Simulation in the Social Sciences

Rainer Hegselmann and Andreas Flache (1998), *Understanding Complex Social Dynamics: A Plea For Cellular Automata Based Modelling*

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Basic features of cellular automata (CA)

Discrete Location: Cells are arranged in a regular D-dimensional grid.

Discrete States: Every cell adopts one out of a finite set of states.

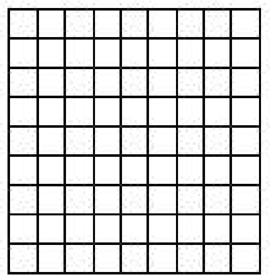
Discrete Time: Time is discrete.

Locality: Cells change their states according to local rules.

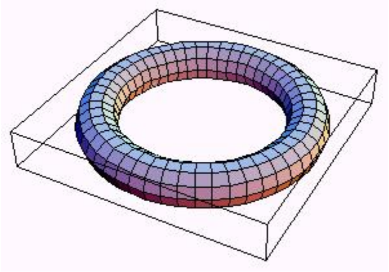
Rules: The same transition rule applies to all cells.

Updates: In each period cells are updated (simultaneously or sequentially).

2D Grid Without Edges

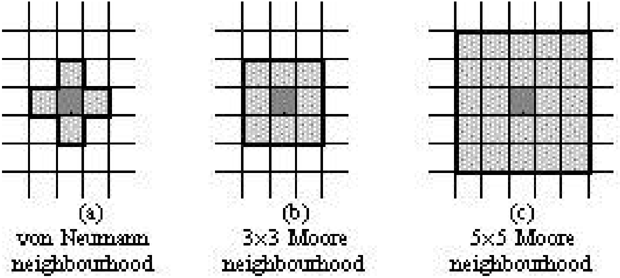


Grid



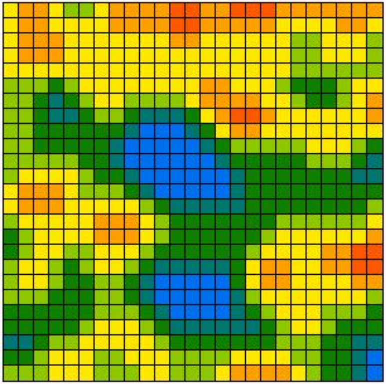
Torus

Locality: Different Kinds of Neighbourhoods



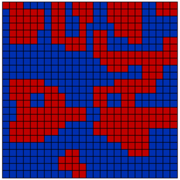
Triangular, hexagonal and irregular grids are also possible.

Opinion Dynamics

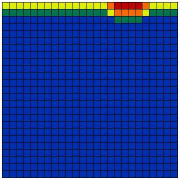


- Cells have Opinions $u_i(t) \in [0, 1]$
- von Neuman neighborhood N_i
- Stepwise Averaging $u_i(t+1) = \frac{1}{\#N_i} \sum_{j \in N_i} u_j(t)$
- Discretisation through step function
- Stewise updating of randomly selected cells

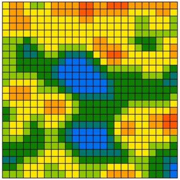
Opinion Dynamics - Typical (stable) Results



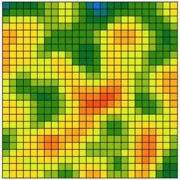
2 possible opinions



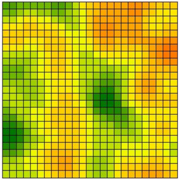
5 possible opinions



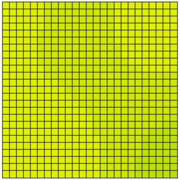
10 possible opinions



15 possible opinions



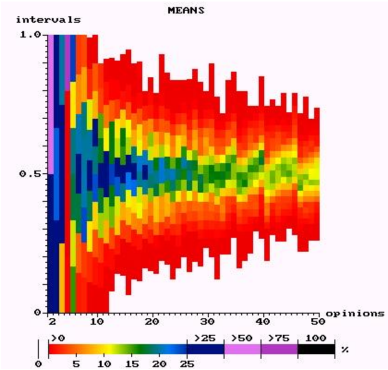
30 possible opinions



continuous opinions

Opinion Dynamics - Interpretation

- CA reach stable state
- Micro rules lead to macro patterns
- More options - more consensus
- Extreme opinions disappear
- Discretisation matters
- Beware of artefacts



A Brief History of CA

1940's First CA models in natural sciences by John von Neumann and Stanislaw Ulam

1949 James M. Sakoda's Checkerboard Model of Social Interaction (published 1971)

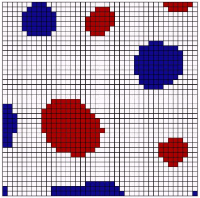
1969 Thomas Schelling's Segregation Model

1975 Peter S. Albin classifies checkerboard models as CA in *The Analysis of Complex Socioeconomic Systems*

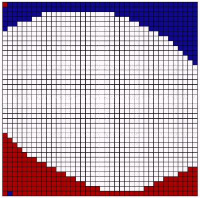
1990's More frequent use of CA models in social and behavioral sciences

Sakoda's Checkerboard Model

- Original model is 8*x*8
- Here: 40*x*40 extension
- Two groups with positive (1), negative (-1) or neutral (0) attitudes to each other
- Migration is possible in a limited radius
  and directed through optimization.
- In segregation setting, meeting points acquire attraction.



