The Role of Local Effects in Collective Decision Processes

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Collective Decisions

- aggregated outcome of many individual decisions
  - most individual implications are averaged out
  - interaction among agents play crucial role
  - system utility (social welfare) $\neq \sum_i U_i^{\mathrm{indep}}$
- *our focus:*
  - prediction of global/system quantities, not of individual decisions
  - role of local/neighborhood effects in collective decisions
  - influence of social elements (herding behavior)

Consensus versus Coexistence

Public polls ⇒ collective decision processes

- examples from Europe (2005):
  - May 29: French vote for/against Europ. constitution (45/55)
  - June 5: Swiss vote for/against Schengen (54.6/45.4)
- characteristic features
  - two alternatives: YES/NO (binary decision)
  - no simple utility maximization
  - hard to predict ($\sim$ 50/50)
- find minimalistic agent models to explain generic dynamics

Voter Models

- simple model of opinion formation with consensus
- population of agents: $i = 1, ..., N$
- each agent i: spatial position i, "opinion" $\theta_i(t) \Rightarrow \{0, 1\}$
- "decision": to keep or change opinion $\theta_i(t)$

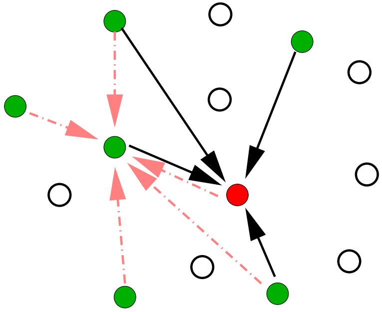
$$\theta_i(t+1) = \begin{cases} \theta_i(t) & \text{keep} \\ 1 - \theta_i(t) & \text{change} \end{cases}$$

- rate to change opinion depends on other agents

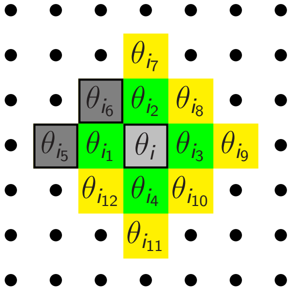
$$w(1-\theta_i|\theta_i) = \kappa(f)\; f_i^{1-\theta_i}$$

  - $0 \leq f_i^{1-\theta_i} \leq 1$: frequency of agents with *opposite* opinions in "neighborhood" of agent i
  - $\kappa(f)$: nonlinear response to frequency of other opinions

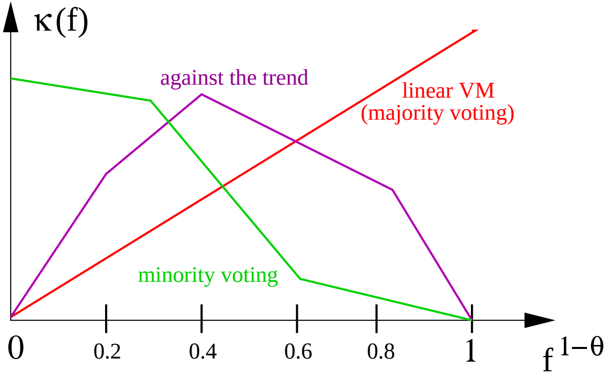
- neighborhoods are defined by an adjacency matrix $\mathcal{C}_{ij}$
  $\Rightarrow$ network structure



- simplified geometry: regular grid



Nonlinear response $\kappa(f)$



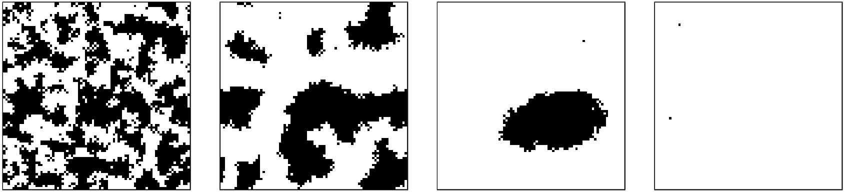
Results of computer simulations

1. Linear voter model

- stochastic simulation, $w(1-\theta|\theta) = f^{1-\theta}$
- initially $x = 0.5$, random distribution

