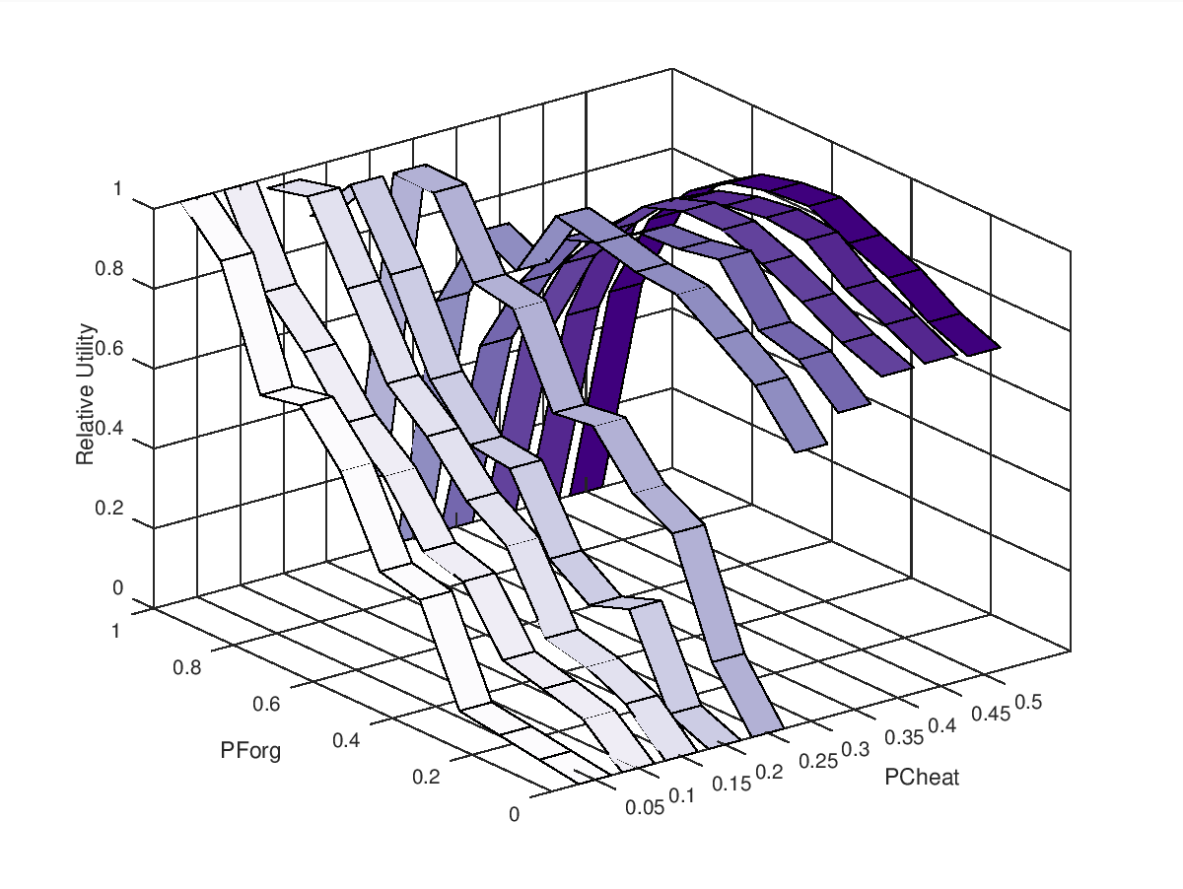


Figure 10: Relative utility for different combinations of $PForg$ and $PCheat$.

In scenarios with low levels of non-compliance ($PForg$), higher utility is achieved by letting eventual non-compliant agents participate in the game, than excluding them through sanctioning.

