Wrocław
University
of Science
and Technology

Towards understanding of the social hysteresis: an agent-based approach

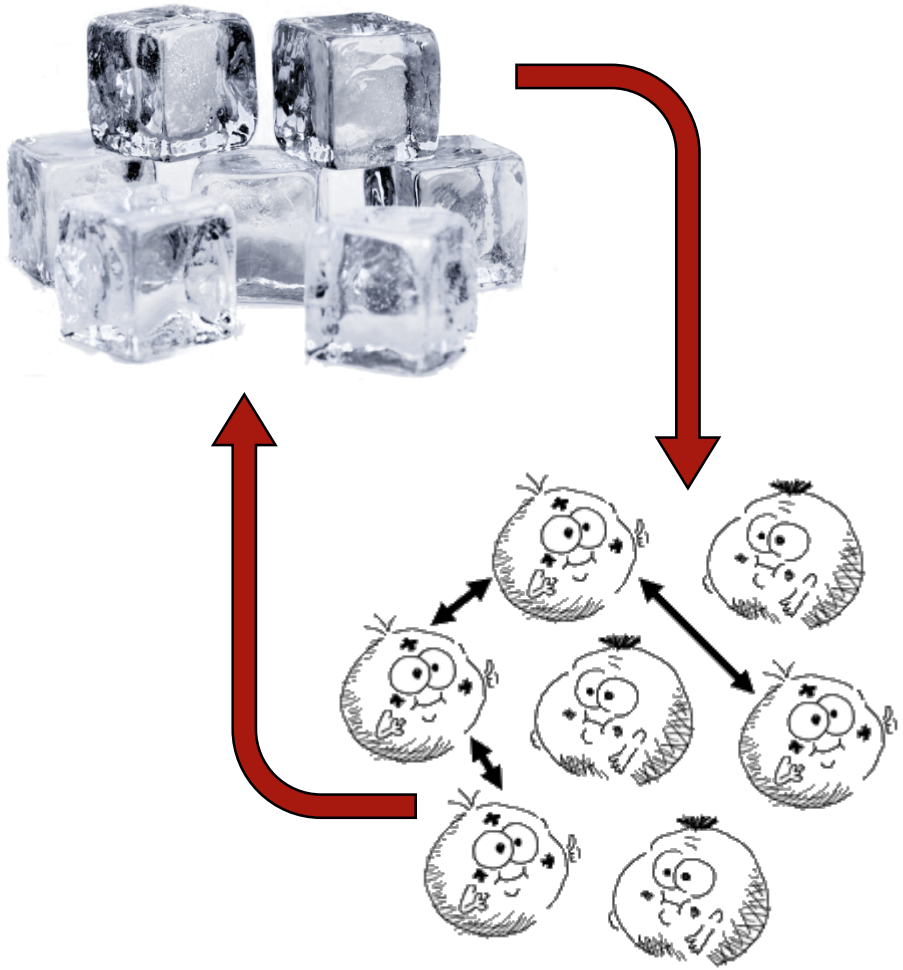
(NCN 2019/35/B/HS6/02530)

Katarzyna Sznajd-Weron
Statistical **P**hysics **i**n **C**omplex S**y**stems (SPiCy) group
Department of Theoretical Physics

Wrocław University of Science and Technology

Why statistical physics?

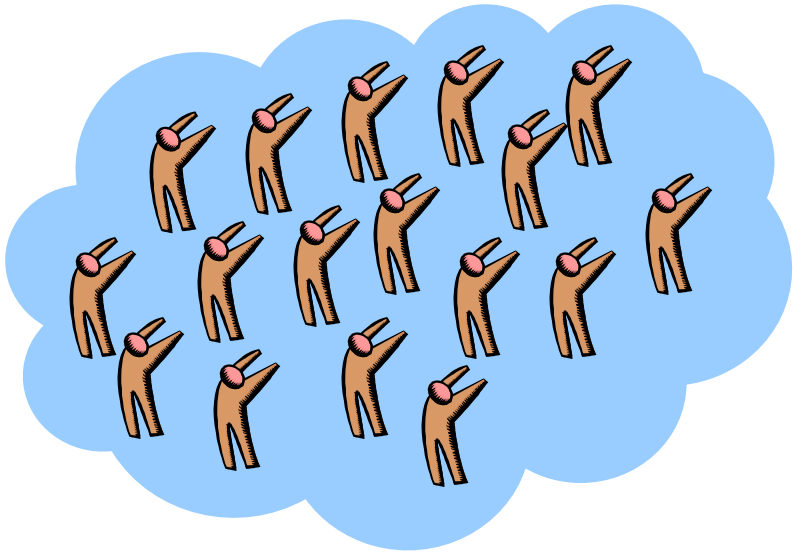
Macro-scale: thermodynamics (How?)



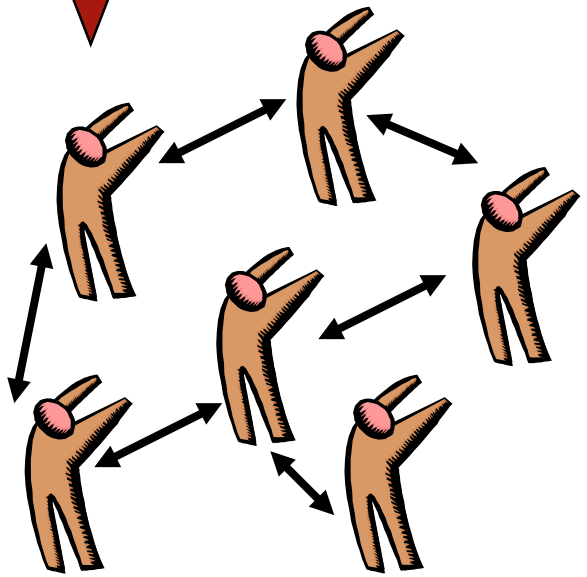
Micro-scale: statistical physics (Why?)

Wrocław University of Science and Technology

Why social systems?

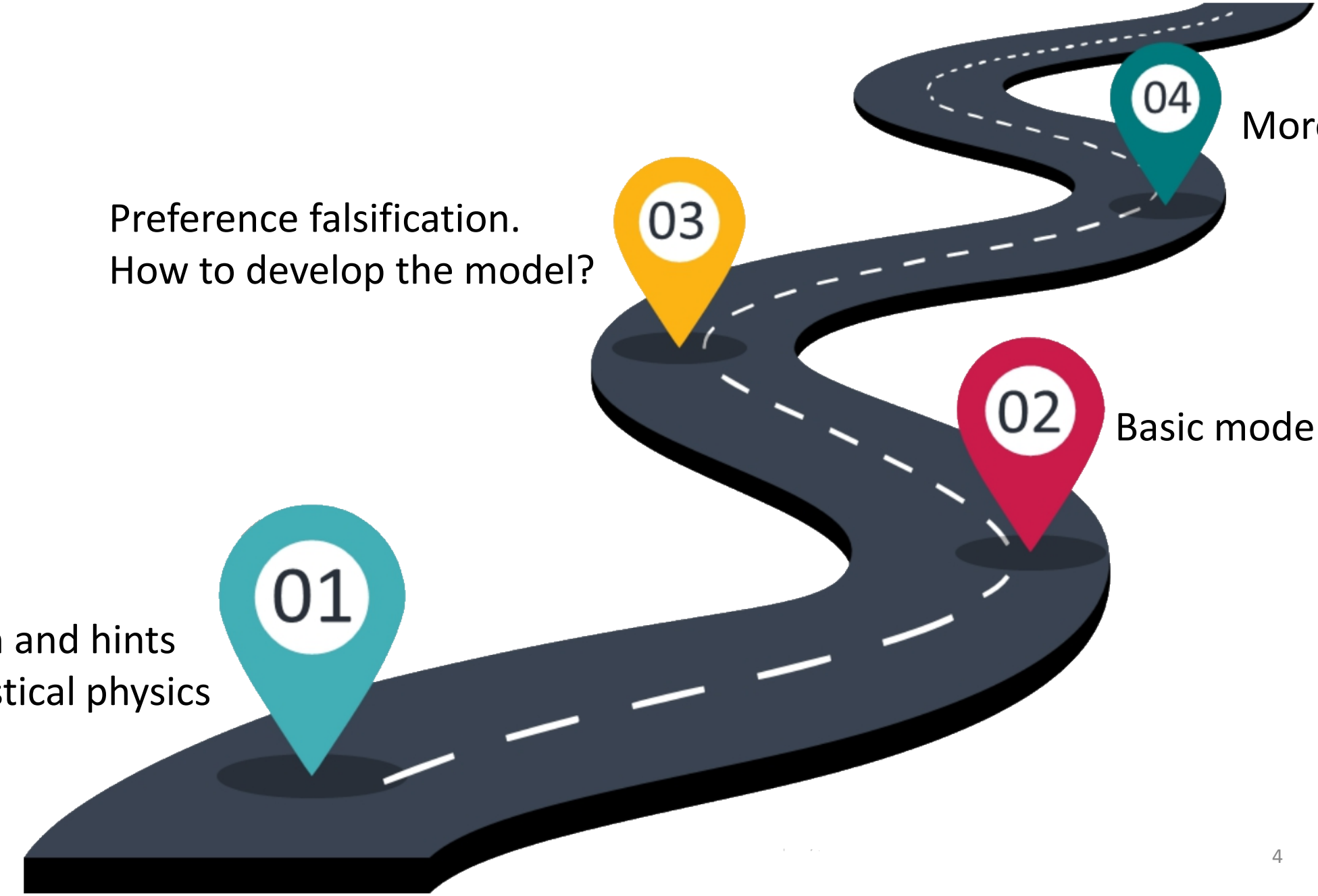


Sociology
Fundamental unit:
a social group (macro-scale)



Social Psychology
Fundamental unit:
a person (micro- scale)

Wrocław University of Science and Technology



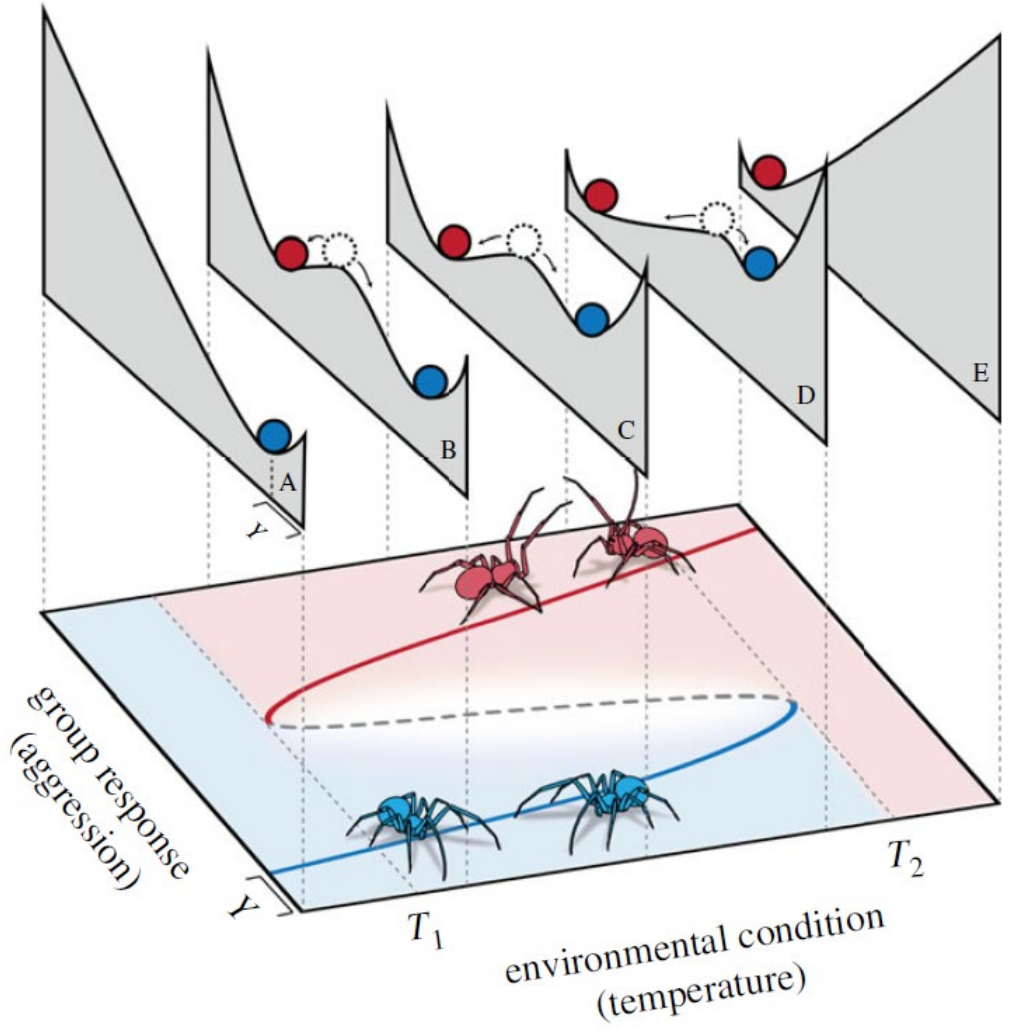
Inspiration and hints from statistical physics

