University of Amsterdam
Institute for Advanced Study

Complex systems approach to psychology

Han van der Maas[1]
Psychological Methods
Institute for Advanced Study
UvA

[1]Thanks to many great co-authors in many years

The human mind is (the ultimate) complex system

- Brain: 100 billion neurons, thousands of connections
- Embedded in very complex embedded social systems
- We are studying *developing* complex systems

- Extremely difficult & extremely important

- Our mission: apply formal models & methods from complex system research in the social sciences

Psychology (social sciences)

- No equations
  - A few nice exceptions: Murray & Gottman model of marriage, Helbing model of panic, neural models of reaction time
- But humans are complex, instable, nonlinear etc.
- How to proceed?
  - Metaphorical
  - Qualitative analysis
  - Statistical approach
  - ‘Toy’ mathematical models
  - *Transitions*
  - *Network approach*

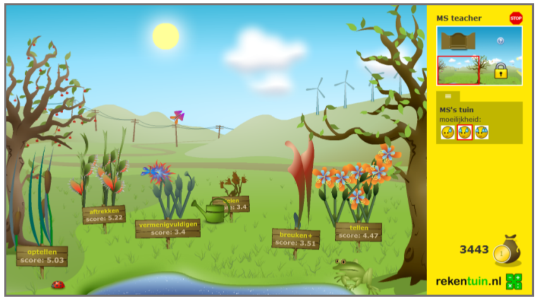
Simple models do (sometimes) well

Fields of applications

- Insight
  - Cognitive development, Math Garden
- Addiction
  - Recreational use as a stable intermediate state
- Intelligence
  - Growing networks of knowledge
- Depression
  - Relapse
- Crime
  - Alternative stable states & legalization

- Attitudes (polarization)

Math Garden



- In order to collect high frequent time series for complex system analysis
- Webbased adaptive training and monitoring
- Spin-off Oefenweb (15 fte)
- 2000 schools

Transitions

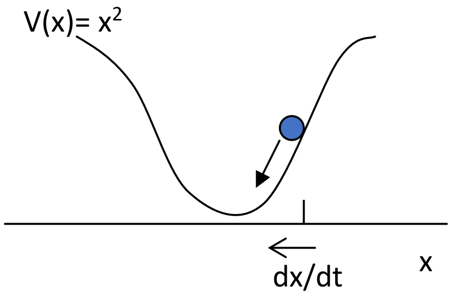
Piagetian conservation task

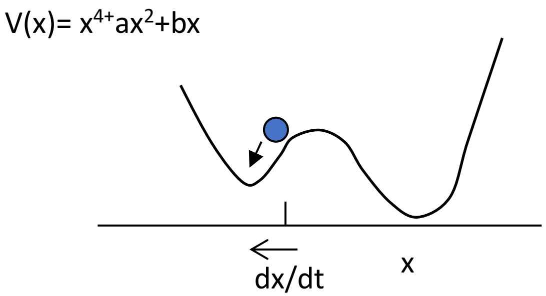
- Cognitive structures
- Equilibration theory
  - Disequilibrium
  - Transitions