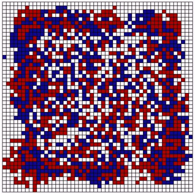
Segregation $[1, -1]$



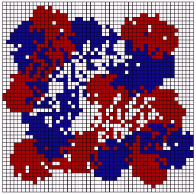
Suspicion $[0, -1]$

Schelling's Segregation Model

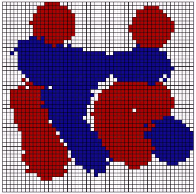
- Considering Moore neighbourhood
- Migrate if frequency of kin is below a given minimum level.
- Go to nearest neighbourhood where this requirement is met.
- Displays the unintended consequences of intentional actions.



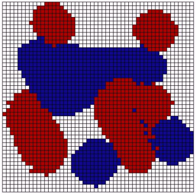
Pref. $<=$ 20%



Pref. $<=$ 30%



Pref. $<=$ 50%

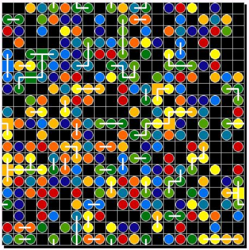


Pref. $<=$ 90%

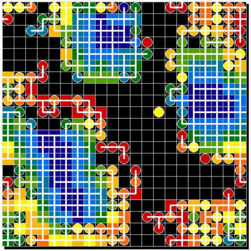
Evolution of Support Networks

- Cells are "rational egoists" and play the *Support Game* in their von Neumann neighbourhood, an extension of the iterated Prisoner's Dilemma.
- Players have different risk classes $p_i \in [0.1, 0.2, \ldots, 0.9]$ (i.e. their probability of needing support).
- Migration opportunities are offered randomly with fixed probability q.
- All p_i and q are known to all players, and they calibrate their strategies accordingly, maximising their expectations in a pessimistic scenario.

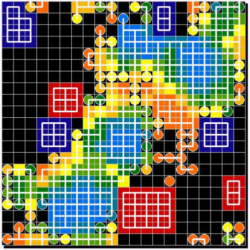
Well-ordered Support Networks emerge



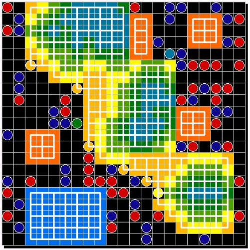
random



$q = 5\%$

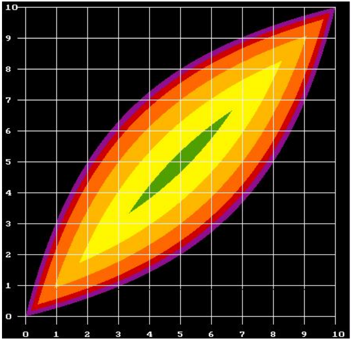


$q = 10\%$



$q = 15\%$

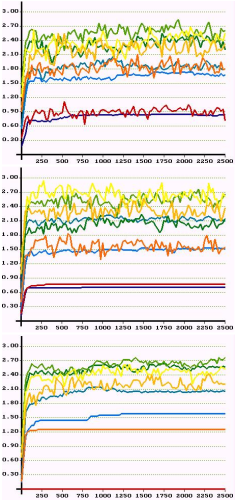
Support Networks - Results



Maximum q possible for support between risk classes.

- Ordered Support Networks emerge.
- Similar risk classes tend to form clusters.
- Annular arrangement of classes.
- Feasibility of cooperation is a function of p_i, p_j and q.
- Expected utility of support decreases at both extremes for risk classes.

Support Networks - Network Dividend



- Comparison with unconnected case.
- Intermediate risk classes gain most from support networks.
- Equality increased in all three setups.

Rational egoism, class segregation, increasing equality and increasing wealth go hand in hand.

Why use Cellular Automata?

- Locality, overlapping neighbourhoods, and repeated interaction are properties of a significant class of dynamic social processes.
- Good examples of unintended consequences in social action. (Schelling, Support Networks)
- Provide quantitative explanations and predictions for artificial worlds. Qualitative understanding for "real" world processes might be derived.
- Explore theoretical assumptions and develop new theories.
- Explore the dynamics of elementary social interactions.

My 2 Cents

I LIKE THIS CONCEPT

- Provides means to explore *dynamics* in social interactions, in a controlled environment, on a level of abstraction and simplicity where we might still be able to trace back the developments.
- Spirit of Simplicity: Uses a clear set of assumptions and a supposedly infallible deduction process. Provides solid ground for further argument and analysis.

I LIKE THIS ARTICLE

- Graphical illustrations are chosen well, they are illustrative and helpful.
- Article gives a concise overview of the state of the art.