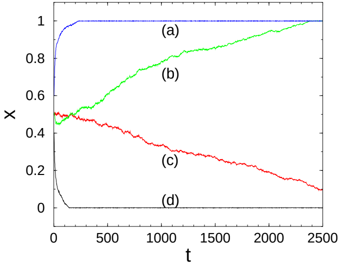
Online Simulation

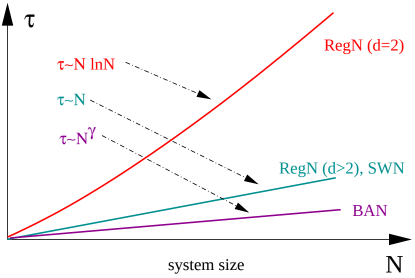
- results:
  - coordination of decisions on medium time scales
  - asymptotically: "no opposition" ($\rightarrow$ equilibrium)



$t = 10^1, 10^2, 10^3, 10^4$

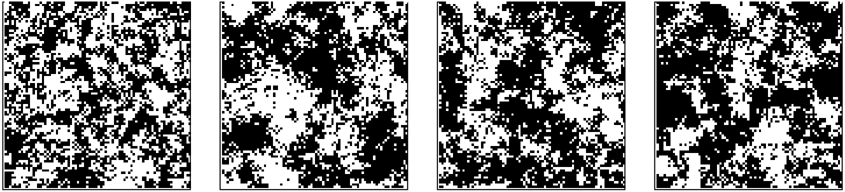
Time to reach consensus τ



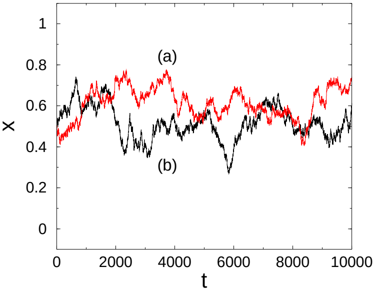


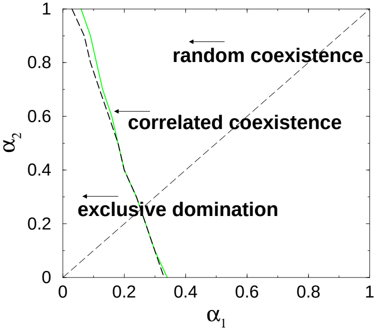
Coexistence? $\Rightarrow$ 2. Non-linear voter model

- Online simulation 1:
  - coexistence, but no spatial coordination
- Online simulation 2:
  - small pertubation for $f^{1-\theta} = 1$ $(\rightarrow \varepsilon = 10^{-4})$
  - coordination of decisions on long time scales
  - asymptotically: coexistence, but non-equilibrium



$\varepsilon = 10^{-4}$ $t = 10^1,\ 10^2,\ 10^3,\ 10^4$



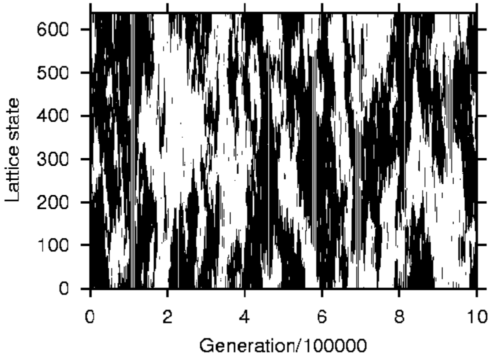


(a) $\varepsilon = 10^{-4}$, $\alpha_1 = 0.2$, $\alpha_2 = 0.4$ (linear VM)

(b) $\varepsilon = 10^{-4}$, $\alpha_1 = 0.25$, $\alpha_2 = 0.25$

Phase diagram for coexistence

1d CA:



- long-term nonstationarity
- only *temporal* domination of one opinion

Results:

- collective decisions ⇒ nonlinearity in the voter model
- consensus:
  - time scale?, symmetry of outcomes?
- coexistence:
  - non/stationarity? spatial correlations?, different attractors?[1]
- missing
  - memory effects, various opinions
  - influence of social structure, agent's utility