- How to test for transitions?
- What is a transition?
  - Ad hoc definition

Bifurcation: degenerate critical points

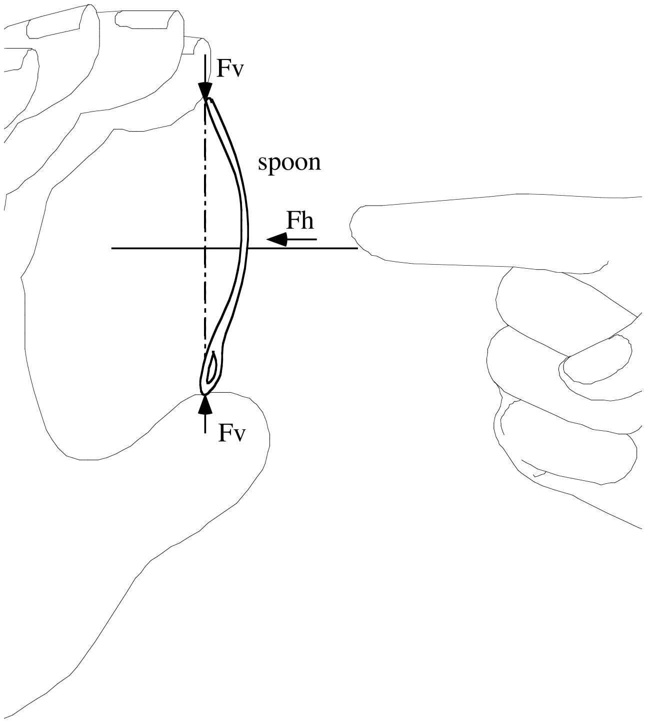
$$\frac{dx}{dt} = -V'(x;c)$$

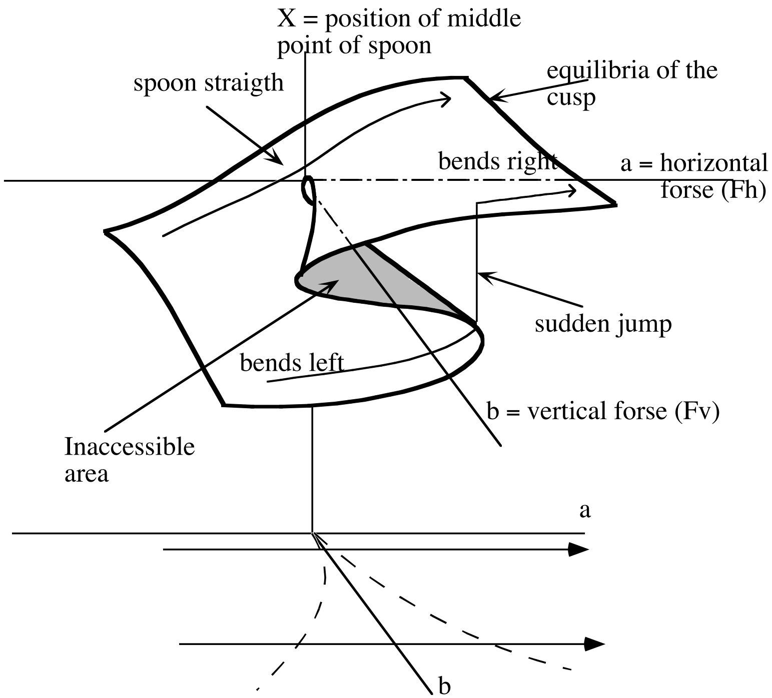




- Change in x over time is defined by the shape of potential function
- Critical point if first derivative is zero
- Degenerate if first and second derivative are zero (compare x^2 with x^3 or x^4)
- Phase transitions
- Catastrophe theory: cusp

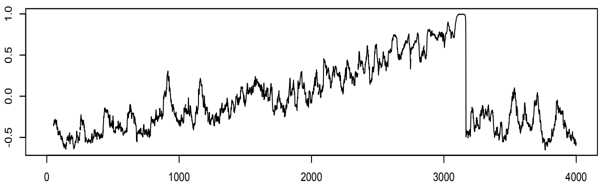
My favorite model

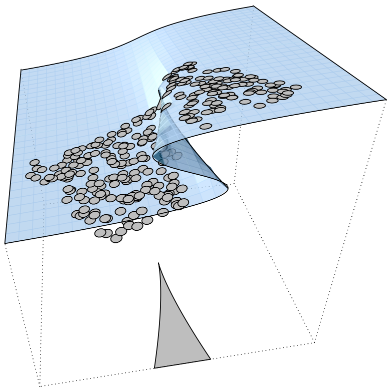




(Statistical) methodology

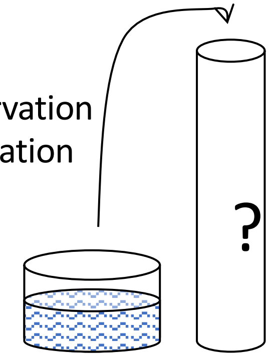
- Catastrophe flags (necessary/sufficient criteria for transitions; early warnings)
  - van de Leemput et al. (2014). PNAS, 11, 87-92
- Hidden Markov models
  - J. of Exp. Child Psy., 111(4), 644-662.
- Threshold autoregressive models
  - Hamaker, Zhang & Van der Maas, (2009). Psychometrika, 74(4), 727-745.
- Latent class analysis & finite mixtures
  - Jansen & van der Maas, H.L.J. (1997). Developmental Review, 17, 321-357
- Fitting the cusp catastrophe to data (R package cusp)
  - Grasman, et al.(2009) J. of Stat. Softw., 32(8), 1-27.



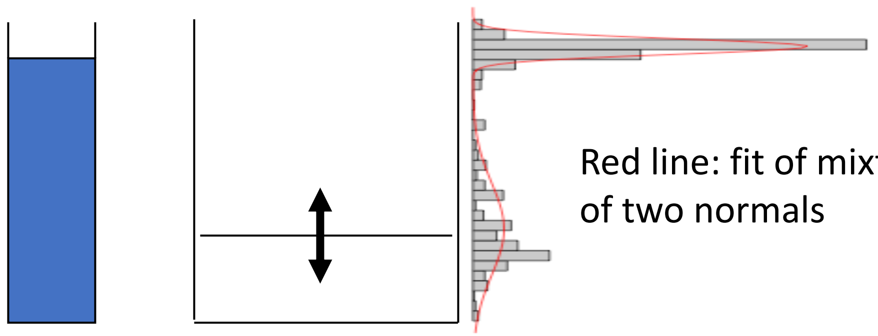


Multimodality example

Conservation anticipation



Example

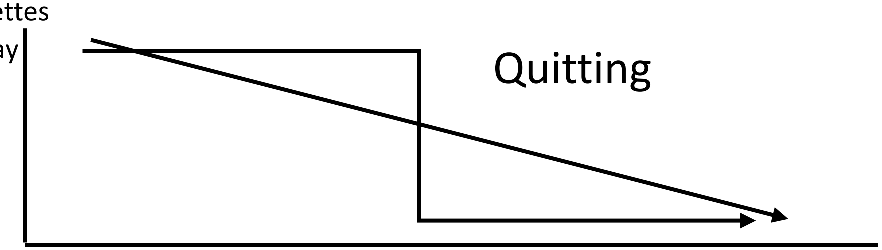


Red line: fit of mixtures of two normals

Conclusion: two different classes, indicating a phase transition

Dolan, C.V., & van der Maas, H.L.J. (1998). Fitting multivariate normal finite mixtures subject to structural equation modeling. Psychometrika, 63, 227-253

Other examples



Ploeger, A., van der Maas, H. L. J., & Hartelman, P. A. I. (2002). Stochastic catastrophe analysis of switches in the perception of apparent motion. Psychonomic Bulletin and Review, 9(1), 26-42

Grasman, J., Grasman, R. P., & van der Maas, H. L. (2016). The Dynamics of Addiction: Craving versus Self-Control. *PLoS One*, *11*(6), e0158323.

