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Self-Governing Multi-Agent Systems
L4/10: Knowledge Management

Jeremy Pitt and **Asimina Mertzani**
Department of Electrical and Electronic Engineering
Imperial College London

IMPERIAL

Aims and Objectives

- Aims
  - Analyse issues of knowledge management in SGMAS
- Objectives
  - Understand and apply algorithms for knowledge aggregation, e.g. for collective decisions concerning interactional justice

A T H E N S - G R E E C E

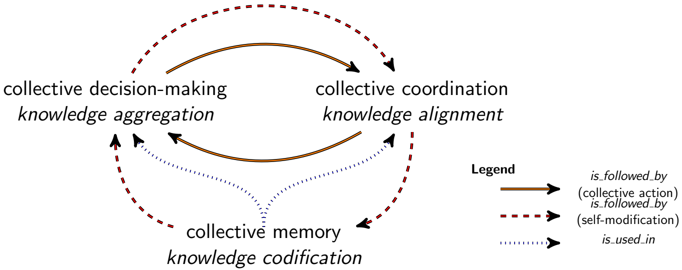
Majority Voting

- Condorcet Jury Theorem
  - Take a jury
  - Suppose that each member of the jury has
    - An equal and independent chance...
    - ...better than random ($p > \frac{1}{2}$) ...
    - ...but worse than perfect...
    - ... of making a correct judgement on some factual proposition
  - The majority of jurors is more likely to be correct than any single juror
  - The probability of a correct judgement approaches 1 as the jury size increases
- Under certain conditions, majority rule is good at "tracking the truth"
- What if we relax the assumption of "independence"
  - How do we make information available for socially productive puposes?

Knowledge Management

- Democracy underpinned the successful and sustainable Athenian state for 180 years (Ober, 2008)
  - Massively outperformed its rival city states: economically, architecturally, militarily, and diplomatically, on a number of independent metrics
  - Despite a relative parity in territorial size, population density, cultural development, and availability of mineral resources
- **It was not (just) about the voting** (Sorry Winston)
- Ober's analysis
  - Greater social benefits derived from higher levels of cooperation
  - Superior capacity for resolving public collective action problems
  - Itself was a product of special features of their participatory and deliberation model of self-governance
  - Transparency across multiple inter-dependent knowledge management processes

- Distinctive Athenian system for organising useful knowledge
  - Knowledge aggregation
  - Knowledge alignment
  - Knowledge codification



Social Networks

- A social network is a social structure made up of:
  - A set of social actors (individuals or organisations)
  - Sets of dyadic ties
  - Representing any social relationship between actors
- Perspective includes
  - Structure of the whole
  - Explaining the patterns observed in these structure
    - For example: organisational hierarchy vs. social network
    - Social proximity: formation of social relationships between 'alikes'
    - Social utility in the context of opportunistic communication
- Key issue: network topology, and how topology effects these patterns
  - Social selection
  - Social influence (see L6)

Opinion Formation for Knowledge Aggregation

- The dissemination of information is a ubiquitous process between people and computers
- Fundamental role in knowledge aggregation
  - Penetration of technological innovation
  - Word-of-mouth (gossip) and spread of rumours
  - Propagation of news
  - Distributed problem solving
- General problem: specify the ‘rules’ for the mathematical description of the dynamic development of **opinions**, which mirror the patterns observed in reality
  - Sznajd model (ferromagnetism in statistical mechanics)
  - Hegelsmann-Krause (HK) model
  - Deffuant model
  - Ramirez-Cano-Pitt model

Hegelsmann-Krause Model

- N-agent system, at time t
  - x_i represents opinion of agent i in an interval on R at time t
  - Changes according to interaction with, and distance from other agents' opinions $x_j, j \neq i$
  - Scaled by an interaction coefficient $a_{i,j}$ accounting for the the weight given by i to the opinion of j
- The opinion of agent i evolves in discrete time

$$x_i(t+1) = a_{i,1}x_1(t) + a_{i,2}x_2(t) + \ldots a_{i,|N|}x_{|N|}(t)$$

- Deffuant model is a continuous-time extension of HK model
- Bounded confidence
  - The interaction is zero for mutual distances above a certain threshold
  - Unlikely for one agent to be influenced by another one whose opinion is too far from its own
  - Opinions are not guaranteed to converge to a single value, but may eventually diverge