Flexible Monitoring and Sanctioning Results - Adaptable Policies

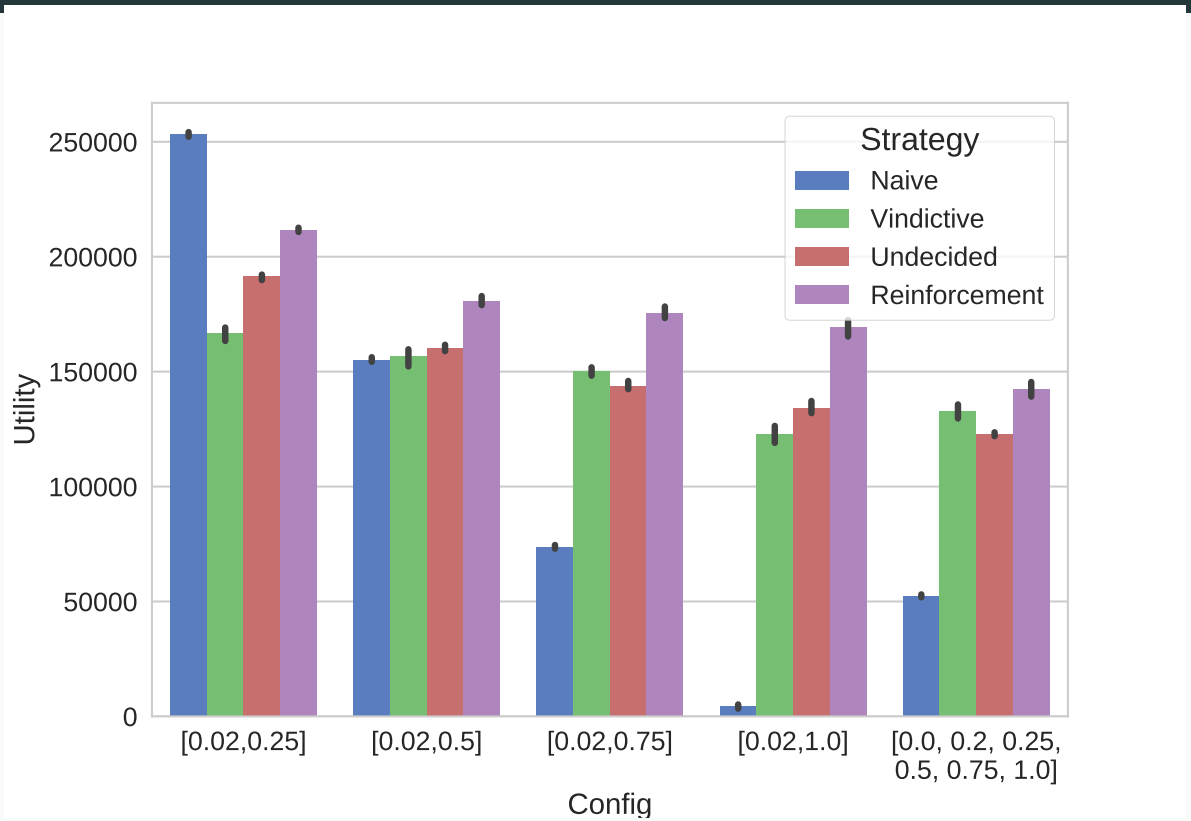


Figure 11: Comparison of utility from different strategies, for various configurations of population. Each configuration label shows the different values of $PCheat$ among the players population.

Compared to fixed policy strategies, flexible strategy (reinforcement, in graph) is able to achieve overall better results, for different scenarios of non-compliance.