Attitudes & polarization

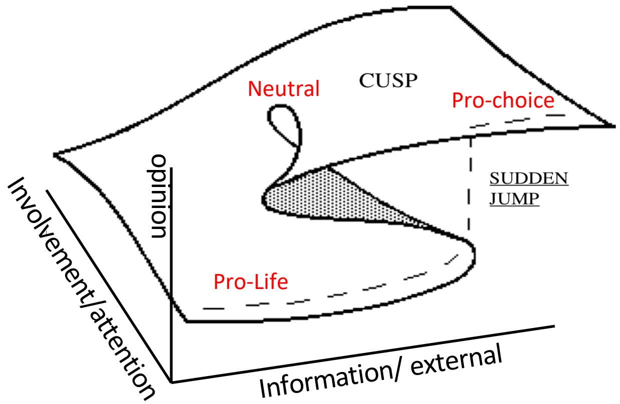
The Psychology of Attitudes

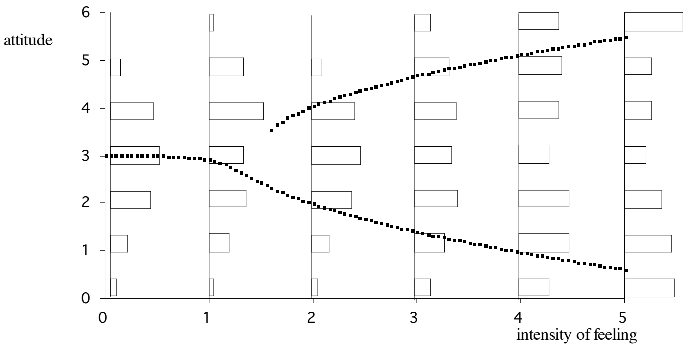
”The most distinctive and indispensable concept in contemporary social psychology.”

- Affective, behavioral, and cognitive components
- Achieve basic goals
  - meaningful, structured environment, reinforce self-image, ego-defensive
- Explicit (self-report) and implicit measures (Implicit attitude test)
- Attitude ambivalence, inconsistency, dissonance, etc.
- Resistance to persuasion

- Many (verbal) theories, insights and phenomena
  - theory of planned behavior, the elaboration likelihood model, the heuristic-systematic model, cognitive dissonance theory, and social judgment theory

Bistability and divergence: attitude towards abortion





van der Maas, H.L.J., Kolstein, R., & van der Pligt, J. (2003). Sudden jumps in attitudes. *Sociological methods & research, 32*(2), 125-152

- High involvement/attention = jumps, bimodality & hysteresis
- Persuasion requires low involvement/attention

Disadvantage: cusp is postulated as model, not derived from micromodel of attitudes

Polarization

- Extremely relevant topic (politics, vaccination, climate, etc.)
- Attitude polarization is *both a between and a within* person phenomenon

- Within person:
  - (Social) psychology
- Between persons:
  - Sociology, political science
  - Statistical physics, computer science

- Challenge: combining both levels of study

Between person perspective

- Statistical physics of social dynamics (Castellano, C., Fortunato, S., & Loreto, V., 2009)
  - Sociophysics
  - Opinion networks (opinions, memes, language, voting, etc.)
  - Very large number of models
- Assumptions on:
  - Opinion (*discrete, continuous*)
  - Interactions between agent (exchange of opinions)
  - Topology (simple CA, scale free social networks)
  - …
- One option: Ising model

Elementary Ising opinion model

e.g. Galam (1997). Rational group decision making: A random field Ising model at T = 0, Physica A 238, 66–80.

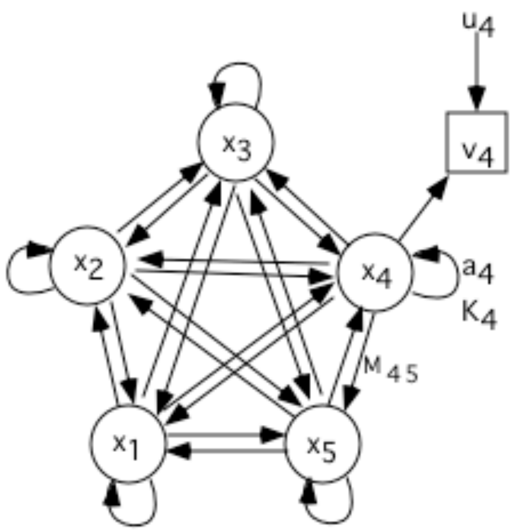
- Spins = agents
- Discrete opinions -1,1
- Topology: 2d CA (8 neighbors)
- External (social) field
- Interactions un-weighted (0,1)

- Hundreds of variations & extensions!
- But agent model often extremely simple (-1,1)

- Richer agent model using the Ising model within persons

Networks

Cognition/Intelligence



Positive reciprocal interaction during cognitive development

$$\frac{dx_i}{dt} = a_i x_i (1 - x_i / K_i) + a_i \sum_{\substack{j=1 \\ j \neq i}}^{n} M_{ij} x_j x_i / K_i$$

van der Maas, H. L. J., Dolan, C. V., Grasman, R. P. P. P. , Wicherts, J. M. , Huizenga, H. M. & Raijmakers, M. E. J. A dynamical model of general intelligence: the positive manifold of intelligence by mutualism. Psychological Review, 113(4), 842-861.