Social Exchange (Ramirez-Cano-Pitt Model)

- Issue (factual proposition) under discussion at time t
- Opinion
  - Agent has a mindset $\mu \in [0, 1]$
  - Communicates the expressed opinion of an agent i about the issue $o_i \in [0, 1]$
- Confidence
  - Weights the relation between an agent and each acquaintance
  - $w_i : N \times T \rightarrow [0.1]$
  - $w_{i,j}(t) \in [0, 1]$ expresses the confidence (function) that agent i assigns to agent j at time t
  - When $i = j$ this is a measure of self-confidence
  - Normalised: $\Sigma_{j=1}^{n} w_{i,j}(t) = 1$
- Affinity
  - Closeness of match between one agent's mindset and another agent's expressed opinion
  - $a_i : N \times T \rightarrow [0.1]$

Dynamic Opinion Formation

- Key differences between HK and RCP models
  - Mindset and (expressed) opinion can differ(social selection)
  - Others' opinions depends on similarity and credibility
  - Perceptions of similarity and credibility can change over time
- Opinion (expressed)

$$o_i(t') = \sum_{j}^{j \in SN_i} w_{i,j}(t) o_{i,j}(t)$$

- Affinity (similarity)

$$a_{i,j}(t') = 1 - \frac{\mid o_{i,j}(t) - \mu_i \mid}{\mathbf{max}(\mu_i, 1 - \mu_i)}$$

- (Self-)Confidence (credibility)

$$w_{i,j}(t') = \frac{w_{i,j}(t) + w_{i,j}(t) a_{i,j}(t)}{\sum_{k}^{k \in SN_i} (w_{i,k}(t) + w_{i,k}(t) a_{i,k}(t))}$$

Interactional Justice

- Informally
  - A user-centric aspect of justice required for realising values of fairness and inclusivity in organisations and communities
  - How does an ‘agent’ *individually* ‘feel’ that it is being ‘treated’ by the outcomes of deliberation
  - How does a group of ‘agents’ *collectively* ‘feel’ that they are being ‘treated’ by the outcomes of deliberation
- What is needed
  - Use social networking to aggregate subjective self-assessments of fairness into a collective assessment
  - Collective assessment will indicate the quality of an institution
  - Use that to motivate its adaptation/self-organisation

Institutions

- Definition

$$\mathcal{I}_t = \langle A, \mathcal{L}, P, \epsilon, \mathcal{G}, \mathcal{V} \rangle_t$$

- where:
  - A is the set of agents (members of the institution)
  - $\mathcal{L}$ is the specification instance (rules)
  - P is the 'game' protocol (for LPG$'$)
  - $\mathcal{G}$ is the social network (defined by a random graph on A)
  - $\mathcal{V}$ which is the set of institutional values
- One rule in $\mathcal{L}$ is the resource allocation method (ration, random, smallest first, largest first, in turn (queue), roles first)

Agents

- Definition

$$i \quad = \quad \langle attr, raf, ije, SN, \rho, \mathcal{J} \rangle$$

where:

  - *attr* is a set of attributes, including behavioural parameters, weights, coefficients and values;
  - *raf* is the resource allocation framework;
  - *ije* is the interactional justice evaluation framework;
  - *SN* is *i*'s social network;
  - ρ is the set of roles occupied by *a* in $\mathcal{I}$;
  - $\mathcal{J}$ is *i*'s set of value-judgements.

- One judgement in $\mathcal{J}$ is to use legitimate claims to evaluate the resource allocation method (or its enactment)

Legitimate Claims

No.	**Legitimate Claim**: rank according to...
$lc1$	... number of rounds agent has participated
$lc2$	... number of rounds agent allocated $r_i > 0.0$
$lc3$	... number of rounds agent has occupied a role
$lc4$	... average amount agent has provisioned
$lc5$	... average amount agent has demanded
$lc6$	... average amount agent has been allocated

Individual Self-Assessment (1)

- Utility of each agent i's appropriation in each round

$$U_i = \begin{cases} \alpha_i q_i + \beta_i (r_i - q_i) & \text{if } r_i \geq q_i \\ \alpha_i r_i - \gamma_i (q_i - r_i) & \text{otherwise} \end{cases}$$