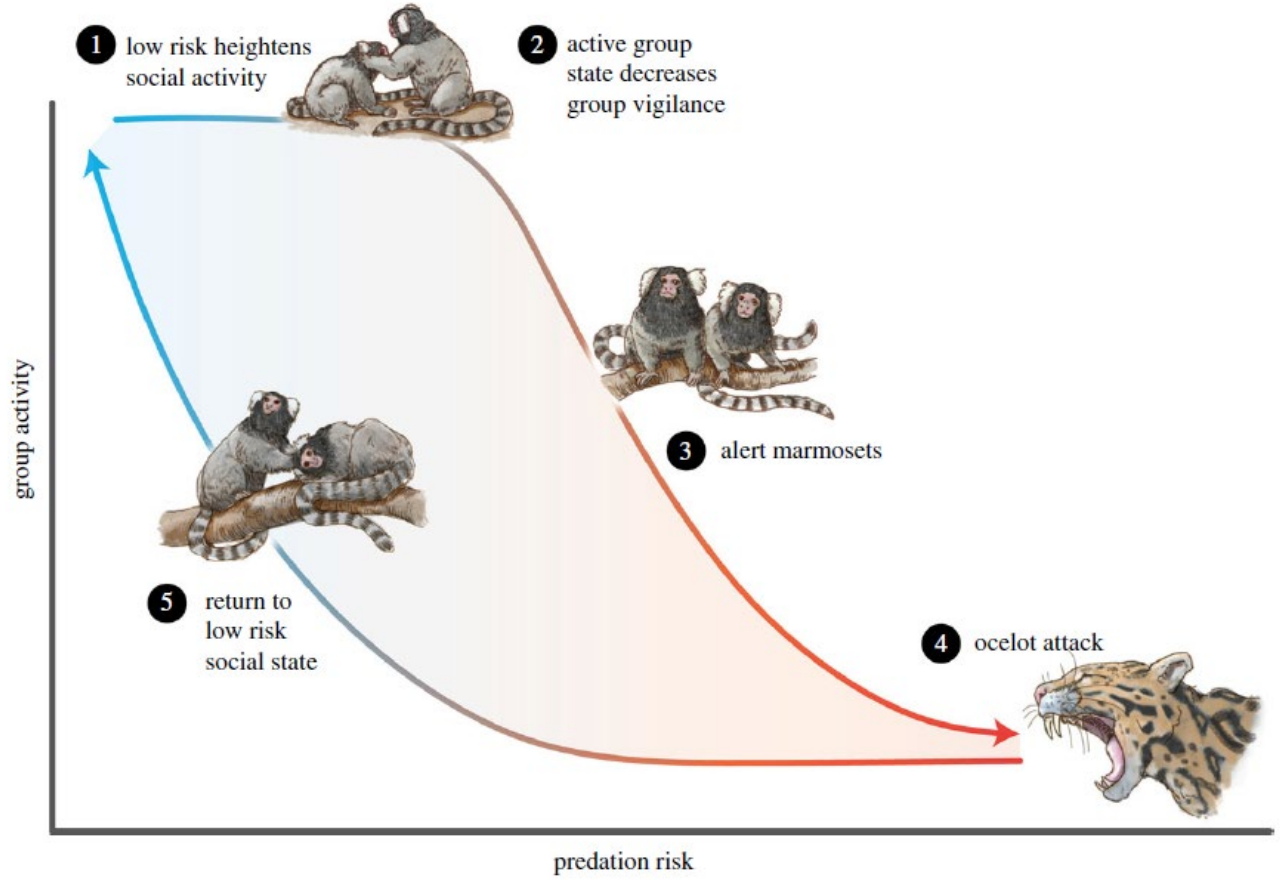
Basic model

Preference falsification. How to develop the model?

More?

Inspiration





Doering GN et al. 2018 Social tipping points in animal societies in response to heat stress: timing, recovery and hysteresis. **Nature Ecol. Evol. 2, 1298–1305.**

Pruitt JN et al. 2018 Social tipping points in animal societies. **Proc. R. Soc. B 285: 20181282**

Wrocław University of Science and Technology

The new inspiration

Covid-19 Comment Pieces

Acta Sociologica
2020, Vol. 63(4) 450–452

DOI: 10.1177/0001699320961814
journals.sagepub.com/home/asj

Hysteresis and the sociological perspective in a time of crisis

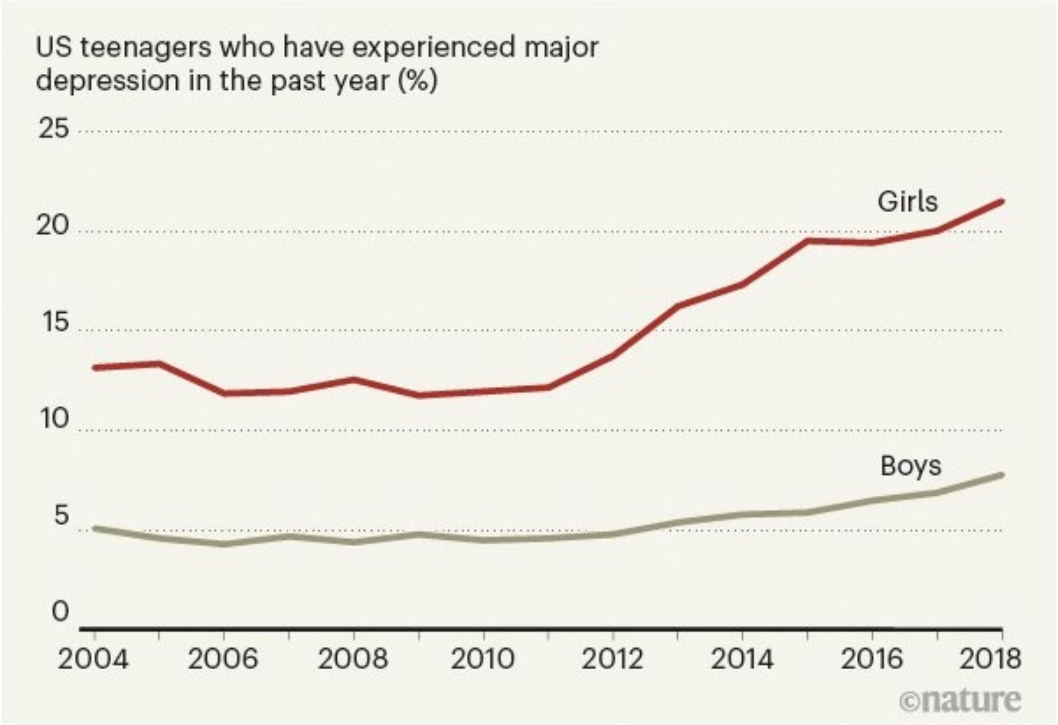
Hannah Graham
University of Stirling, UK

Abstract

Hysteresis is a versatile concept for volatile times. Pierre Bourdieu's sociological use recognises hysteresis in times of dislocation and disruption between field and habitus, 'in particular, when a field undergoes a major crisis and its regularities (even its rules) are profoundly changed' (Bourdieu, 2000: 160). In considering the issues and implications of the COVID-19

Questions

- Why achieving a desirable rate of vaccination in modern societies is challenging?
- What can be the reason of the rise of mental health disorders among undergraduate students?
- Why some ideas, practices and products spread so fast while the diffusion of other is hampered?



https://www.nature.com/articles/d41586-020-00296-x

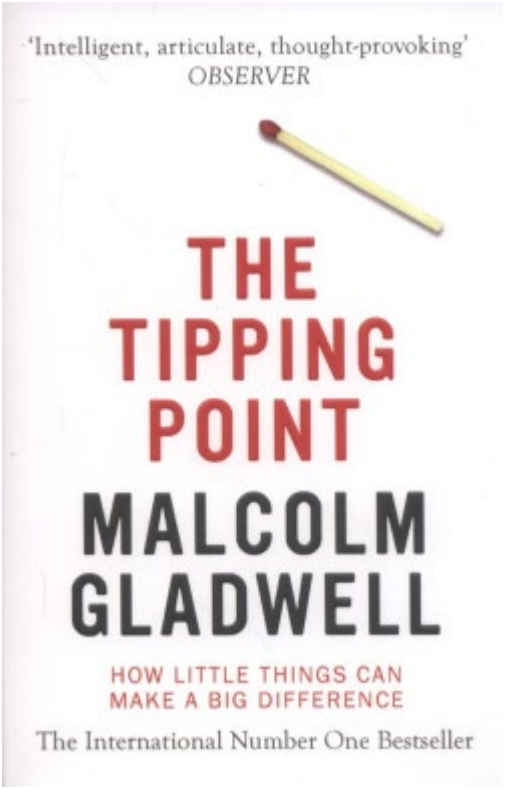
Hysteresis – what is it?

- The dependence of the state of a system on its history
- The term is derived from ὑστέρησις = lagging behind (Ancient Greek)
- It was coined ~ 1890 by Sir James Alfred Ewing to describe the behavior of magnetic materials
- Everyday example?
- What it has to do with social systems?

https://www.fizzicseducation.com.au

Hysteresis & tipping points in public opinion

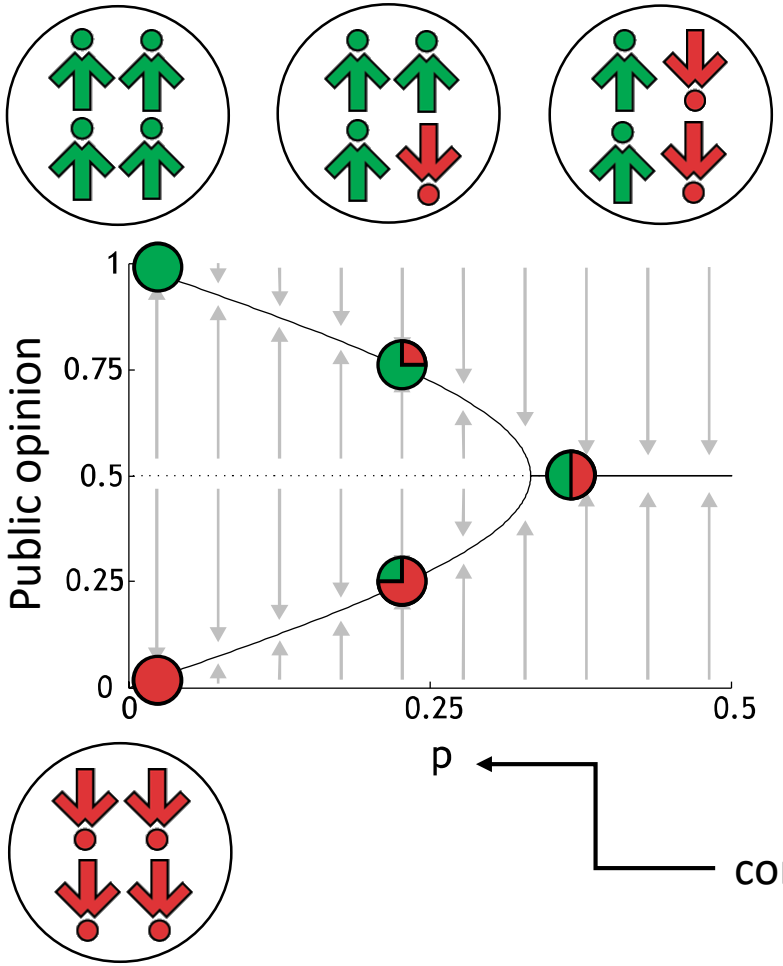
- Empirical studies suggest that:
  - it remains seemingly resistant to change (hysteresis)
  - sudden, abrupt shift of opinion can be observed at the tipping point

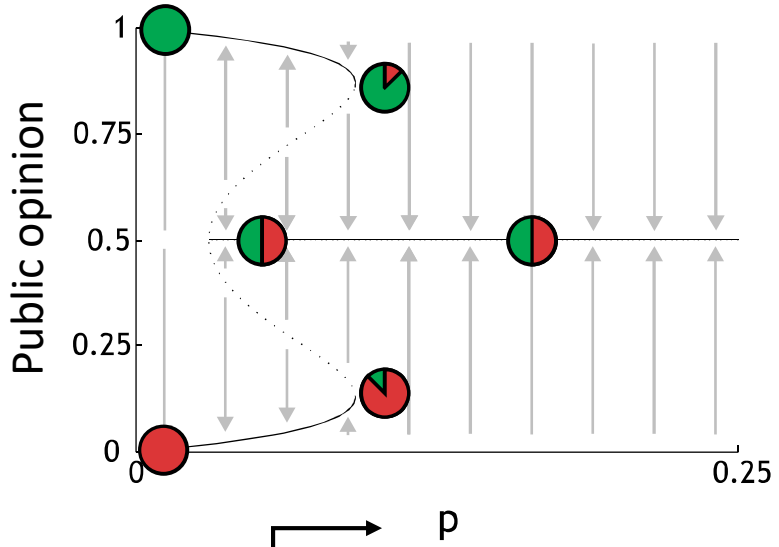


[1] M. Scheffer, etal, Slow response of societies to new problems: Causes and costs. Ecosystems (2003)