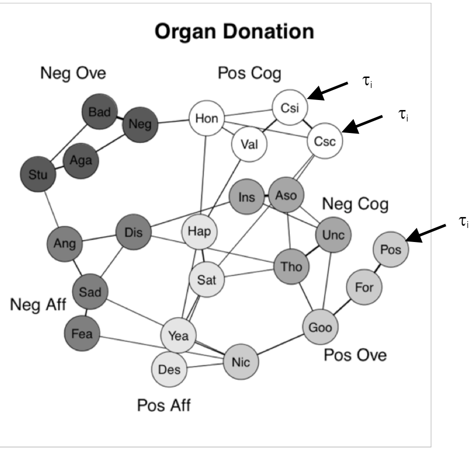
Psychological disorders

Denny Borsboom

Symptom networks as alternative for the classic 'disease' view of a underlying common cause

Within person approach: Ising attitude model

- **Nodes X**: Attitude elements (beliefs, feelings, behaviors)
- **Edges ω**: interactions
- **Thresholds τ**: dispositions of evaluative reactions based on external information



Assumption 1: Nodes (representing the attitude elements) are binary of nature
reasonable when nodes are defined at a low level of description
Assumption 2: Interactions between nodes are symmetrical (undirected)
as long as they are mostly positive, directed edges are allowed
Assumption 3: Nodes have thresholds

Dalege, J., Borsboom, D., van Harreveld, F., van den Berg, H., Conner, M., & van der Maas, H. L. J. (2016). Toward a formalized account of attitudes: The Causal Attitude (CAN) model. *Psychological Review, 123*, 2-22.

Dalege, J., Borsboom, D., van Harreveld, F., & van der Maas, H. L. (2018b). The Attitudinal Entropy (AE) Framework as a General Theory of Individual Attitudes. Psychological Inquiry, 29(4), 175-193.

Entropy reduction

- The inconsistent and instable state (high attitudinal entropy) is the natural state of an attitude
- The equivalent of inverse temperature, β = attention payed to the issue (~involvement)
- Hebb learning (what fires together wires together)
- Attention → consistency → learning

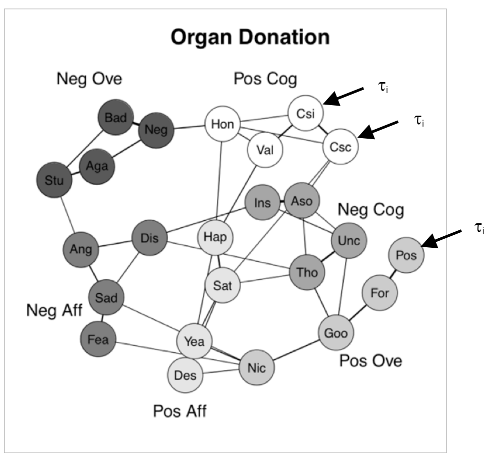
$$\Pr(X = x) = \frac{\exp(-\beta H(x))}{Z},$$

$$\omega_{ij}^{t+1} = (1 - d_\omega)\,\omega_{ij}^{t} + d x_i x_j$$

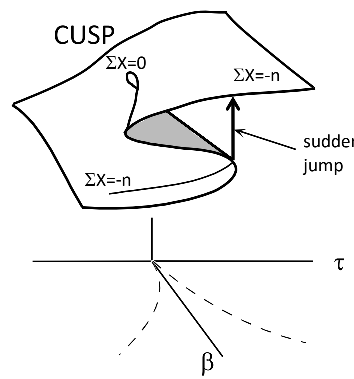
Dalege, J., Borsboom, D., van Harreveld, F., & van der Maas, H. L. J. (2018).
The Learning Ising Model of Attitude (LIMA): Entropy reduction by Hebbian learning.
Manuscript in preperation.

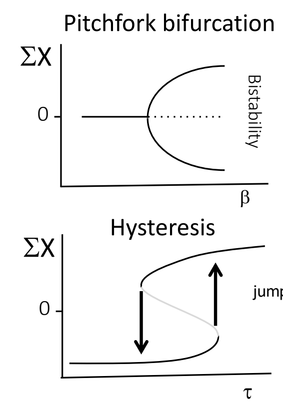
Why use the Ising model?

- Is is overly simplistic, but
    - Dalege et al. (2016, 2018b): measurement theory for attitudes + applications.
    - Ising model ⇔ popular statistical models
        - loglinear model, logistic regression, collider models, and item response theory models (e.g., Marsman et al., 2018)
    - Mean field reduction to the cusp!



If not too sparse & most interaction are positive





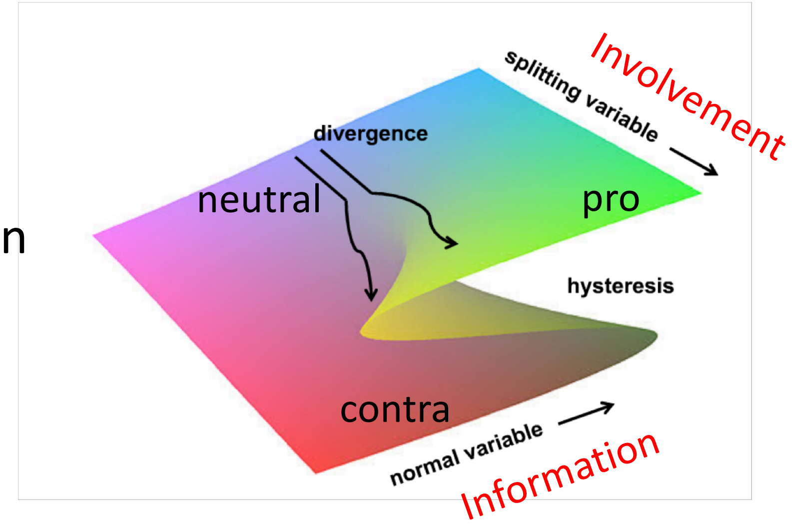
- Pitchfork bifurcation : mere thought effect
- Hysteresis: resistance to persuasion
- Attitudes behave continuously or discretely depending on β