My 2 Cents

Parametrisation

- Seemingly arbitrary parametrisations / implementations
- Any other motivations for mechanisms - besides computational simplicity?
- e.g. Opinion Dynamics: Why is an opinion $u_i \in [0, 1]$?
- e.g. Opinion Dynamics: Averaging in neighbourhood

Alternative Interpretations

- Processes are so general many alternative interpretations might be possible
- e.g. Opinion Dynamics: Study effort

My 2 Cents

Methodology

- How much tweaking was necessary to produce results
- e.g. Support Networks: $q = (0.05, 0.1, 0.15)$

Interpretation

- Highly reliant on the description of pictures
- Some analytic explanations only for Support Networks

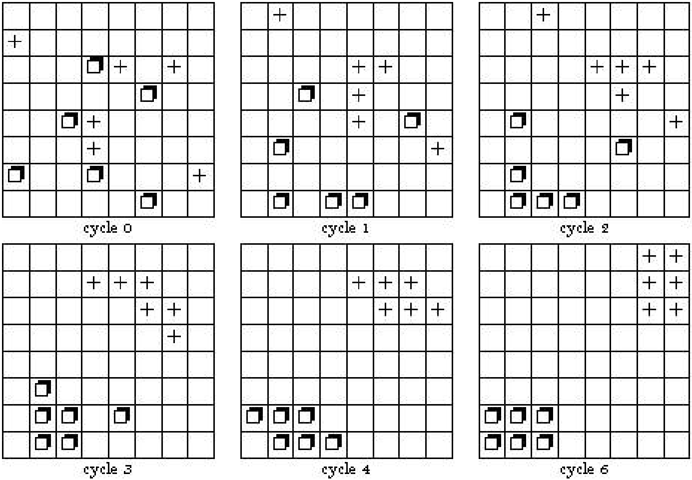
My 2 Cents

Robustness

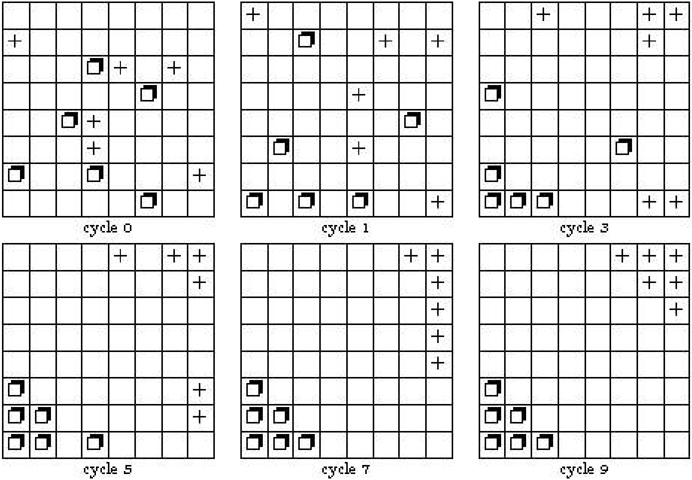
- How robust are findings?
- Highly reliant on graphical, i.e. qualitative means.
- Are there measures for qualitative robustness, given abundant simulation data?
- Possibly, robustness analysis could tell us more about real world phenomena.
- e.g. Sakoda: How about values besides $1, 0, -1$
- Nicely done by Schelling - provides a minimum level for segregation.

Thanks

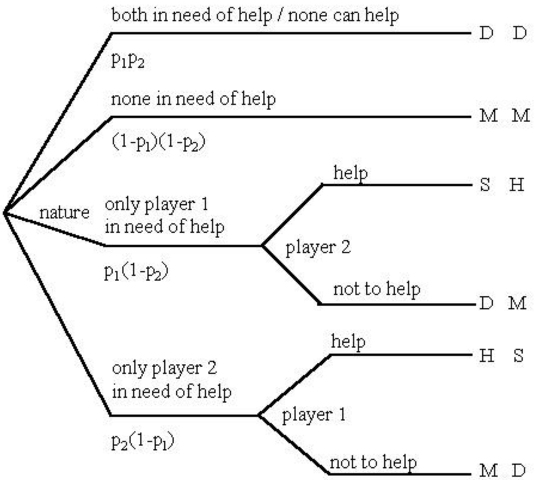
Original Setup - Segregation



Original Setup - Suspicion



Support Game - Structure



Support Game - Formulae

PD-condition (mutual support is profitable for both)

$$p_i(1-p_j)(S-D) > p_j(1-p_j)(M-H) \; i \neq j. \tag{1}$$

- Defection is the dominant strategy in a one shot game
- Mutual support is profitable for both players (over time)

COOP-condition (existence of a cooperative game solution)

$$a_i \geq \frac{1}{1-p_j(1-p_i)+p_i(1-p_j)\frac{S-D}{M-H}} = a_i^+ \; i \neq j \tag{2}$$

$$a = (1-q)^2 \tag{3}$$

- Cooperative supergame equilibria exist if the probability of being involved in a further iteration of the game is sufficiently high.