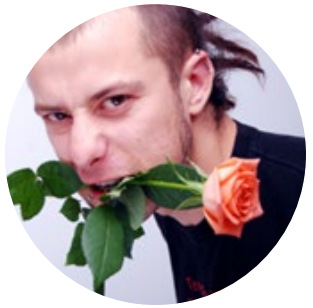
[2] D. Centola, etal. Experimental evidence for tipping points in social convention. Science (2018)

Hints from the theory of phase transitions





control parameter



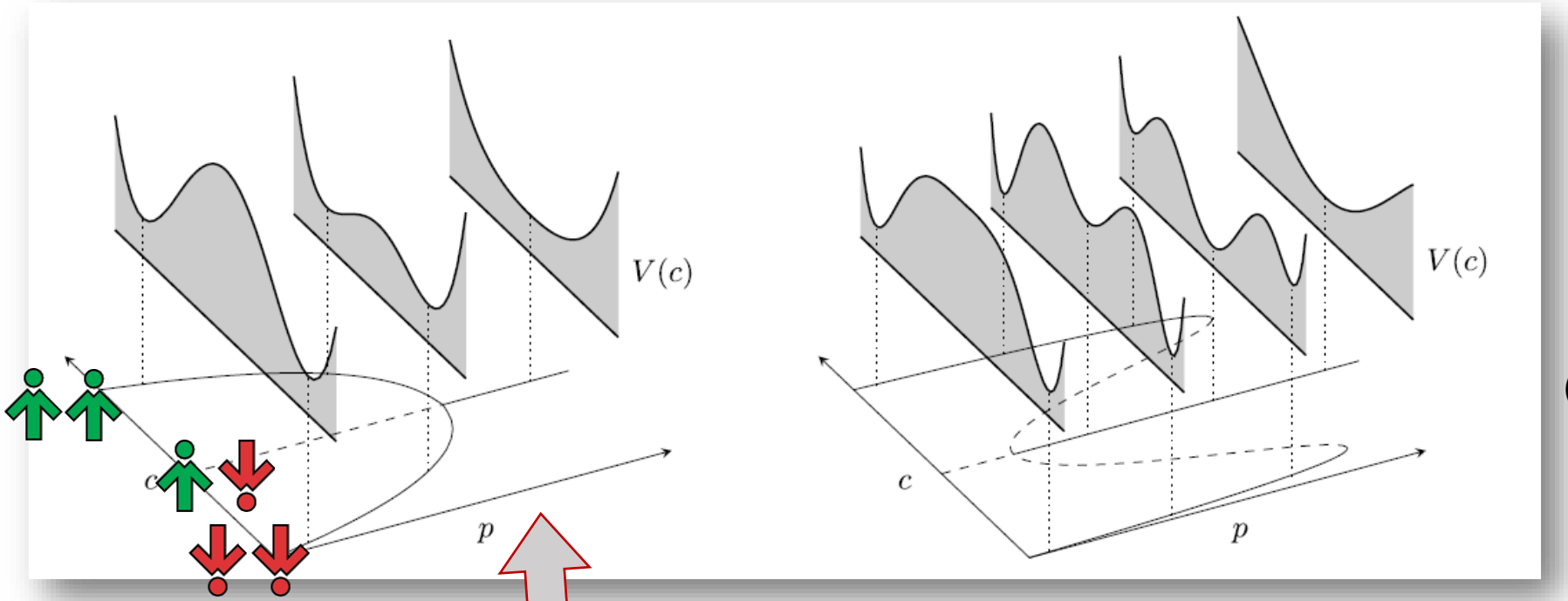
(c) 2013 Piotr Nyczka

Continuous phase transitions

Discontinuous phase transitions

Wrocław University of Science and Technology

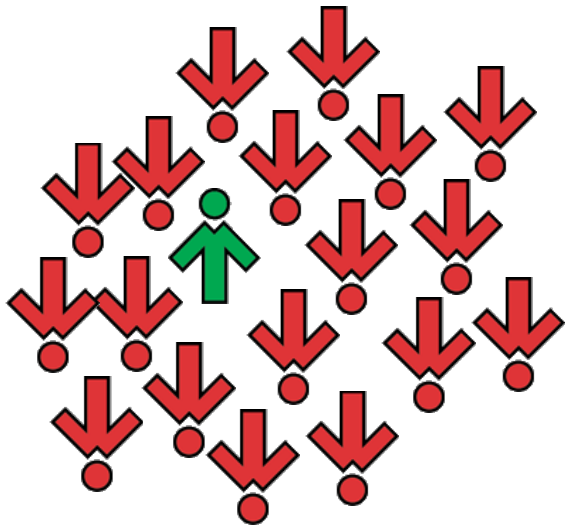
Hints from the theory of phase transitions



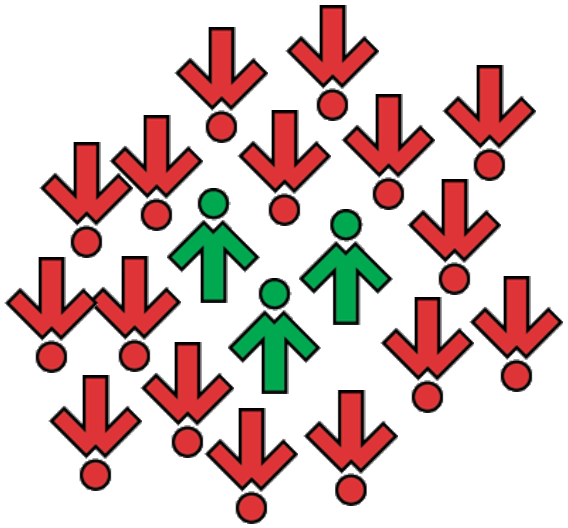
(c) 2019 Arek Jędrzejewski

	CONTINOUS	DISCONTINOUS
Metastability, hysteresis, phase coexistence		✔
Latent heat (energy)		✔
critical nucleus (seed)		✔

Hysteresis and critical nuclei (critical mass)



Not enough

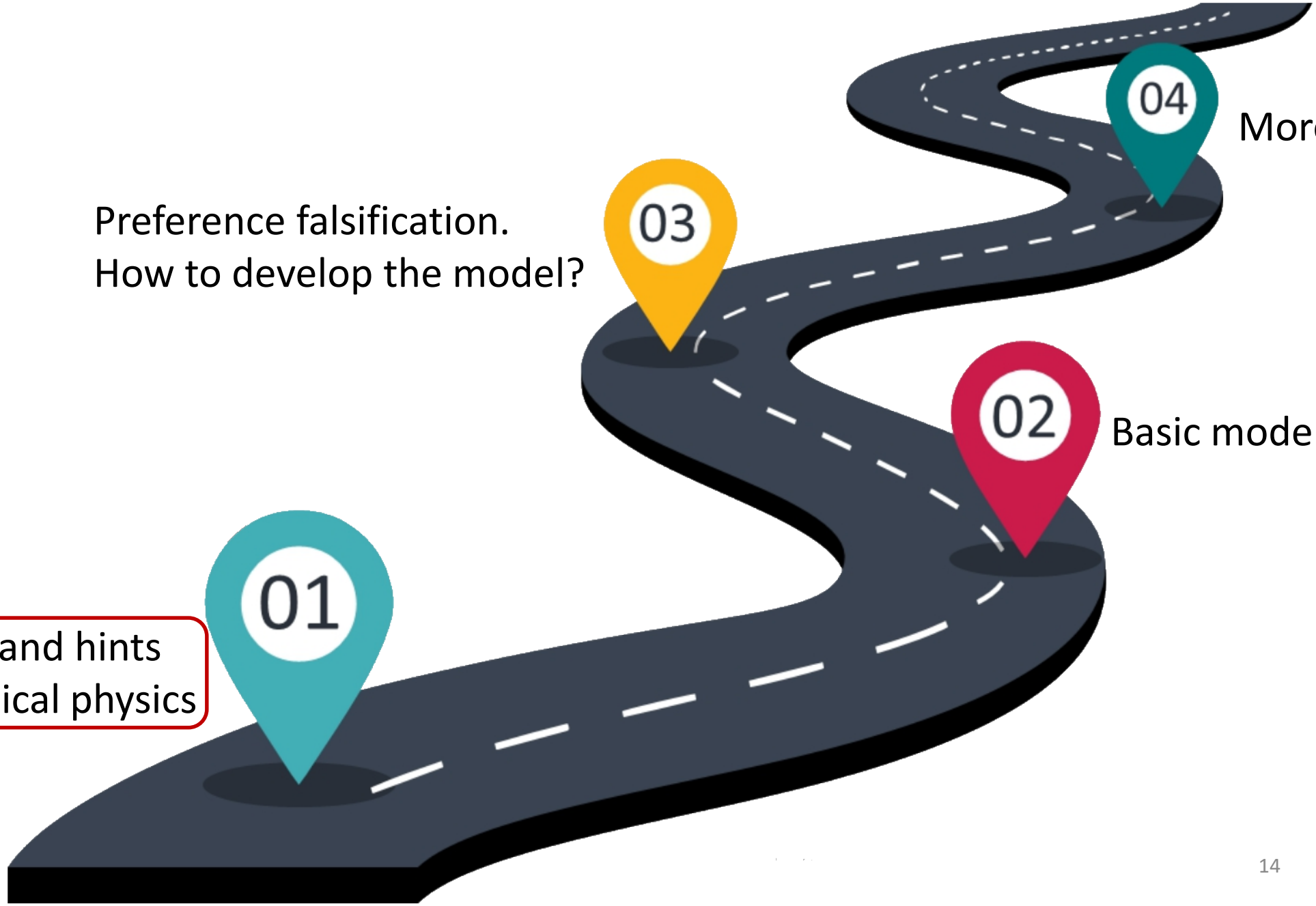


Critical mass

[1] D. Centola, etal. Experimental evidence for tipping points in social convention. Science (2018)

What factors hamper and what factors promote social hysteresis?

Wrocław University of Science and Technology



Wrocław University of Science and Technology

The answer within agent-based models

- Expected: inertia (memory) on the individual level supports social hysteresis
- Surprise: memoryless agents can also „produce” hysteresis (memory of the system)
  - The size of the group of influence
  - …

How to investigate it? Example: the q-voter model

Contents lists available at ScienceDirect

Comptes Rendus Physique

www.sciencedirect.com

ELSEVIER

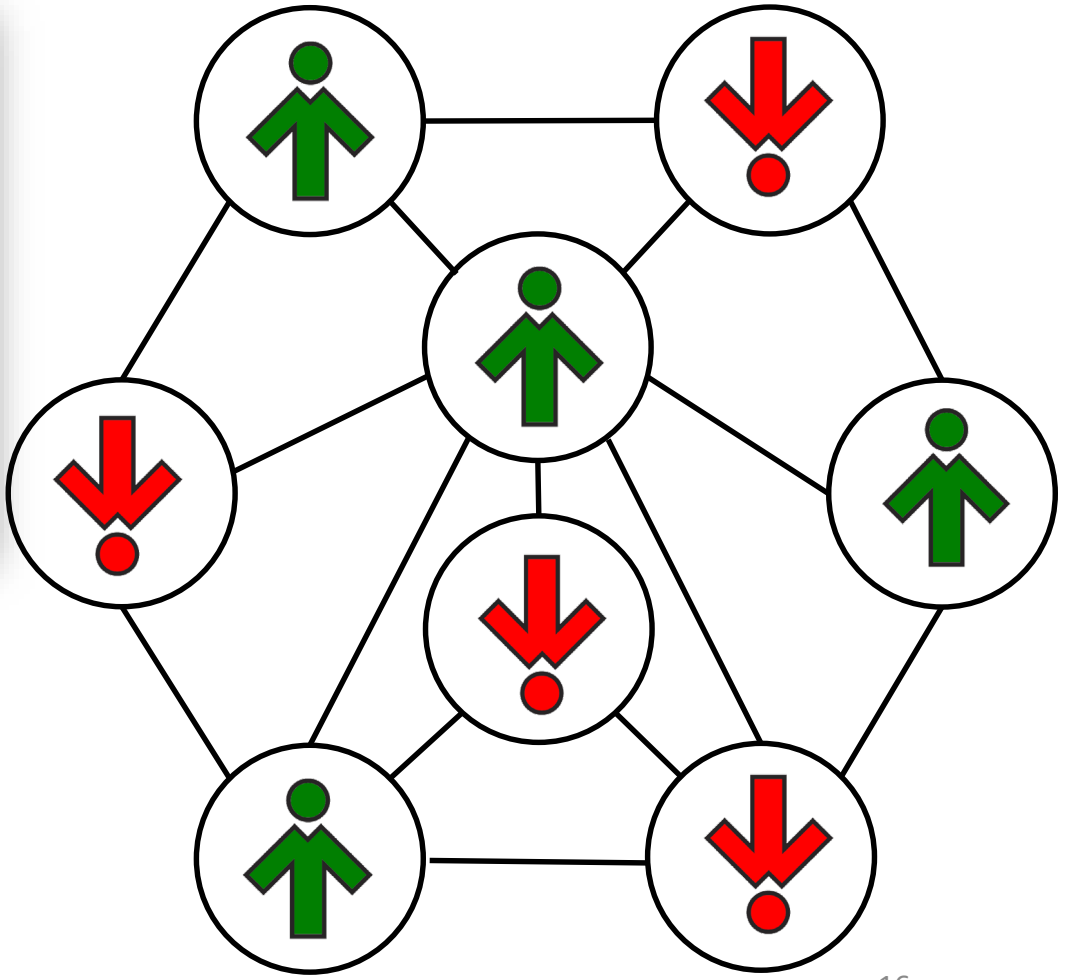
From statistical physics to social sciences / *De la physique statistique aux sciences sociales*

Statistical Physics Of Opinion Formation: Is it a SPOOF?