Details explained in:

- Dalege, J., Borsboom, D., van Harreveld, F., van den Berg, H., Conner, M., & van der Maas, H. L. J. (2016). **Toward a formalized account of attitudes: The Causal Attitude Network (CAN)** model. *Psychological Review*, 123, 2-22.
- Dalege, J., Borsboom, D., van Harreveld, F., & van der Maas, H. L. J. (2017). **Network analysis on attitudes: A brief tutorial.** *Social Psychological and Personality Science*, 8, 528-537.
- Dalege, J., Borsboom, D., van Harreveld, F., Waldorp, L. J., & van der Maas, H. L. J. (2017). **Network structure explains the impact of attitudes on voting decisions**. *Scientific Reports*, 7, 4909.
- Dalege, J., Borsboom, D., van Harreveld, F., & van der Maas, H. L. J. (2018). **A network perspective on attitude strength: Testing the connectivity hypothesis.** *Social Psychological and Personality Science*.
- Dalege, J., Borsboom, D., van Harreveld, F., & van der Maas, H. L. J. (accepted). **The Attitudinal Entropy (AE) Framework as a General Theory of Individual Attitudes.** *Psychological Inquiry*.
- Dalege, J., Borsboom, D., van Harreveld, F., & van der Maas, H. L. J. (in prep). **The Learning Ising Model of Attitude (LIMA): Entropy Reduction by Hebbian Learning**

Within & between persons

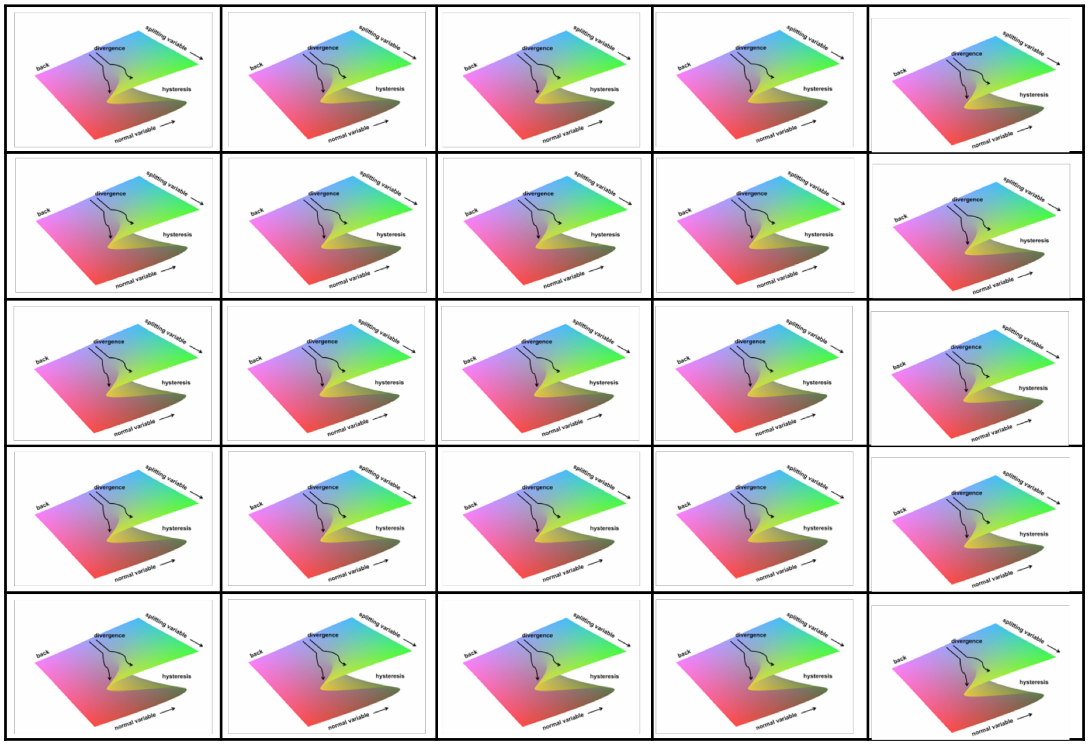
- HOM: Hierarchical opinion model
- Assume agent opinion consists of attitude networks
  - Network of networks
- Make use of mean field approximation
- Person's attitude = cusp model
  - Behavior: opinion O
  - Splitting: attention, involvement I
  - Normal: information K