Flexible Monitoring and Sanctioning Results - Justice Perception

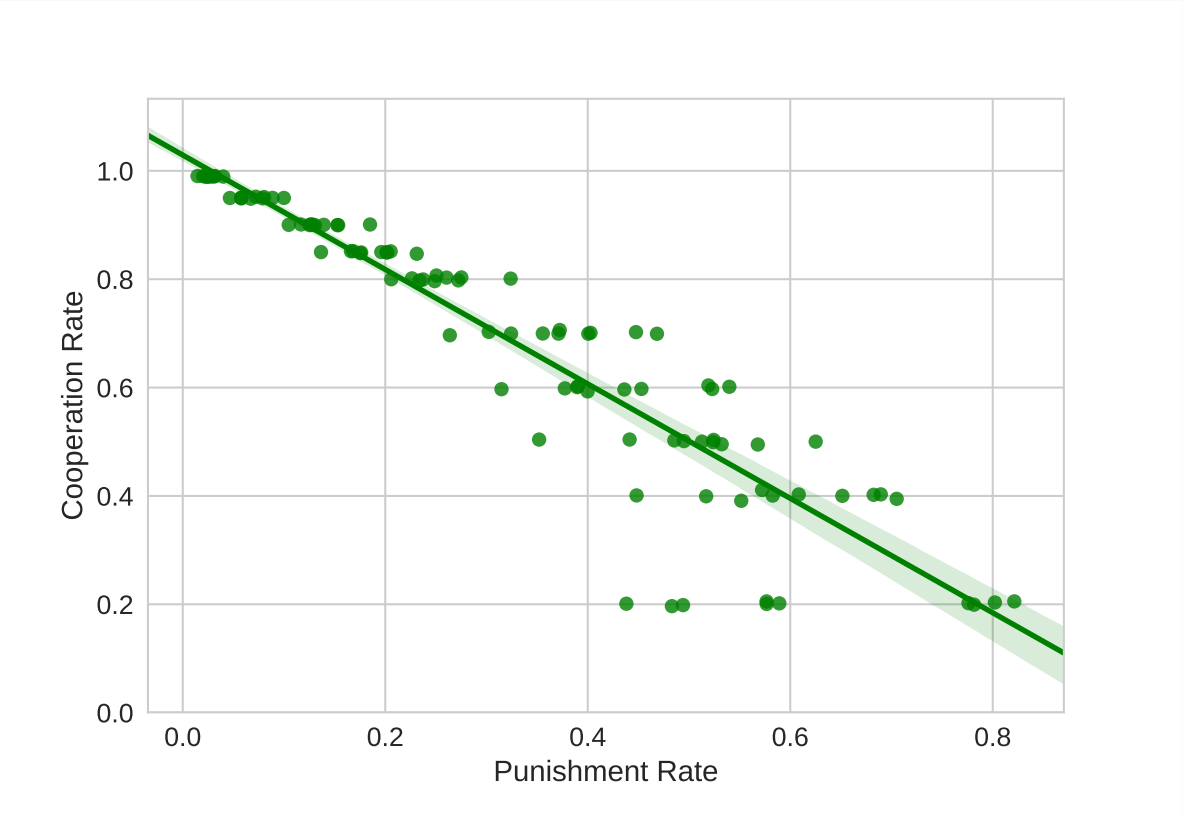


Figure 12: Relationship between cooperation rate (#cooperations/#turns) and punishment rate (#sanctions/#non-compliance)

In scenarios where PVP is learned and exercised, agents with high levels of cooperation receive proportionally less sanctions than the ones who do not cooperate as often.

Discussion and Conclusions

Summary of results

- **Common Pool Resources Management** problem in self-governing socio-technical systems requires robust, resilient and adaptive solutions;
- Open and transparent **Knowledge Management Processes**, inspired by classical Athenian democracy, give principles on how communication and collective decision processes should be conducted;
- Experimental results are practical implementations of principles 7, 8, 9:
  - Voices - distributed social knowledge and epistemic diversity for assessment of system fairness;
  - Distributed Distributive Justice - procedure rules to ensure that requests for resources are evaluated. Trust and reputation act as filtering processes for assessing the relevance of different requests;
  - Flexible Monitoring and Sanctioning - processes for collective action against violations and non-compliance, with hierarchy of punishments depending on the seriousness of violation.

Acknowledgemnts

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Thank you!