[1] Schweitzer, F.; Zimmermann, J.; Mühlenbein, H.: Coordination of Decisions in a Spatial Agent Model, Physica A 303/1-2 (2002) 189-216

Including memory effects

- $\nu_i(\tau_i)$: reluctance of agent i to change opinion θ_i
  - persistence time τ_i (opinion was *not* changed) $\Rightarrow$ "history"
  - reflects local experience with agents in neighborhood

$$\frac{d\nu}{d\tau} = \mu\,\nu(1-\nu) \quad \Rightarrow \quad v_i = \frac{1}{1+e^{-\mu\tau_i}}$$

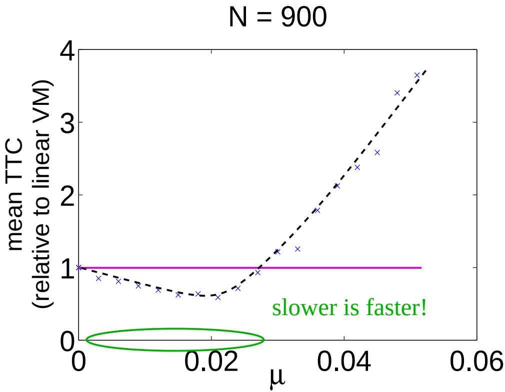
- decision dynamics:

$$w(\theta_i'|\theta_i) = [1-\nu_i(\tau_i)]\;f_i^{\theta_i'}$$

  - $\mu > 0$: slowing down of opinion dynamics
- consensus vs. coexistence of opinions ??
  - decision between 3 opinions: $\{-1, 0, +1\}$

Simulation Video

Time to reach consensus



- *heterogeneity* of agents important:
  - local groups of “confident” agents convince an indifferent neighborhood

Do not change the Status Quo

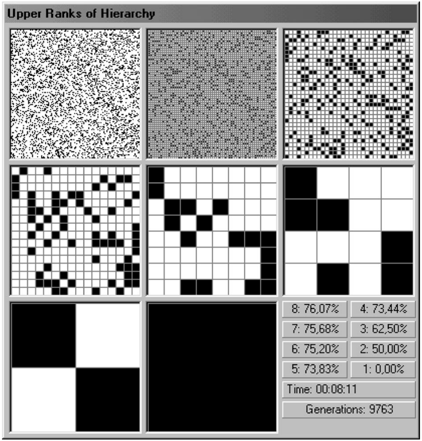
- conservative society: if you are in doubt, stay to the established opinion (Galam 2000, 2002)
- N agents with $\theta_i \in \{-1, +1\}$; ruling opinion $\theta_G = +1$
- government proposal $\Rightarrow$ N_+ supporters, N_- objectors

  ? how much support needed to accept the proposal?

  ! depends on mechanism of collective opinion formation!

example: local interaction between 4 agents

- majority rule: $\{4+, 0-\} \rightarrow 4+$, $\{3+, 1-\} \rightarrow 4+$, $\{1+, 3-\} \rightarrow 4-$, but: $\{2+, 2-\} \rightarrow 4+$
- n consecutive random interactions



initial condition: 24% supporters (black), 76% objectors
result: after 7 iterations or voting levels $\Rightarrow$ 100% support
$\Rightarrow$ *minority wins*

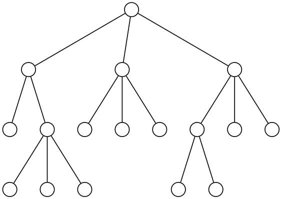
(Galam 2000, 2002)

Decisions in hierarchical organizations

Problem: propagation of new ideas through organization

- initialization on lowest level $\Leftrightarrow$ conviction at the top level??
- depends on acceptance threshold f_c and social structure
  - asymmetry of $\mathcal{C}_{ij}$
  - reporting/authority links

$$\theta_i(t+1) = \Theta\left[f_i^{(1)}(t) - f_c\right]$$



Online simulation

Local versus global trends

- agents exploit two different information
  - *local:* "do what your neighbors do"
  - *global:* "do not follow the trend"
- dynamics: N agents on a lattice, two opinions $\theta_i \in \{-1, +1\}$

$$\theta_i(t+1) = \begin{cases} +1 & \text{with } p = \dfrac{1}{1 + \exp\{-2\beta h_i(t)\}} \\ -1 & \text{with } 1 - p \end{cases}$$

$$h_i(t) = \sum_{j \in NN} J_{ij}\theta_j - \alpha\theta_i \left| \frac{1}{N} \sum_j \theta_j \right|$$