note: if involvement is high agents behave discretely

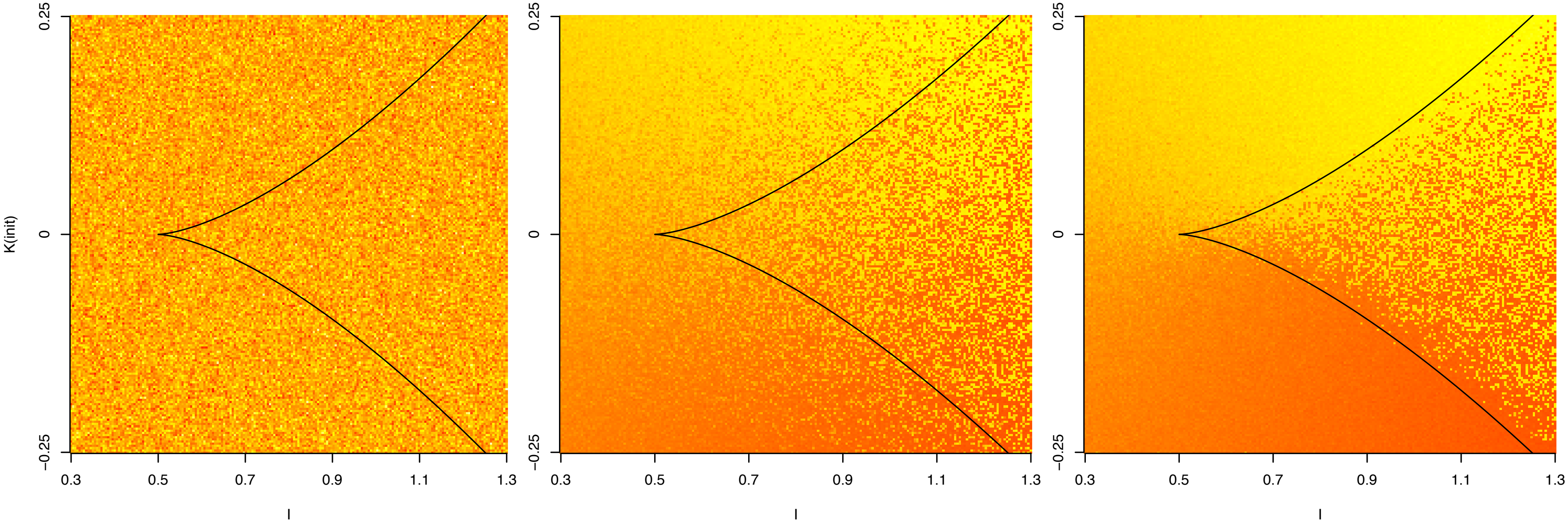
Cusp: $O^3 - IO - K = 0$

HOM Social Network (CA) of person networks (cusps)

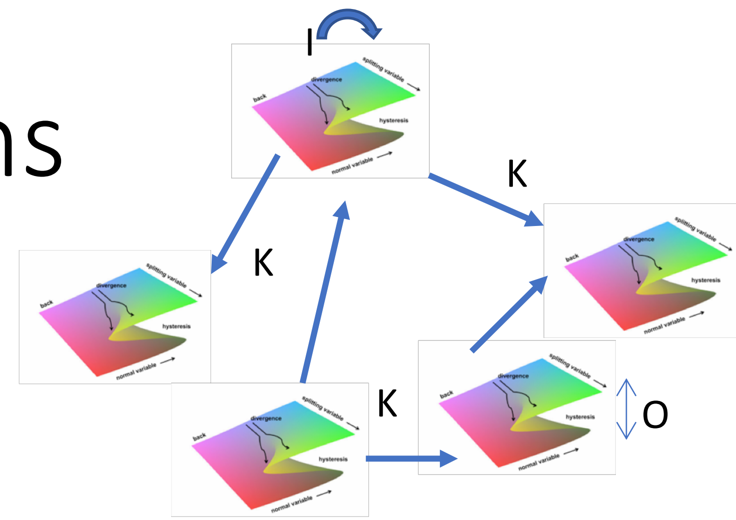


Cusp of cusps

Involvement increases along x axis
Information varies (-.25 to 25) at y-axis
Involvement fixed
Averaging information between neighbors



Dynamic assumptions



1. P(agent selection) depends on involvement
   (asynchronous update)
2. Involvement decays
3. Involvement increases when neighbors interact
4. Averaging information weighted by involvement
5. Opinion updated according to (stochastic) cusp equation

$$p(select\ agent_{ij}) = I_{ij} \Big/ \sum_{i=1}^{N} \sum_{j=1}^{N} I_{ij}$$

$$dI_{ij} = -(d_i/N^2)I_{ij} + u_{ij}d_i + s_I\, dW_{ij}(t)$$

$$K_A = (K_A I_A^p + K_B I_B^p)/\ (I_A^p + I_B^p) + \mathrm{N}(0, s_K)$$

$$dO_{ij} = -\left(O_{ij}^3 + (I_{ij} + I^{min})O_{ij} + K_{ij}\right) dt + s_O dW_{ij}(t)$$

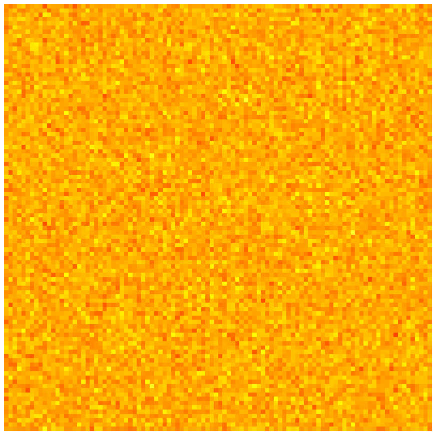
Scenario 1: polarization

- Axelrod (1997): “If people tend to become more alike in their beliefs, attitudes, and behavior when they interact, why do not all such differences eventually disappear?”
- At one thirds of the simulation we shrink K to zero, such that we end with a population of agents with equal neutral information. At two third we shrink involvement too.