  - where α_i, β_i and γ_i are agent-specific coefficients with $\alpha_i > \gamma_i > \beta_i$
- Personal satisfaction

$$\sigma_i = \begin{cases} \sigma_i + \delta_i (1 - \sigma_i) & \text{if } r_i \geq q_i \\ \sigma_i - \eta_i \sigma_i & \text{otherwise} \end{cases}$$

  - where δ_i and η_i are also agent-specific coefficients that influence positive and negative reinforcement respectively

Individual Self-Assessment (2)

- Fairness of the allocations with respect to its sets of legitimate claims

$$F_i = \sum^{l \in LC_i} w_l accuracy(l)$$

  - where the *accuracy* of a legitimate claim is the (weighted) average *distance* that the agent 'observes' between what the legitimate claim specifies that the allocation should have been, and the actual allocation produced by the selected method
- Distance between two allocations
  - Let $pw(\vec{v})$ be the set of pairwise comparisons between ordered elements of $\vec{v}$ (i.e. if $\vec{v} = \langle x, y, z \rangle$ then $pw(\vec{v}) = \{(x, y), (x, z), (y, z)\}$)

$$distance(\vec{v}_1, \vec{v}_2) = \frac{\mid pw(\vec{v}_1) \cap pw(\vec{v}_2) \mid}{\mid pw(\vec{v}_1) \mid}$$

Mindset

- Compute the Gini index of each agent i's own and its received self-assessments for each metric M_*

$$gini(M_*) = 1 - \frac{1}{2}\frac{1}{\mu}\frac{1}{|\mathcal{A}_i|^2}\sum_{i=1}^{|\mathcal{A}_i|}\sum_{j=1}^{|\mathcal{A}_i|} | \phi_i - \phi_j | \qquad (1)$$

- where
  - $\mathcal{A}_i = SN_i \cup \{i\}$
  - μ (here) is the mean
  - ϕ_x is the computed assessment for each $x \in \mathcal{A}_i$):
- Compute μ_i (mindset) by a sum of individual measures and Gini indices

$$\begin{aligned} \mu_i = \quad & w_1 gini(M_U) + w_2 gini(M_\sigma) + w_3 gini(M_F) \\ & + w_4(U_i/IU_i) + w_5\sigma_i + w_6 F_i \end{aligned} \qquad (2)$$

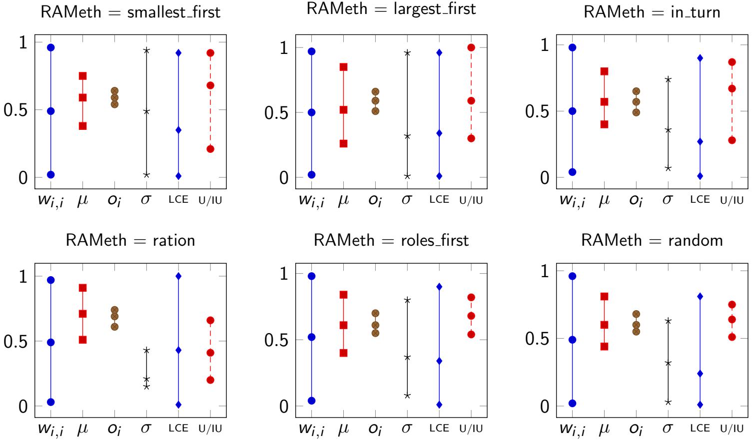
Opinion Formation – Algorithm

for each agent $i \in A$ **do**
  for each agent $j \in SN(i)$ **do**
    send(i, j, inform(U_i, σ_i, F_i)
  end for
  compute μ_i
end for
for n rounds of opinion formation **do**
  for each agent $i \in A$ **do**
    for each agent $j \in SN(i)$ **do**
      send(i, j, inform(opinion(o_i))
    end for
  end for
  for each agent $i \in A$ **do**
    update opinion o_i
    update affinities $a_{i,j}$
    update weights $w_{i,j}$
  end for
end for