Online Simulation[2]

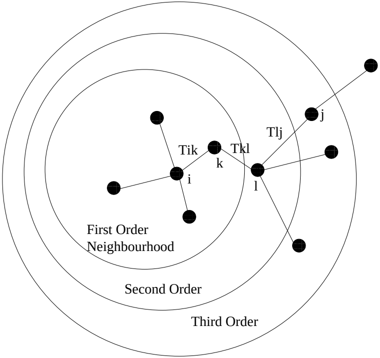
[2](Bornholdt 2001, cond-mat/0105224)

Using Social Networks for Decisions

- decision based on recommendations
  - cope with information overload through filtering
- advantages: get *personalized* information
  - *majority rules*: based on frequency of recommendations
  - *similarity-based*: low effort, but passive and no active tuning
- *social network*: reduced effort *and* tuning of the recommendation at the same time!
  - *use an agent's social network* to reach distributed knowledge
  - *incorporate trust* to filter reachable knowledge
- "Trust": appropriateness and reliability of former recommendations
  - → *trust-based*: high effort, not passive but active tuning

Sketch of Model Outline

- agents with *preference profiles* select products with *feature profiles* based on recommendations (from distant agents)



Decision Making

- querying agent a_q chooses from k responses obtained from the network: $\{f_{a_r,p}, \tau_{a_q,a_r}\}$, $r = 1, ..., k$
  - $f_{a_r,p}$: preference of recommender, τ_{a_q,a_r}: trust along the path

$$\tau_{a_q,a_r} = \prod_{(a_k,a_l)\,\in\,\mathrm{path}(a_q,a_r)} T_{a_k,a_l}$$

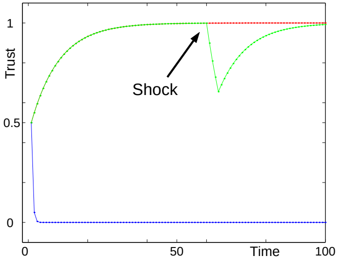
- probability of selecting recommendation r:

$$P_{a_q,p_r} = \frac{\exp(\beta \tau_{a_q,a_r} f_{a_r,p_r})}{\sum_r \exp(\beta \tau_{a_q,a_r} f_{a_r,p_r})}$$

  - β: measure of the *risk aversion* of agents

Update of Trust

- only towards neighbours a_j of agent a_i and only if
  1. a_i has chosen an item directly recommended by a_j
  2. a_i chooses a recommendation which came through a_j
- *local information:* agents only know the identity of a_n, (neighbour that the recommendation came through)



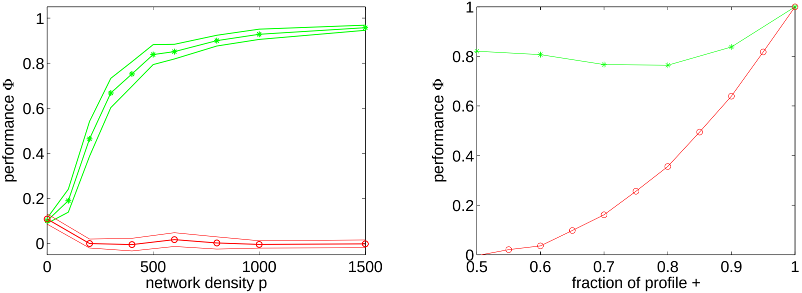
Results on Trust-Based Networks

Recommendation systems in trust-based networks outperform majority-based recommendation systems within a range of:

- *network density*:
  - if the network is not dense enough, agents receive replies with recommendations on only a fraction of the items they query about
- *preference heterogeneity*:
  - if agents are very homogeneous, there is no need for filtering, almost any recommendation will be appropriate
  - if agents are too heterogenous, they cannot find other agents that act as suitable filters