result

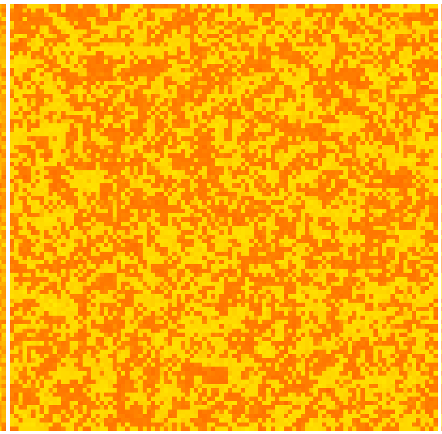
All agents same K & I

Random initial state



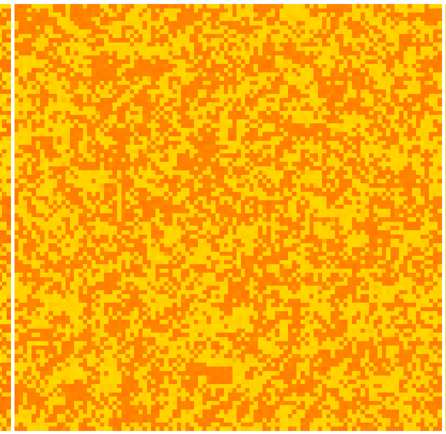
Information = random
Involvement = 1

Polarization



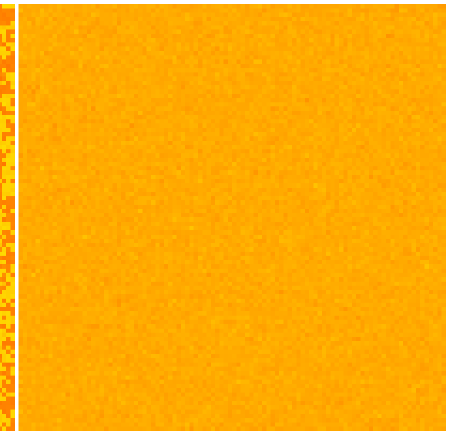
Information = random
Involvement = 1

Polarization

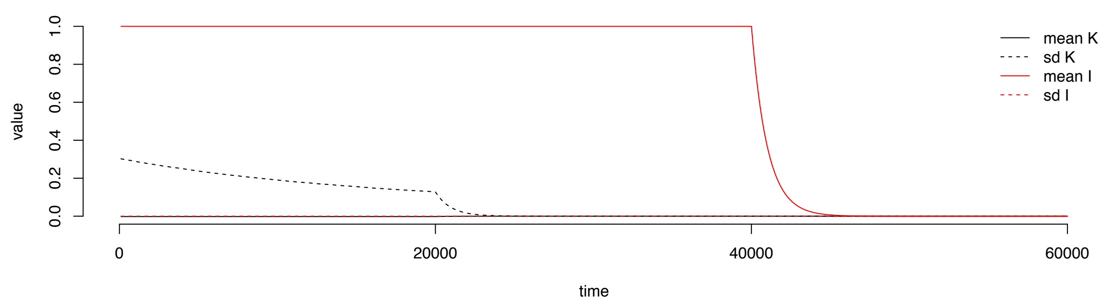


Information = 0
Involvement = 1

De-polarization



Information = 0
Involvement = 0



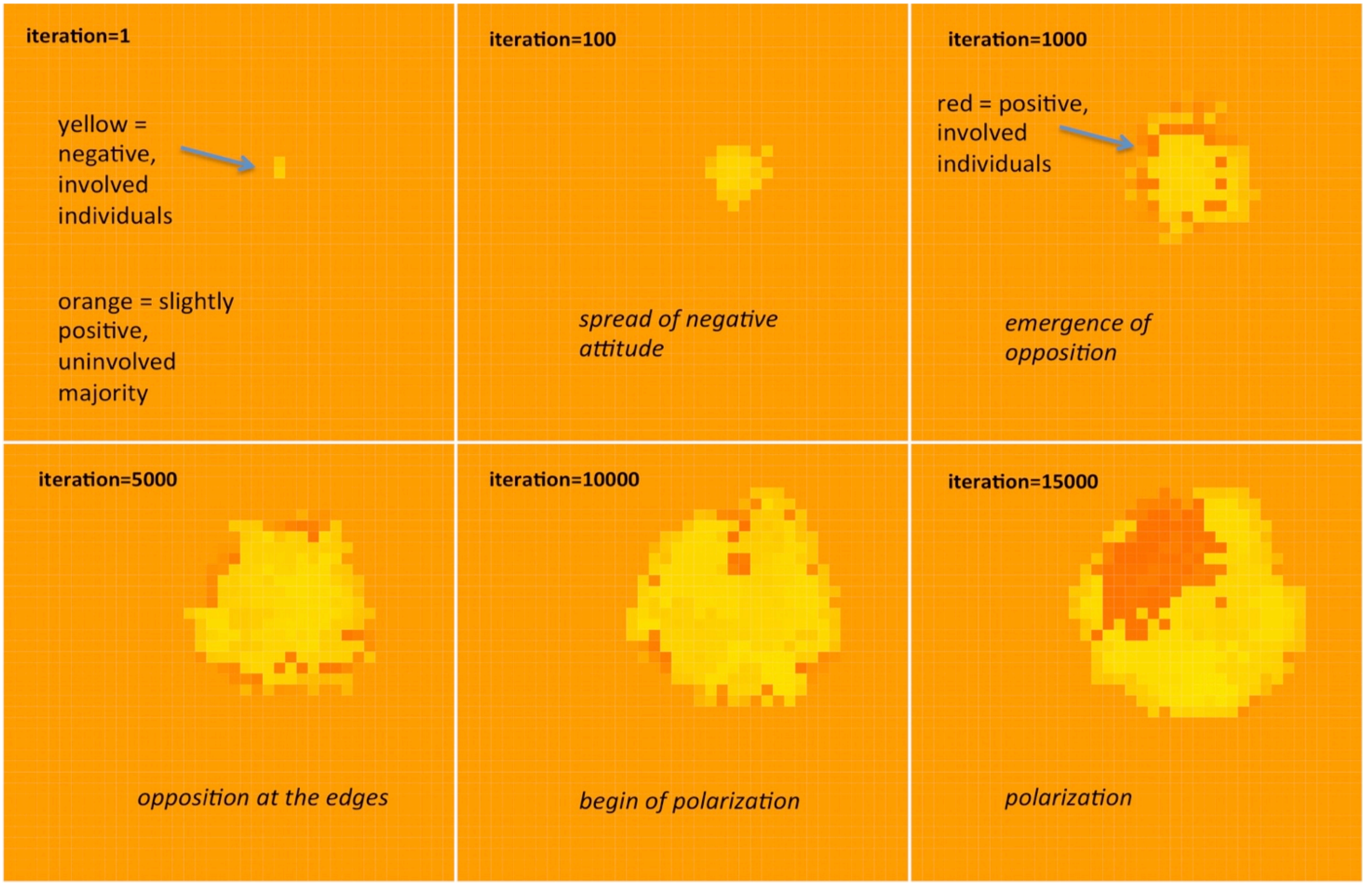
Scenario 2: Black Pete

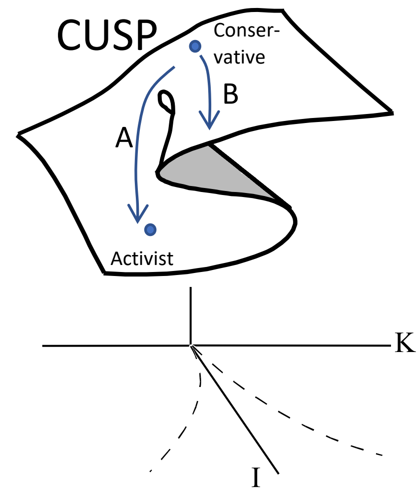
- all agents are slightly positive but not much involved at all
- some agents becomes highly involved with the opposite opinion

- Thus these agents are almost always selected for interaction
  - assumption 1
- and these agents win all debates, they copy their K to less involved neighbors (with some noise)
  - assumption 4

- What will happen?

Black Pete


iteration=1
yellow = negative, involved individuals
orange = slightly positive, uninvolved majority
iteration=100
spread of negative attitude
iteration=1000