Physique statistique de la formation d'opinion : est-ce une blague ?

Arkadiusz Jędrzejewski *, Katarzyna Sznajd-Weron

Department of Theoretical Physics, Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, Wrocław, Poland

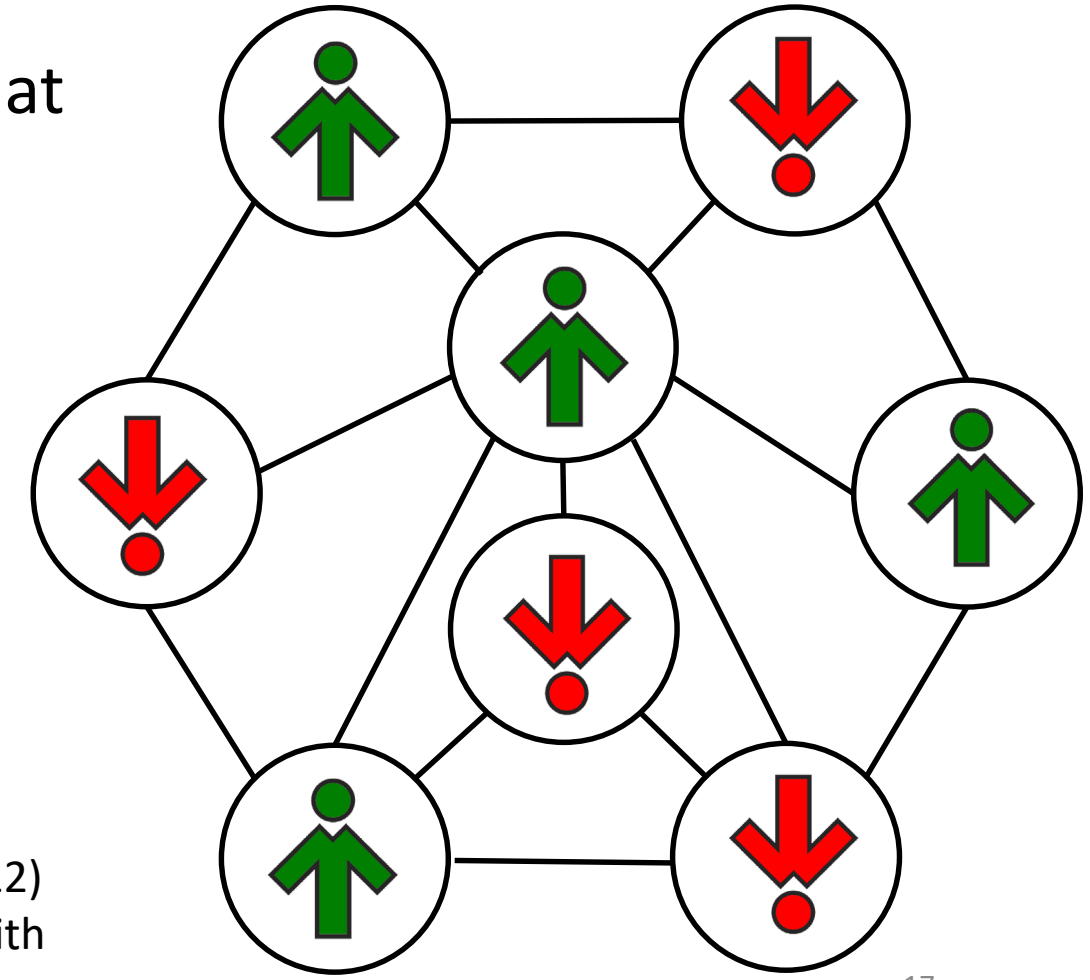


$S_i(t) = \pm 1$ Individual opinion

Wrocław University of Science and Technology

The q-voter model with independence

1. Choose one voter at random, located at site i



[1] P. Nyczka, K. Sznajd-Weron, and J. Cislo, *Phase transitions in the q-voter model with two types of stochastic driving*, PRE (2012)
[2] A. Jędrzejewski, Pair approximation for the q-voter model with independence on complex networks, PRE (2017)

Wrocław University of Science and Technology

The q-voter model with independence

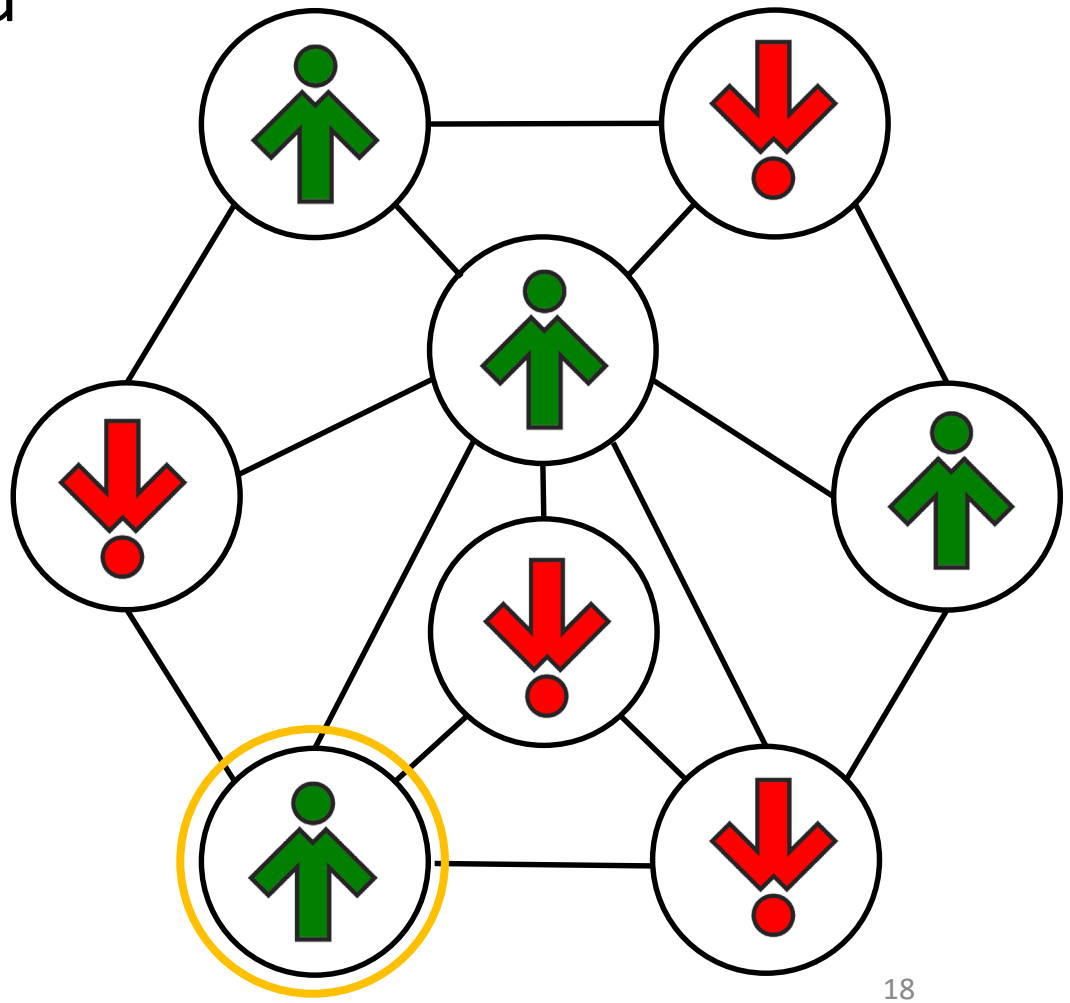
1. Choose one voter at random, located at site i
2. Update the opinion S_i
   i. Independence with probability $\boldsymbol{p}$
      → change the opinion to the opposite one with probability $\boldsymbol{f}$

How?

1. Choose $r \sim U(0,1)$, if $r < p$ then independence

Example 1:

$$r = 0.1, p = 0.2, f = 1$$



Wrocław University of Science and Technology

The q-voter model with independence

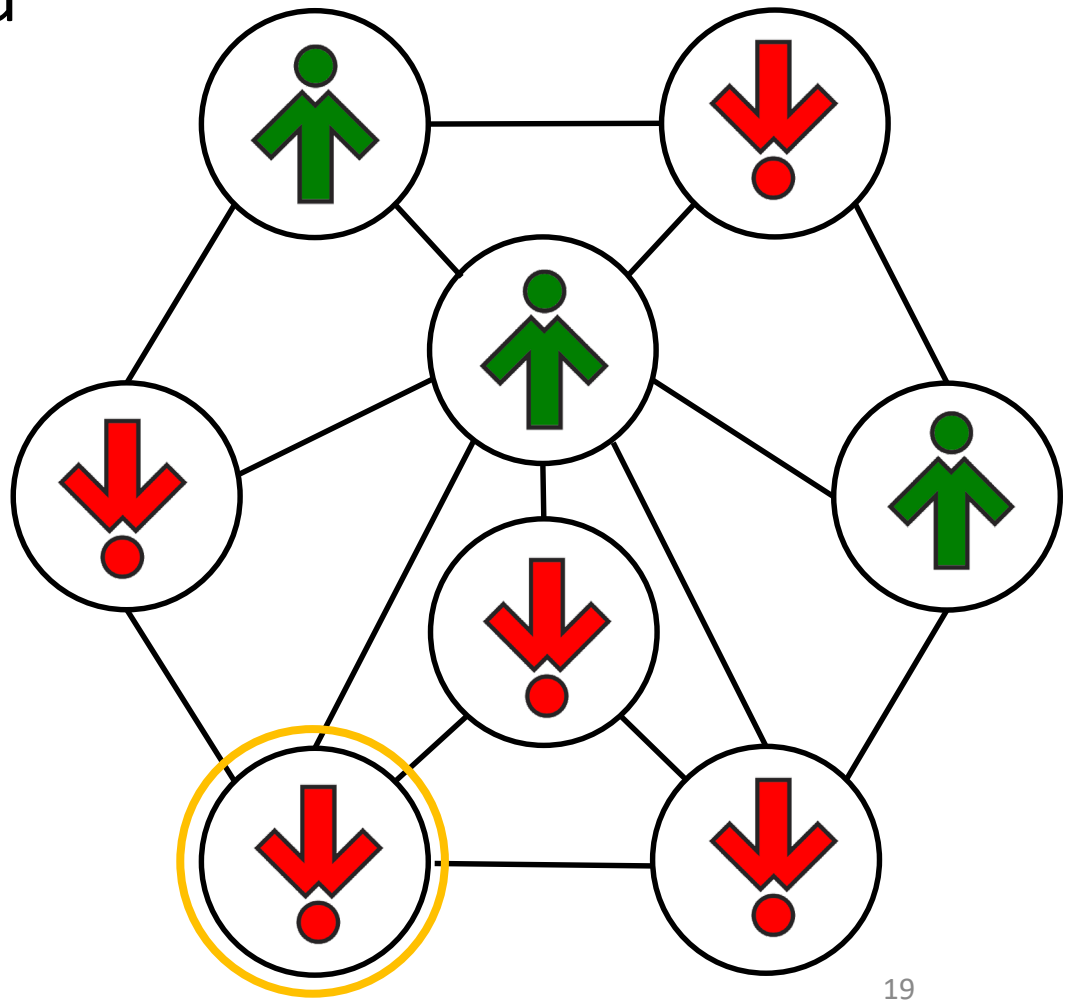
1. Choose one voter at random, located at site i
2. Update the opinion S_i
   i. Independence with probability $\boldsymbol{p}$
      → change the opinion to the opposite one with probability $\boldsymbol{f}$

How?