Results of Computer Simulations

- special case: only two preferences $\{-1, +1\}$
  social network: directed random graph with density p

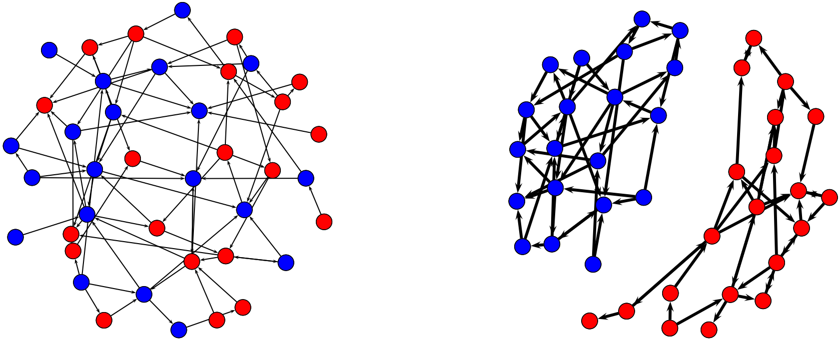


- Trust causes a performance gain above a critical density
- Performance gain decreases with increasing homogeneity

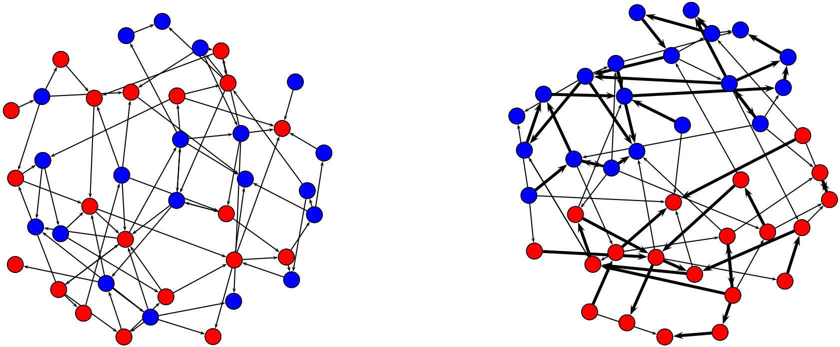
Evolving Social Network

- rewiring based on trust: $P_{\text{rewire}} = 1 - T_{a_i,a_j}$, $P_{\text{keep}} = T_{a_i,a_j}$

(a) $t = t_{\text{start}}$, $\beta = 0$ (b) $t = t_{\text{end}}$, $\beta = 0$



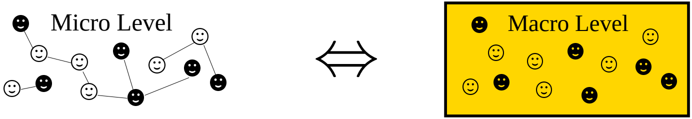
(c) $t = t_{\text{start}}$, $\beta = 1$ (d) $t = t_{\text{end}}$, $\beta = 1$



Result: links between agents of different profiles become weaker, between agents of the same profiles stronger

Conclusions

- collective decisions ⇔ aggregated individual decisions??
- theory of complex systems:
  - *How are the properties of the elements and their interactions ("microscopic" level) related to the dynamics and the properties of the whole system ("macroscopic" level)?*



- approach: multi-agent models
  - agent: "intermediate" internal complexity $\longrightarrow \theta_i$
  - simple update dynamics: non-linear VM, utility maximization, ...
  - interaction: local neighborhood $\longrightarrow \mathcal{C}_{ij}$: topology, trust dynamics

- *minimalistic agent models:*
  - cover generic features of collective decisions
    e.g. influence of hierarchies, memories, lobbies, ...
  - fitting with data within reach
  - but: will not predict your next "Volksabstimmung"
- KISS *(Keep It Simple, Stupid)* principle
  - details: not as much as possible, only as much as necessary
  - systematic understanding: role of parameters, feedbacks ...
  - abstract modeling level: elucidates dynamic key features