Experiments

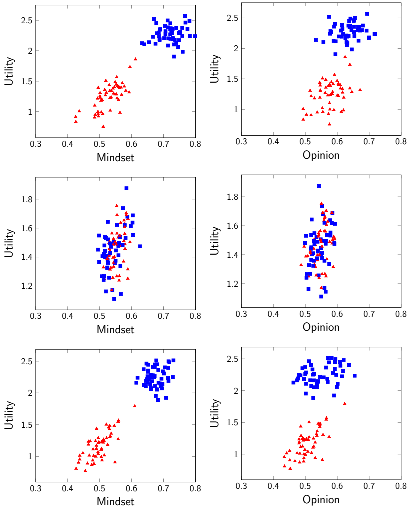
- Independent variables
  - 30 Agents, $p = 0.15$
  - $g_i < q_i$ – **economy of scarcity**
  - $\mathcal{L}$ includes rules for
    - role assignment by random or by vote
    - resource allocation method (RAMeth): smallest first, largest first, in turn, ration, roles first, random
    - 100 rounds resource allocation, 50 rounds opinion formation
    - self-confidence: $(w_{i,i})$ in random(1)
    - $\mathcal{J} = \langle \sigma_{gini}, U_{gini}, F_{gini} \rangle$
  - $lc \subset LC$ – LC is a set of legitimate claims
- Dependent variables
  - Utility (actual utility and maximum ('ideal') utility)
  - Mindset (initial opinion) and final opinion (o_i)
  - Satisfaction and Fairness (LCE: Legitimate Claim Evaluation)

Experiment 1: Economy of Scarcity



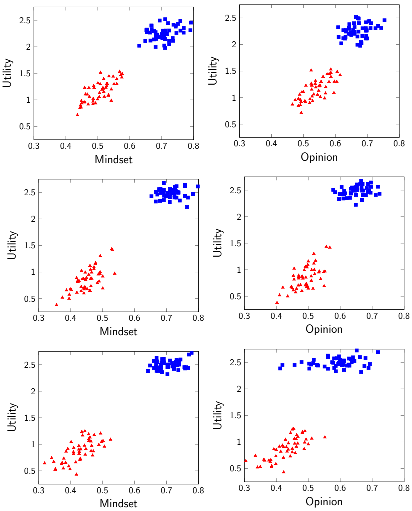
- No 'simple' allocation method can produce (what the agents individually think is) a 'fair' distribution
- Interactional justice can produce (what the agents collectively think is) a satisfactory outcome, if it is 'same for everyone'

Experiment 2: Clique Detection and Protection



- In the presence of a 'clique'
  - A corrupt allocator favouritising members of a clique is indistinguishable from a 'simple' allocation method
  - Opinion formation still drags group consensus to 'same for everyone'
  - Compare experiences to 'reinforce' self-confidence; more 'opinionated' agents are less likely to converge opinion to 'satisfactory'

Experiment 3: Network Variations



- A fully connected clique only strengthens the 'grip' . . .
- . . . And can over-appropriate with apparent impunity . . .
- . . . But a fully connected outgroup can resist this
- It is in the interests of an oligarchy to operate an 'establishment', to offer 'bread and circuses' to the outgroup, limit social mobility, and practise 'divide and conquer'

Quasi-Stability and Well-Ordered Society

- Quasi-stable (Ashby): a system for which, after a period of disruption, some of its control variables return to an equilibrium value for a ('sustained') period of time
- Well-Ordered Society (Rawls)
  - *"A well-ordered society is quasi-stable with respect to the justice of its institutions and the sense of justice needed to maintain this condition. While a shift in social circumstance may render its institutions no longer just, in due course they are reformed as the situation requires, and justice is restored."*
- So we hypothesise:
  - That a self-organising open system can form a "well-ordered institution" which is "quasi-stable" with respect to the "justice of its institutions" and a (collective) "sense of justice", and
  - That such a society can determine whether or not its institutions are no longer just, can adapt ("reform") its institutions "as required", and justice can be "restored"

Summary

- Effective knowledge management is critical to sustainability of self-governance
- But: we need to leverage knowledge codification for constitutional choice for
- Plenty of paradoxes in voting and judgement aggregation to keep things moving
  - Condorcet Paradox (preference ordering)
  - Condorcet's Other Paradox (scoring rules)
  - Arrow's Theorem
  - Simpson's Paradox (districts)
  - Anscombe's Paradox (multiple isses)
  - Doctrinal Paradox
  - Discursive Dilemma