1. Choose $r \sim U(0,1)$, if $r < p$ then independence

Example 1:

$$r = 0.1, p = 0.2, f = 1$$



Wrocław University of Science and Technology

The q-voter model with independence

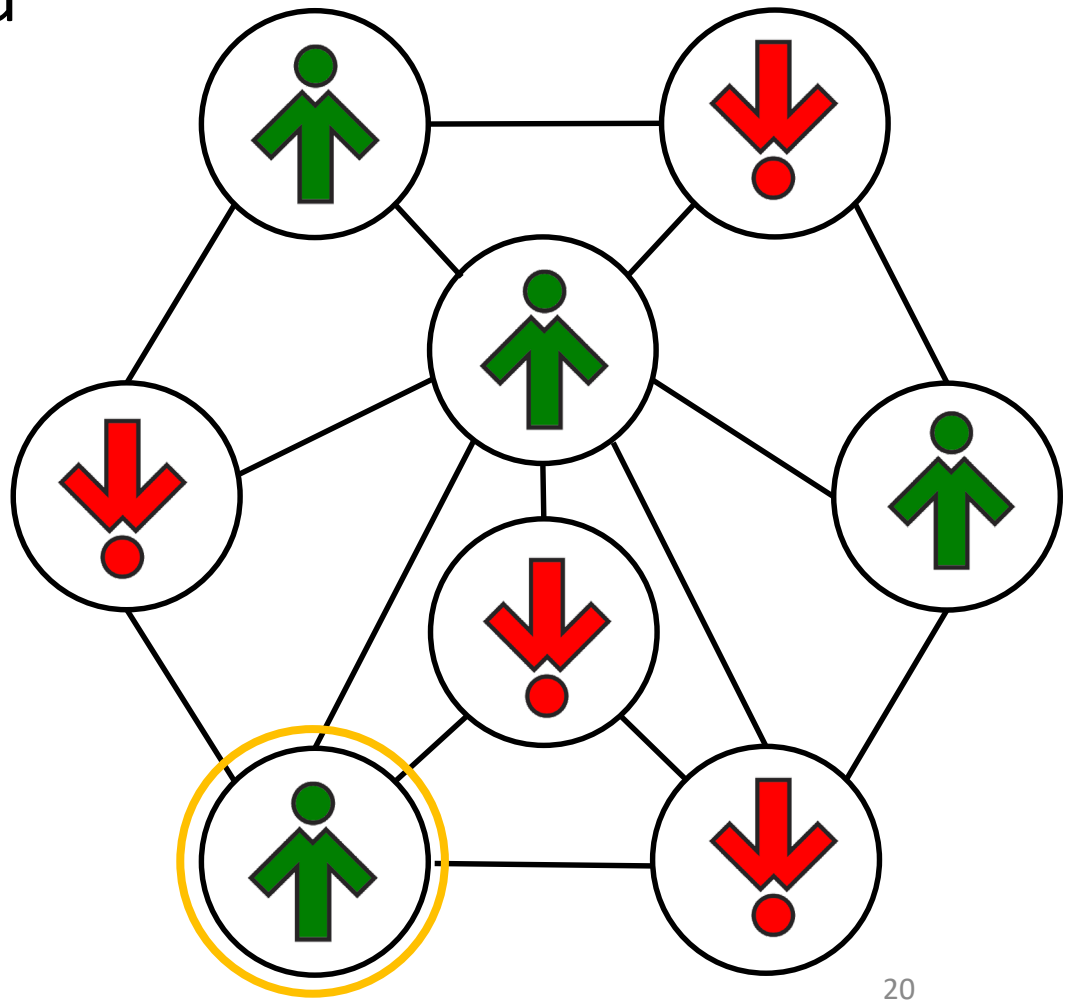
1. Choose one voter at random, located at site i
2. Update the opinion S_i
   i. Independence with probability $\boldsymbol{p}$
      → change the opinion to the opposite one with probability $\boldsymbol{f}$

How?

1. Choose $r \sim U(0,1)$, if $r < p$ then independence

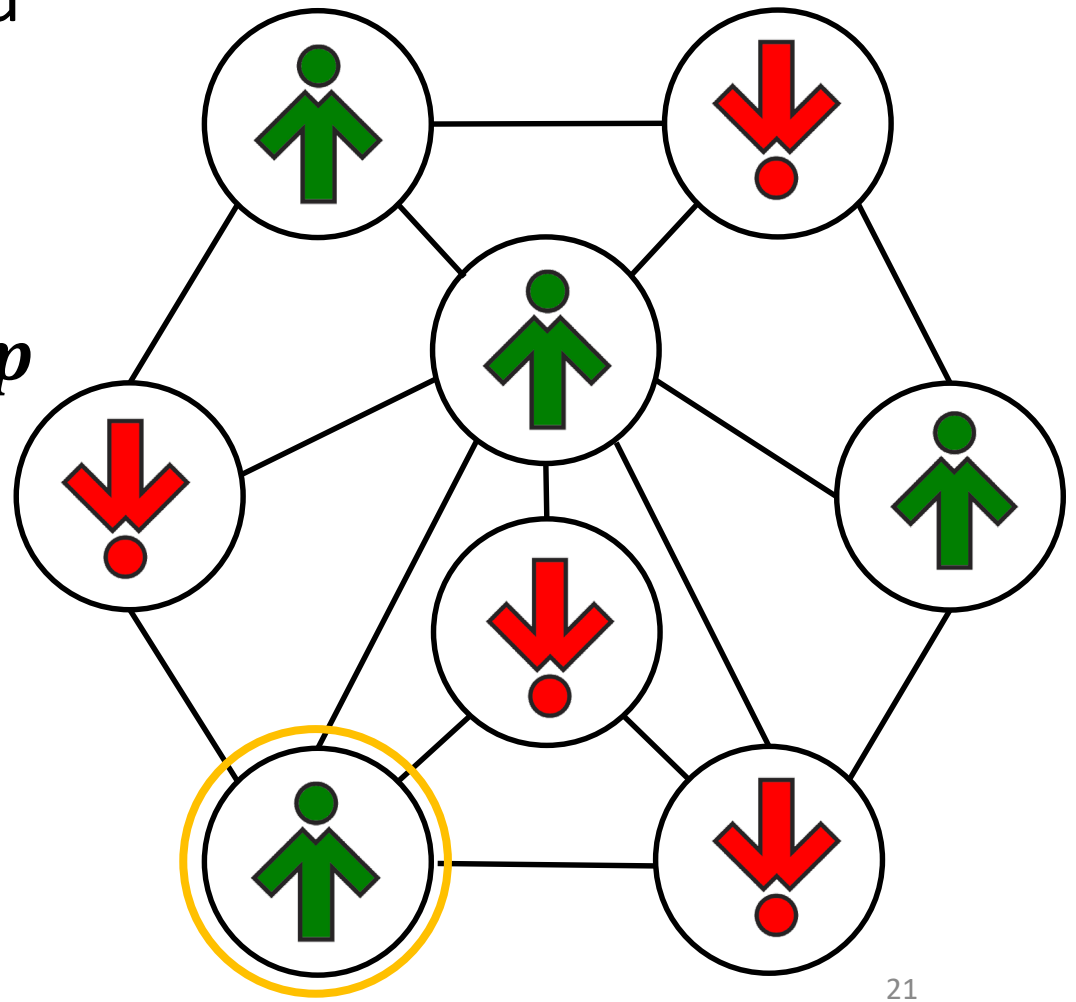
Example 2:

$$r = 0.3, p = 0.2, f = 1$$



The q-voter model with independence

1. Choose one voter at random, located at site i
2. Update the opinion S_i
   i. Independence with probability $\boldsymbol{p}$
   ii. Conformity with probability $1 - \boldsymbol{p}$
   → pick randomly $\boldsymbol{q}$ neighbors without repetition



Wrocław University of Science and Technology

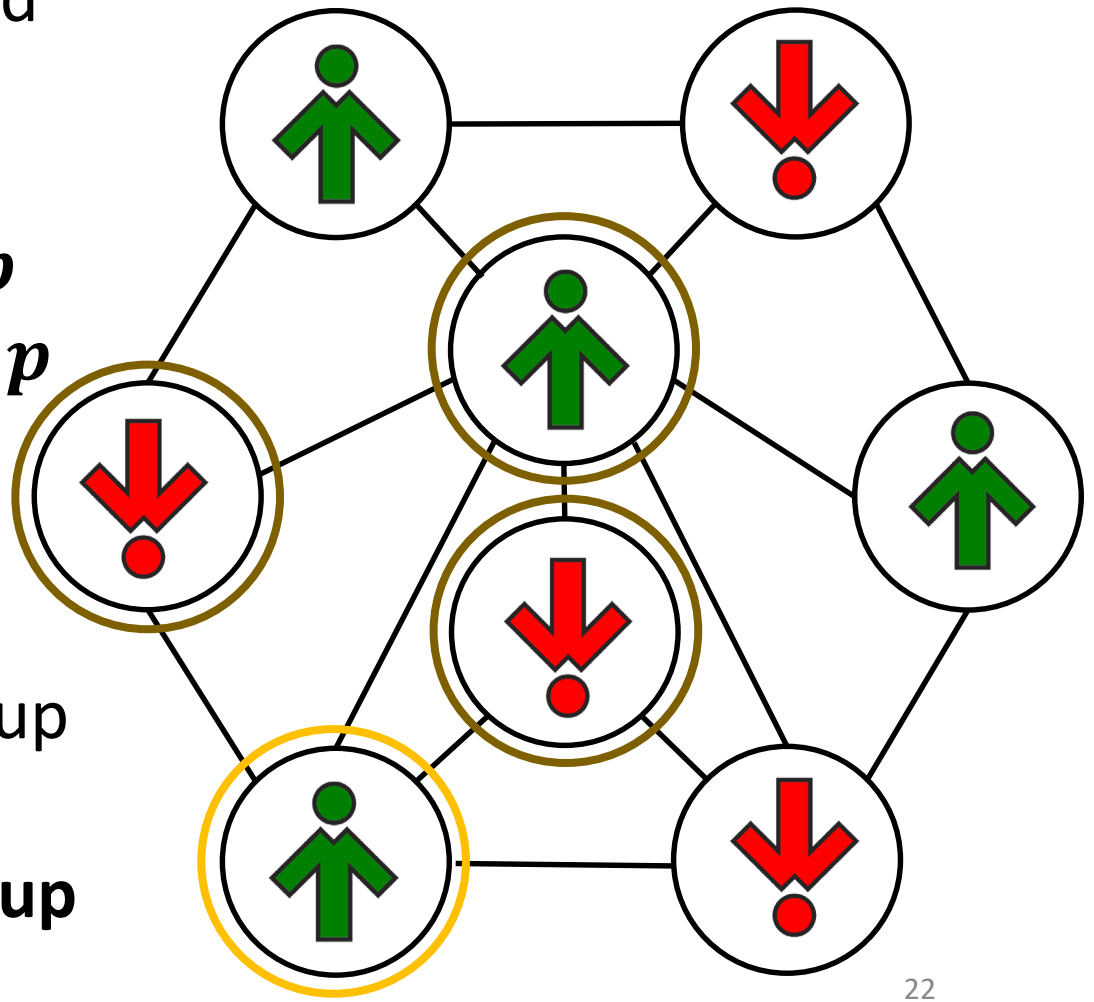
The q-voter model with independence

1. Choose one voter at random, located at site i
2. Update the opinion S_i
   i. Independence with probability $\boldsymbol{p}$
   ii. Conformity with probability $1 - \boldsymbol{p}$

