Distributed Distributive Justice

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Introduction

Introduction - Resource Allocation in Open Systems

The prevalence of open systems – e.g. smart grids, cellular networks and cloud computing – is driving a demand for ‘better’ solutions to a standard **resource allocation problem**:

- How to collectivise and distribute a set of common-pool resources, considering
  - Fairness
  - Inclusivity
  - Sustainability
- How to overcome problems such as
  - No centralised authority
  - No full disclosure
  - Economy of scarcity

Computational Justice

- How resources can be distributed in a fair manner?
    - How to **prioritise** requests?
    - What **fairness criteria** should be considered when judging merit (equality, equity, proportionallity, ...)
    - How to **avoid abuses** in the system (*free-riding*, deceiving, non-compliancy)

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Towards a Computational Justice framework

- Centuries of experience in the context of social organisations can be transfered to new and current technical systems;
- Not only concerned with solution's efficiency, but also aspects such as "correctness", "appropriateness" and "acceptability".

Solutions both generic and yet flexible, and both efficient and yet effective.

Experimental Setting - LPG$'$ Game

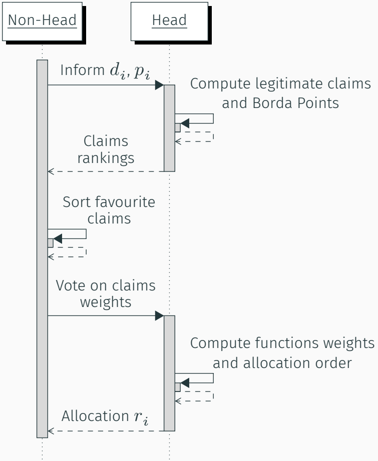
Linear Public Game creating a scenario where agents receive resources independently and can decide to cooperate or not.

- n agents share an environment with scarce resources and strive to persist on it for as long as possible
- At each timestep (turn) t, each agent:
  - Determines the resources it has **available**, $g_i \in [0, 1]$
  - Determines its **need** for resources, $q_i \in [0, 1]$
    - (In an economy of scarcity, $q_i > g_i$)
  - Makes a **demand** for resources, $d_i \in [0, 1]$
  - Makes a **provision** of resources, $p_i \in [0, 1]$ ($p_i \leq g_i$)
  - Receives an **allocation** of resources (defined externally), $r_i \in [0, 1]$
  - Makes an **appropriation** of resources, $r'_i \in [0, 1]$
- If $p_i = g_i \land d_i = q_i \land r'_i = r_i$ we say that an agent is complying with the game; otherwise it is considered non-compliant.

Towards a Distributive Justice Framework

Former Solution: *DJ*

- Consider different metrics to evaluate fairness
- Formalisation of Nicholas Rescher's **legitimate claims of justice**



- Four-way algorithm:
  1. Agents inform a 'head' demands and provisions;
  2. Head ranks agents according to different criteria (legitimate claims);
  3. Agents vote on criteria to be prioritized;
  4. Head, considering criteria weights and agents condition, decide an order of allocation.

Distributed Distributive Justice (DDJ)

- Maintain the formalisation of Rescher’s legitimate claims as a plural metric for fairness;
- Develop a trust and reputation framework, allowing the computation of priorities and needs in a decentralised and independent way.
- Steps:
    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

Personal Opinion Formation (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	$\phi_i^8(S) = \frac{\sum_{t=0}^{S} \mathbb{I}(p_i(t)=g_i(t)\wedge d_i(t)=q_i(t)\wedge r_i'(t)=r_i(t))}{S}$

- Individual opinion vector:

$$\Phi_i(t) = \{\phi_i^1, \phi_i^2, \phi_i^3, \ldots, \phi_i^8\} = \{\phi_i^c : c \in |\mathcal{C}|\}$$

- Individual aggregated opinion:

$$\phi_i(t) = \sum_c \frac{1}{|\mathcal{C}|} \cdot \phi_i^c(t)$$

- Accordance index:

$$\tau_{ij}(t) = \text{diff}(\bar{\phi}_{N_i - j}(t),\ \phi_j^c(t))$$

$$\bar{\phi}_{N_i - j}(t) = \frac{\sum_{n \in N(i) \cap \{i\} - \{j\}} \phi_n(t)}{|N(i)| + 1}$$

- Trust:

$$T_{ij}(t) = \begin{cases} 0.0 & \text{if } j \notin N(j) \\ (1-\gamma)T_{ij}\,(t-1) + \gamma \tau_{ij}(t) & \text{if } i \neq j \wedge j \in N(j) \\ 1.0 & \text{if } i = j \end{cases}$$

Principles

1. Trust more those who say coherent things (according to yourself!)
2. It takes time to change an impression

Information Exchange and Trust Update

Update trust, based on common neighbours' trusts

- Iterative process:

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

where:

$$N_{ij} = (N(i) \cap N(j)) \cup \{i\} - \{j\}$$

Allocation guided by reputation

Define final metrics to perform allocation

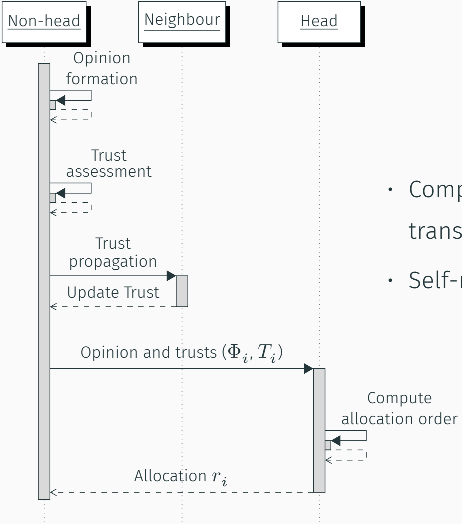
- Reputation index:

$$R_i(t) = \frac{1}{|N_i|} \sum_{j \in N_i} T_{ji}(t)$$

- Urgency index:

$$U_i(t) = R_i(t) * (1 - \Phi_i(t))$$

Algorithm summary



- Computation is made locally, just transmitting a 'veredict' to the head
- Self-moderation of opinions and trusts

Results and Analysis

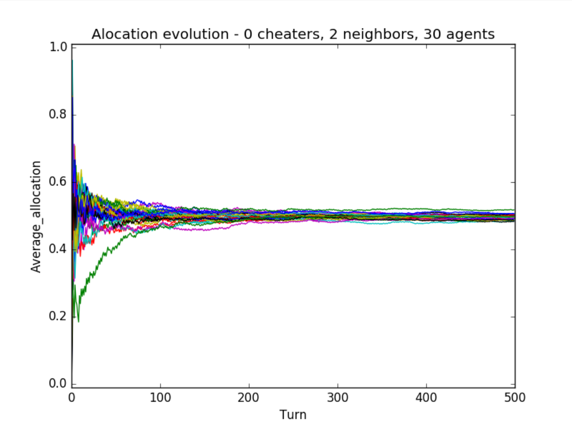


Figure 1: Allocation in scenario without non-compliant agents. Each coloured line represents a different agent.

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

Dealing With Non-compliant Behaviour

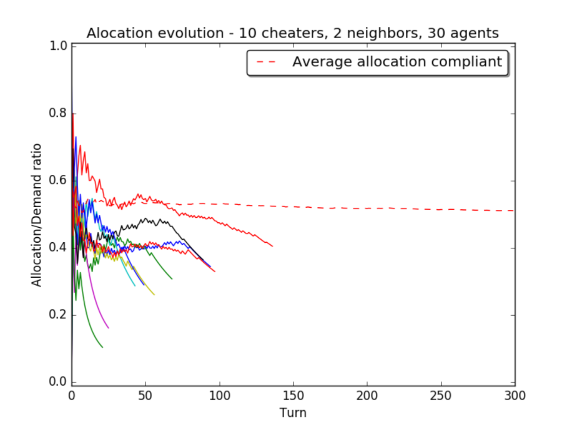


Figure 2: Individual allocations for non-compliant agents (solid lines) compared to compliant average (dashed).

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

Exploring Effects of Connectivity

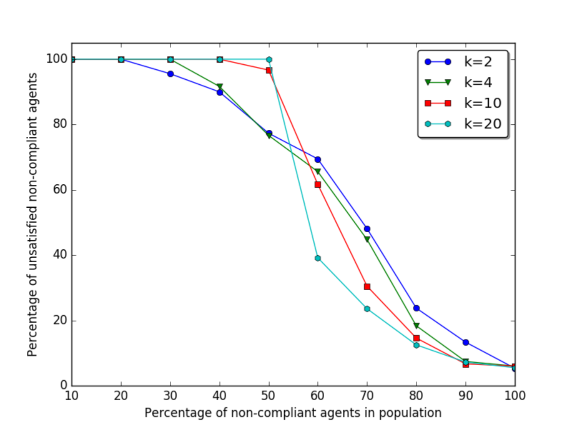


Figure 3: Ability of non-compliant behaviour detection, by size of neighbourhood (k).

- 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.

Conclusion

Final Remarks

- Presented solution demonstrate that it is possible to define fair policies of resource allocation in environments characterized by decentralisation, scarcity and no full information disclosure, using independent agents' accounts.
- Lessons learned:
  - Independent subjective assessment of justice can be considered, if inserted into a context of **influence** and **trust**;
  - Authority emerges from **reputation** autonomously;
  - Ability to aggregate individual, subjective assessments, into **collective, objective facts**.
- Future steps:
  - Explore asynchronous game;
  - Distributed pool of resources;
  - Collective mechanisms of verification.

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Thank you!