red = positive, involved individuals
emergence of opposition
iteration=5000
opposition at the edges
iteration=10000
begin of polarization
iteration=15000
polarization


CUSP
Conser-vative
B
A
Activist
K
I

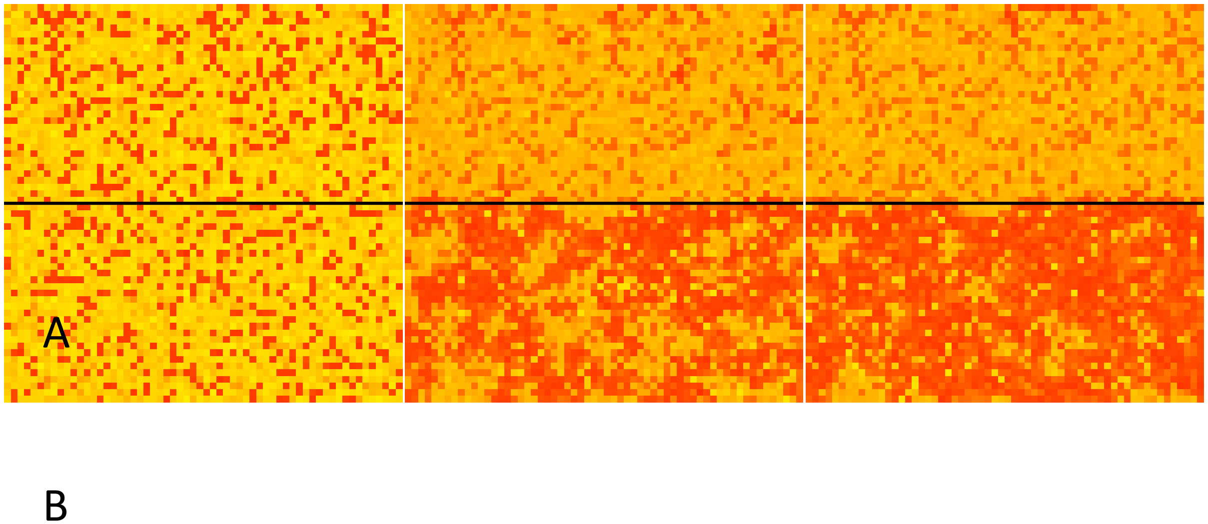
Continuous opinion models

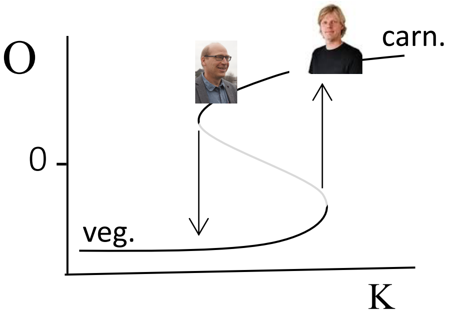
- Opinion is continuous
- Polarization:
  - Sparse network (de Groot model)
  - Susceptibility (Friedkin-Johnsen model)
  - Bounded confidence (no exchange when opinions differ too much): Deffuant–Weisbuch (DW) and the Hegselmann–Krause (HK) model

- Ho to resolve polarization in the Bounded confidence models?

"solution"

- Add 'meat eating vegetarians' (B)





Discussion

- New dynamics in sociophysics models by ‘richer’ model of agent
  - Integrates the two main branches (discrete and continuous models)
- Ising attitude model is promising
- Network approach in Psychology is booming
  - Denny Borsboom, Sacha Epskamp,
- Methodology for transition research available
- Formal complex system approach to social science is possible