   → pick randomly $\boldsymbol{q}$ neighbours without repetition,

   unanimous group - S_i adjust the group

Example 3: q=3, not unanimous group of influence – nothing changes

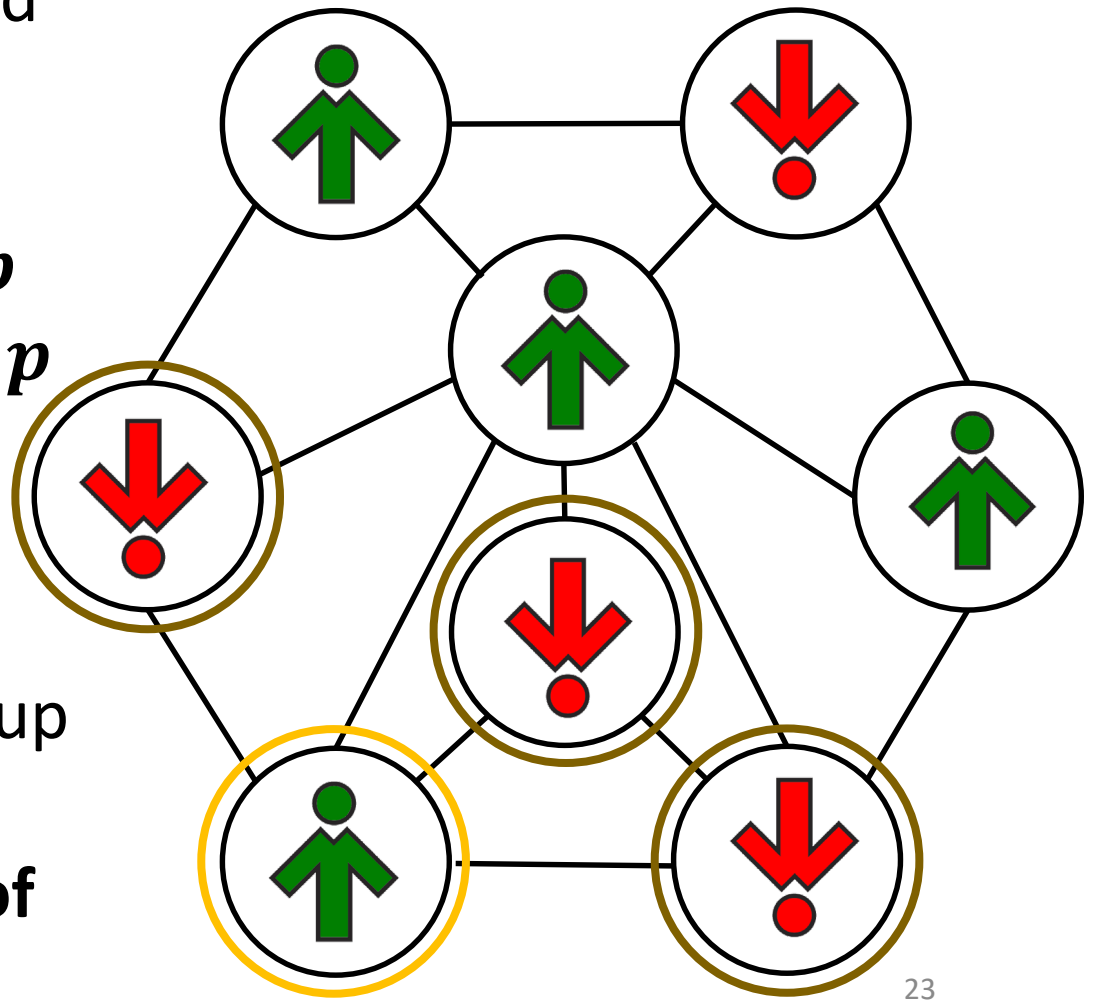


The q-voter model with independence

1. Choose one voter at random, located at site i
2. Update the opinion S_i
   i. Independence with probability $\boldsymbol{p}$
   ii. Conformity with probability $1 - \boldsymbol{p}$
   → pick randomly $\boldsymbol{q}$ neighbours without repetition,

   unanimous group - S_i adjust the group

Example 4: q=3, unanimous group of influence – adjust

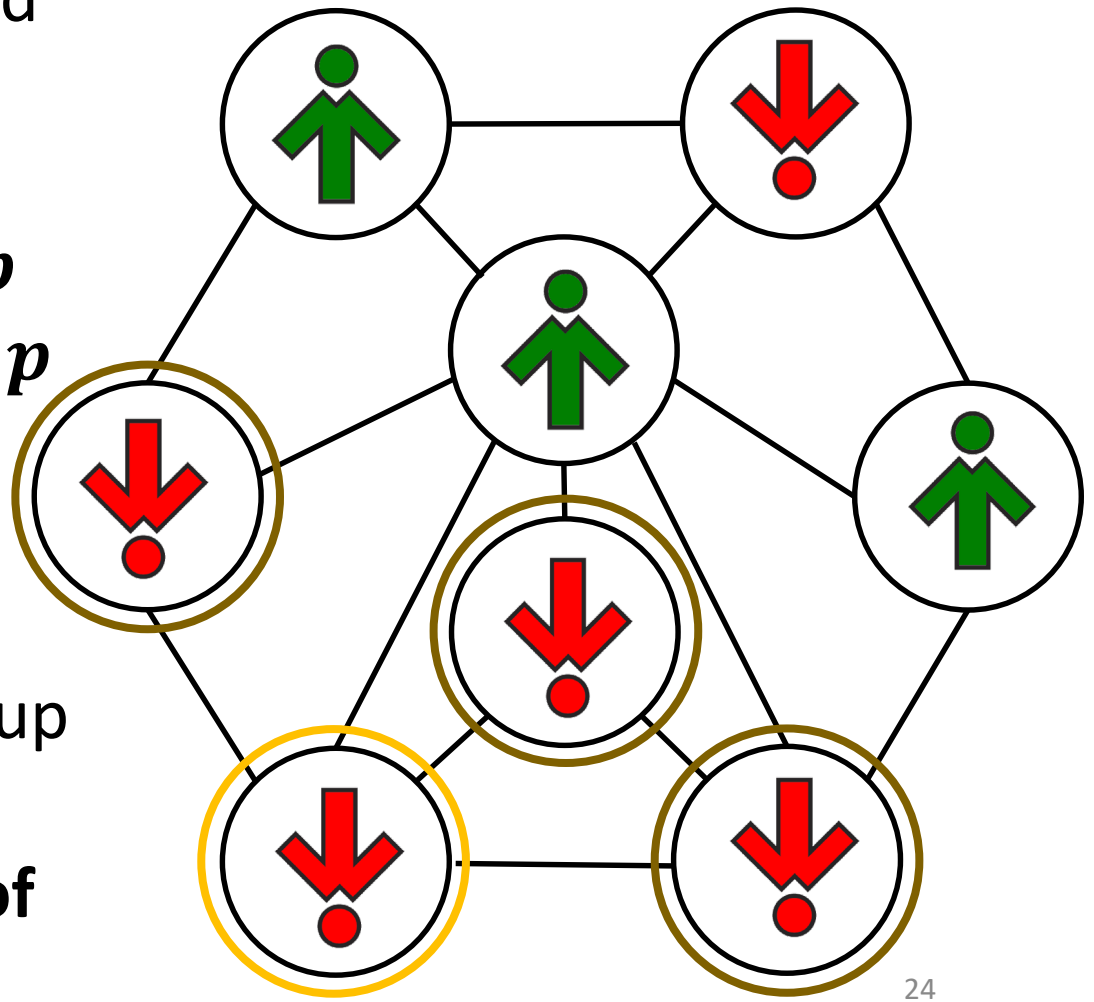


The q-voter model with independence

1. Choose one voter at random, located at site i
2. Update the opinion S_i
   i. Independence with probability $\boldsymbol{p}$
   ii. Conformity with probability $1 - \boldsymbol{p}$
   → pick randomly $\boldsymbol{q}$ neighbours without repetition,

   unanimous group - S_i adjust the group

Example 4: q=3, unanimous group of influence – adjust



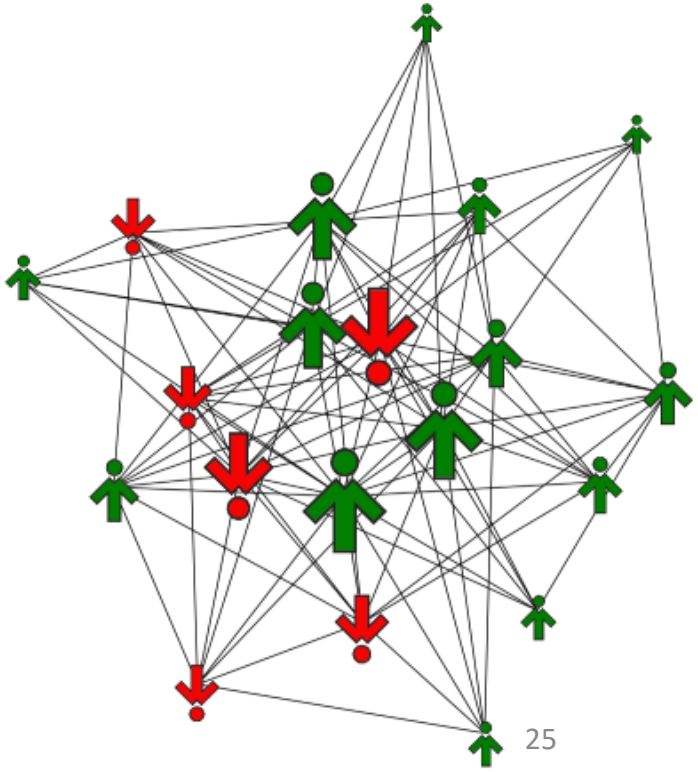
Wrocław University of Science and Technology

Variables, parameters and measurements

- N – the number of agents (constant)
- $S_i(t) = \pm 1, \ i = 1, \dots, N$ individual opinion (dynamical variable)
- t – time measured in Monte Carlo Steps (MCS)
- 1 MCS = N updates

- Model's parameters:
  - q (size of the influence group), p (independen
    f (flexibility, usually $f = 1/2$)

- What do we measure?
  - $m(t) = \frac{1}{N}\sum_i S_i(t) = \frac{N_+(t) - N_-(t)}{N}$
  - $c(t) = \frac{N_+(t)}{N}, \ m(t) = 2c(t) - 1$

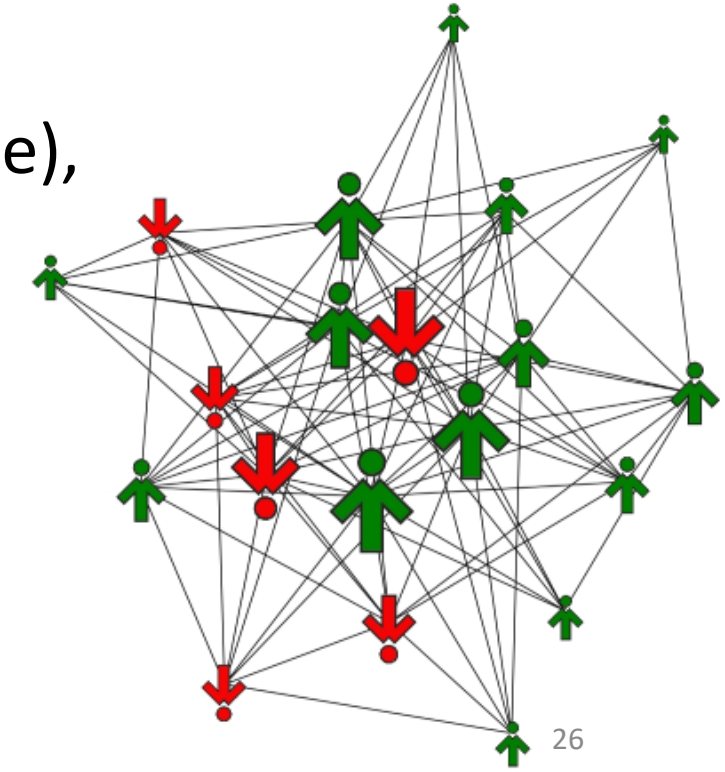


Wrocław University of Science and Technology

Variables, parameters and measurements

- N – the number of agents (constant)
- $S_i(t) = \pm 1,\ i = 1, \ldots, N$ individual opinion (dynamical variable)
- t – time measured in Monte Carlo Steps (MCS)
- 1 MCS = N updates

- Model's parameters:
  - q (size of the influence group), p (independence), f (flexibility, usually $f = 1/2$)
- What do we measure?
  - $m(t) = \frac{1}{N}\sum_i S_i(t) = \frac{N_+(t) - N_-(t)}{N}$
  - $c(t) = \frac{N_+(t)}{N},\ m(t) = 2c(t) - 1$



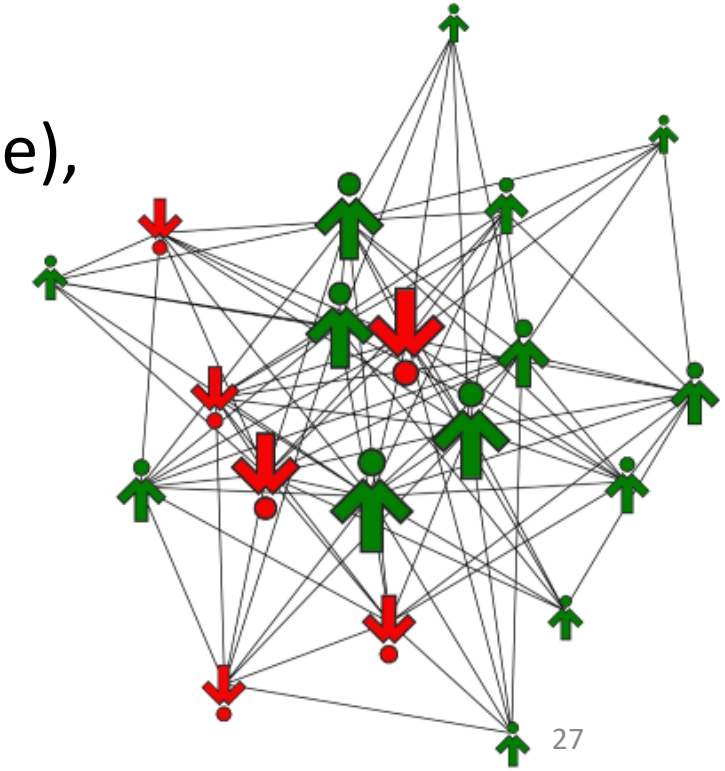
Wrocław University of Science and Technology

Variables, parameters and measurements

- N – the number of agents (constant)
- $S_i(t) = \pm 1,\ i = 1, \ldots, N$ individual opinion (dynamical variable)
- t – time measured in Monte Carlo Steps (MCS)
- 1 MCS = N updates

- Model's parameters:
  - q (size of the influence group), p (independence), f (flexibility, usually $f = 1/2$)

- What do we measure?
  - $m(t) = \frac{1}{N}\sum_i S_i(t) = \frac{N_+(t) - N_-(t)}{N}$
  - $c(t) = \frac{N_+(t)}{N},\ \ m(t) = 2c(t) - 1$



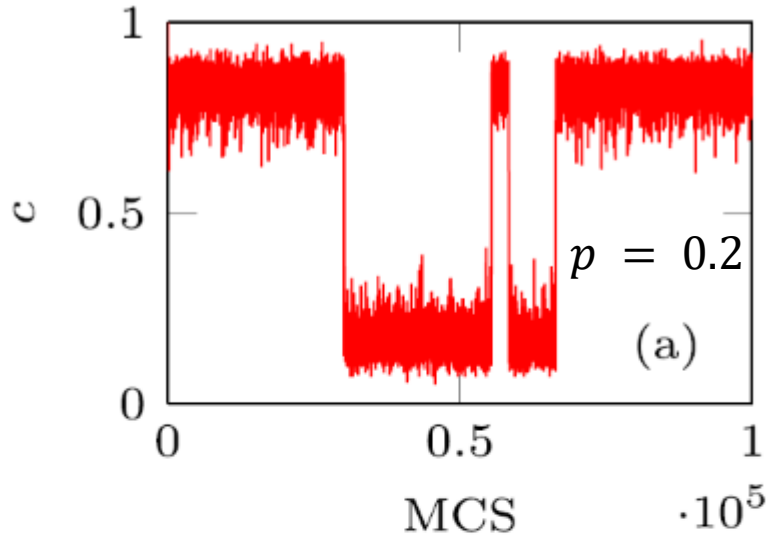
Wrocław University of Science and Technology

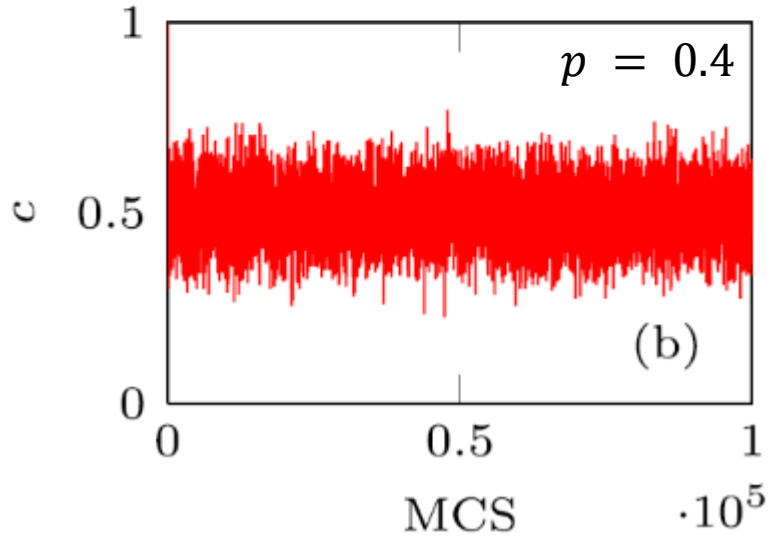
Sample trajectories

PHYSICAL REVIEW E **95**, 012307 (2017)

Pair approximation for the q-voter model with independence on complex networks

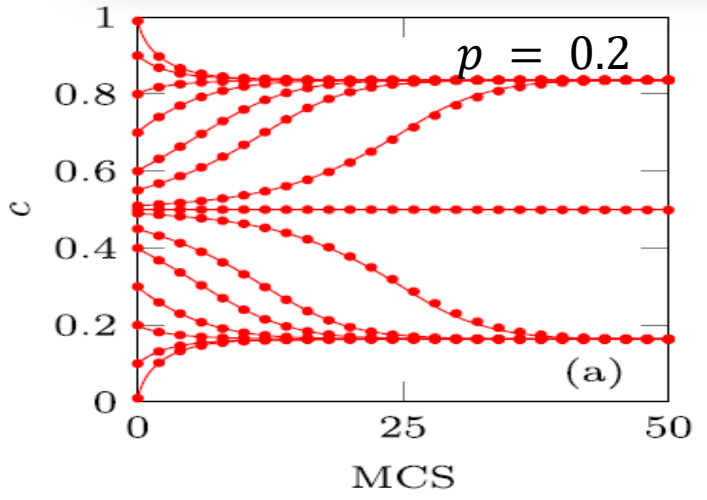
Arkadiusz Jędrzejewski*
Department of Theoretical Physics, Wrocław University of Science and Technology, Wrocław, Poland
(Received 26 July 2016; published 10 January 2017)

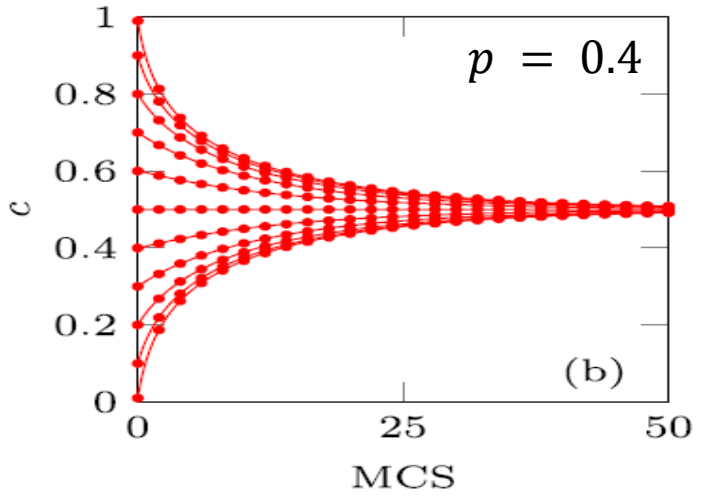




Small system

Example: $q = 2, N = 200, c(0) = 1$



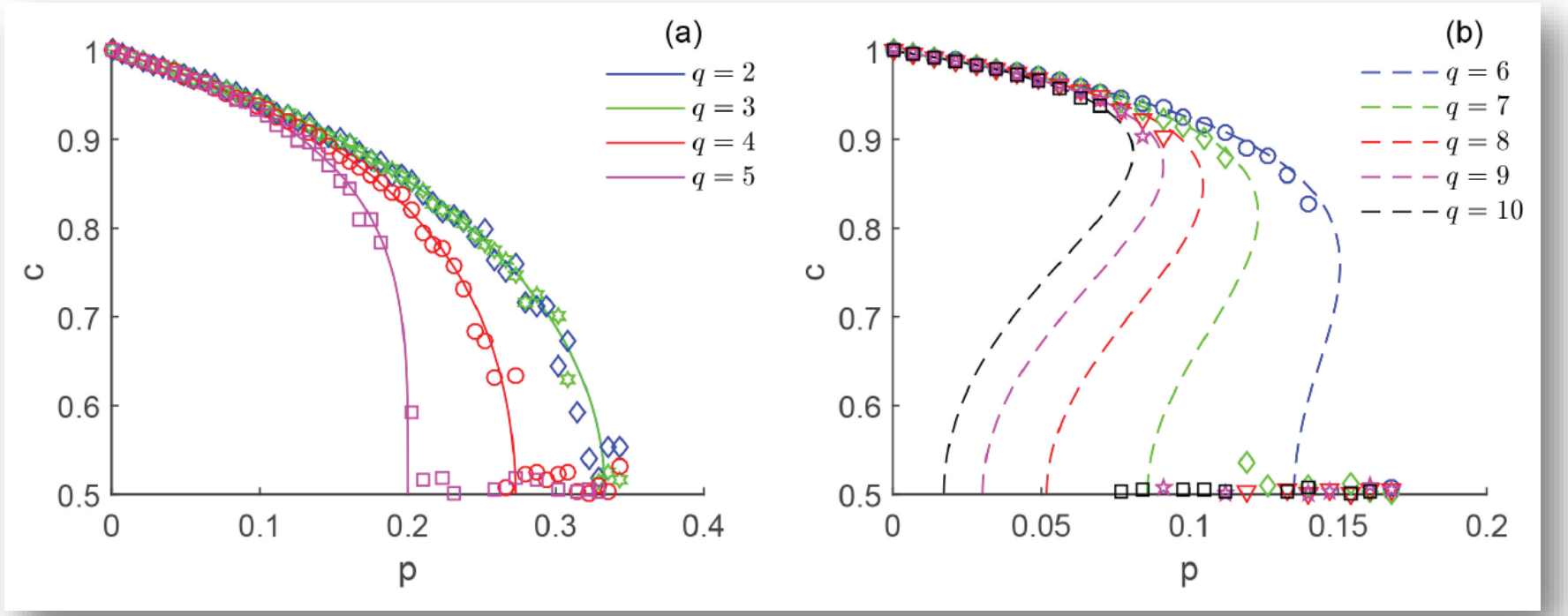


Large system

Example: $q = 2, N = 10^5, c(0) = c_0 \in (0,1)$

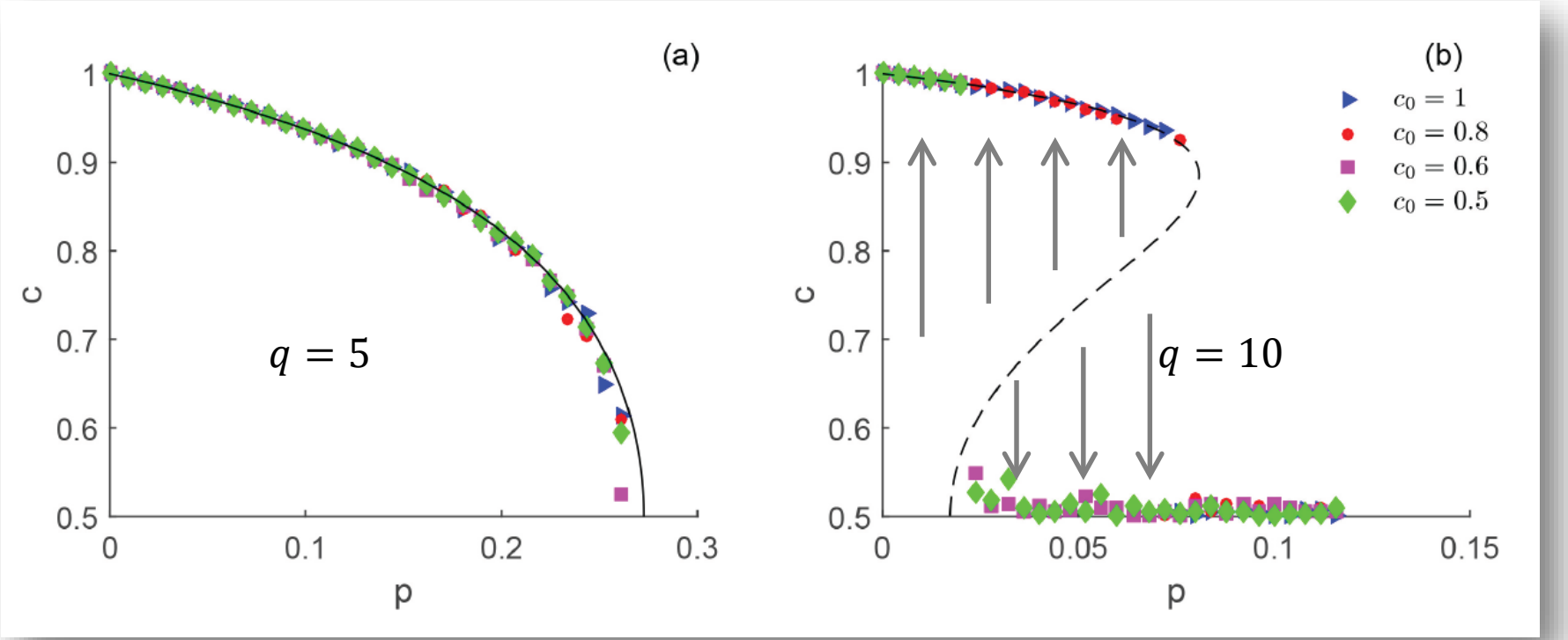
Wrocław University of Science and Technology

Stationary states – „small simulations”



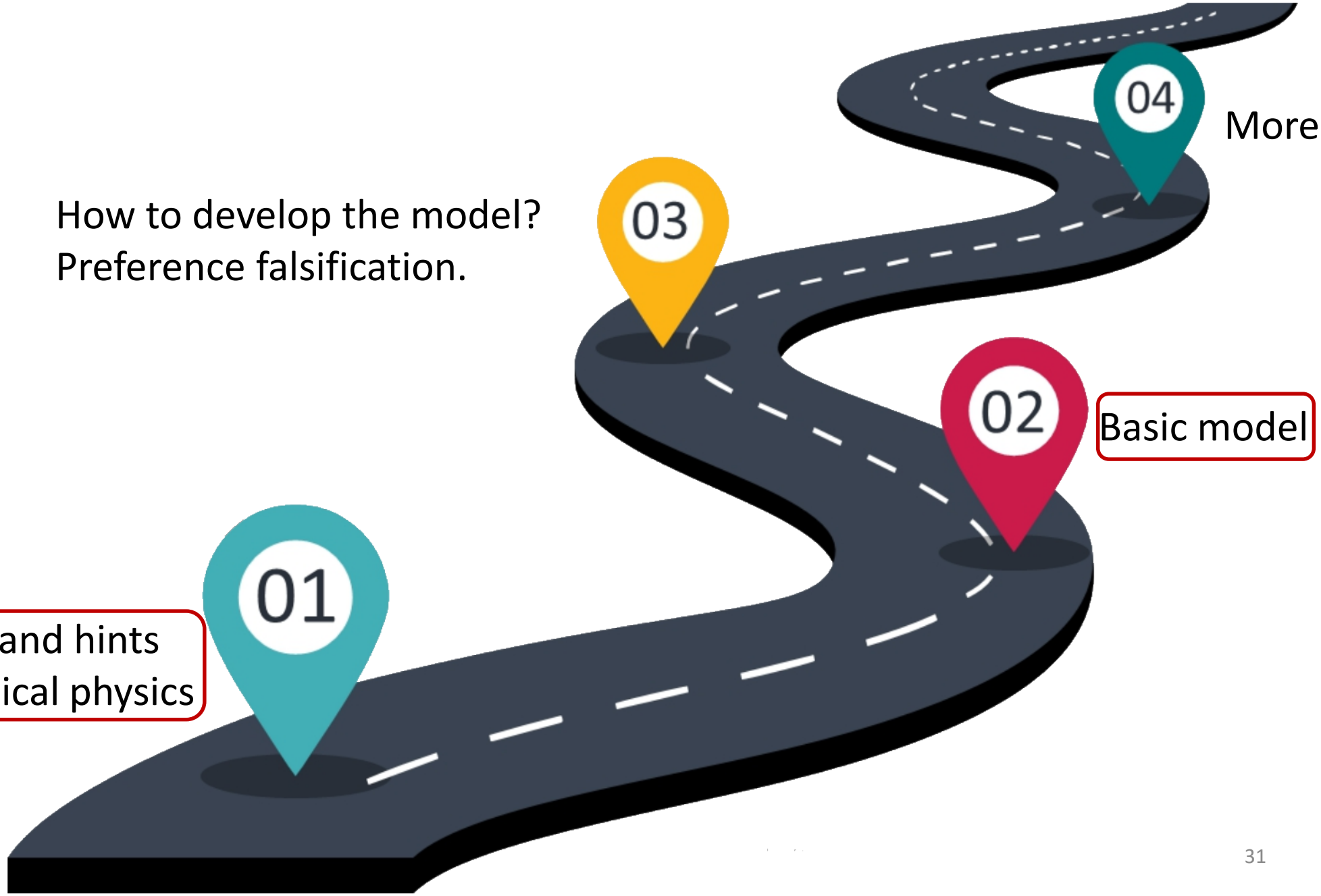
- Simulations on the complete graph, $N = 1000$
- Measurement after $1000\ MCS$
- Average over the small number of samples
- Simulations by Urszula Grochocińska (3rd year student)

How the hysteresis can be seen?



- Simulations on the complete graph, $N = 1000$
- Measurement after $1000\ MCS$
- Average over the small number of samples
- Simulations by Urszula Grochocińska (3rd year student)

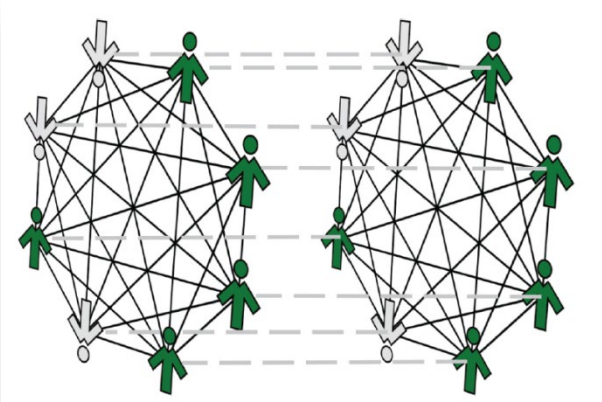
Wrocław University of Science and Technology



Wrocław University of Science and Technology

The answer within agent-based models

- Expected: inertia (memory) on the individual level supports social hysteresis
- Surprise: memoryless agents can also „produce” hysteresis (memory of the system)
  - The size of the group of influence
  - The number of layers in the social network
  - Hidden preferences



Each node possesses a counterpart node in the second level

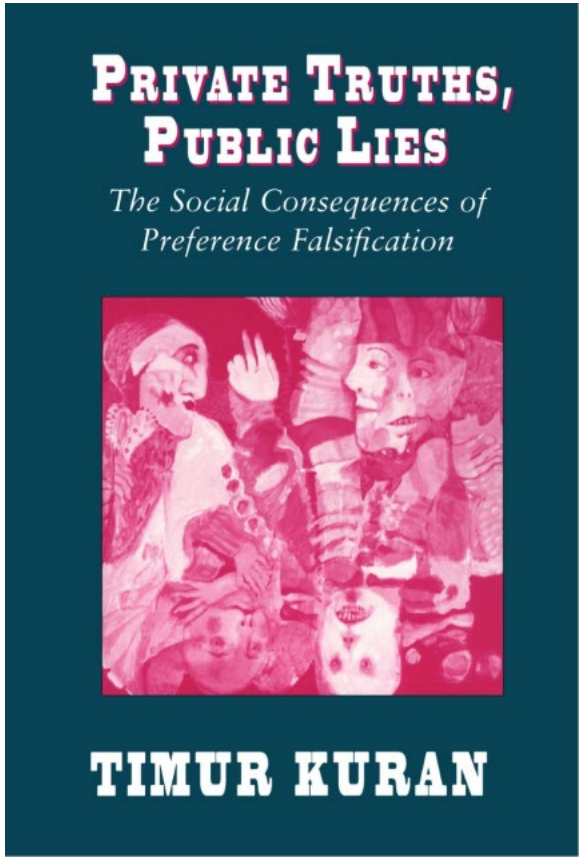
PHYSICAL REVIEW E **92**, 052812 (2015)

Phase transitions in the q-voter model with noise on a duplex clique

Anna Chmiel and Katarzyna Sznajd-Weron
Department of Theoretical Physics, Wroclaw University of Technology, Wroclaw, Poland
(Received 11 March 2015; revised manuscript received 20 July 2015; published 24 November 2015)

Preference falsification

- The act of communicating a preference that differs from one's true preference
- Main reason: believe the expressed preference is more acceptable socially
- Huge social and political consequences, ex: unanticipated revolutions
- Opinion on two levels: public and private
- Not like in the CODA model:
  - André C.R. Martins, Continuous opinions and discrete actions in opinion dynamics problems, IJMPC 19 (2008)

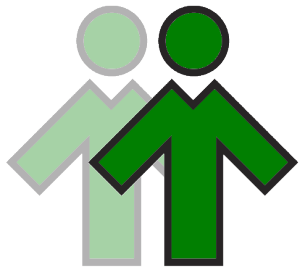
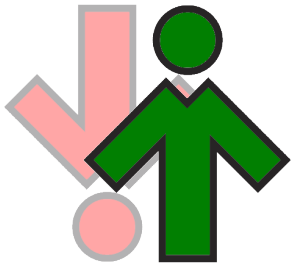


Wrocław University of Science and Technology

A new work of art in your boss's home

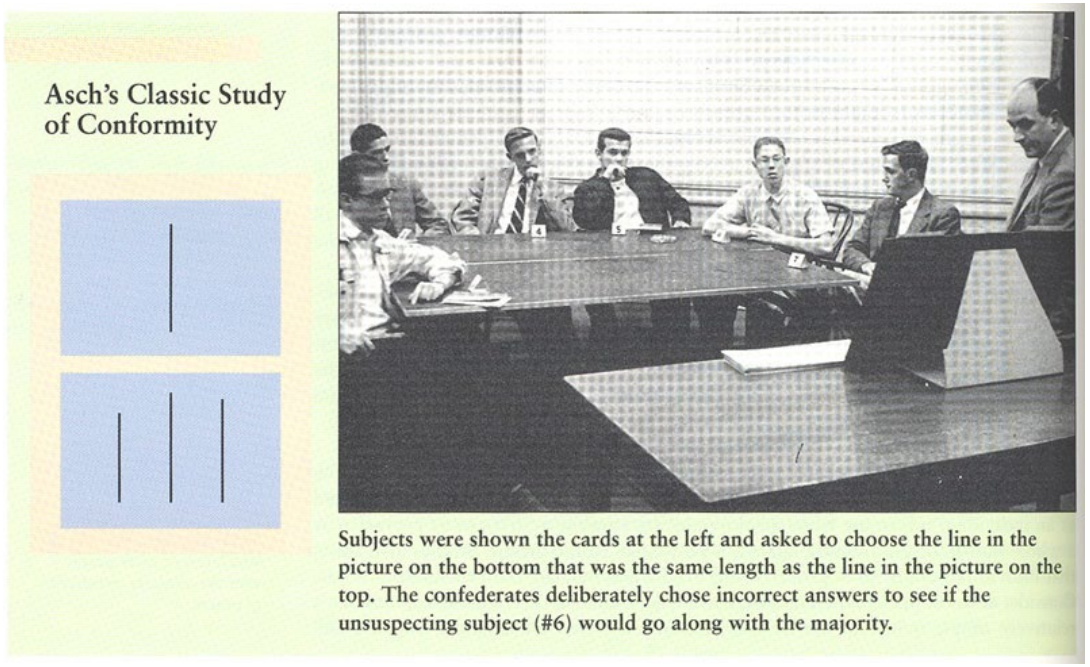
The model

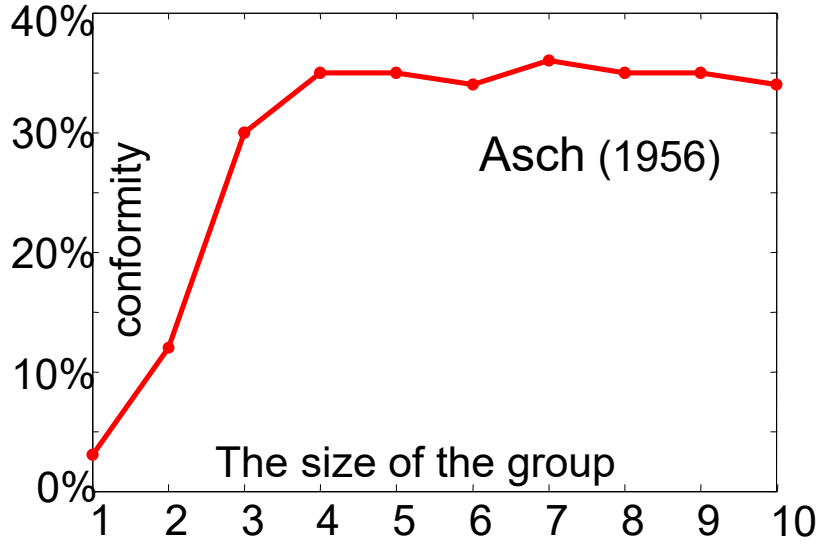
- N agents
  - Public opinion $S_i(t) = \pm 1$
  - Private opinion $\sigma_i(t) = \pm 1$
- Only $S_i(t)$ is seen by others
- Two types of social responses
  - Independence with p
  - Conformity with $1 - p$
- Conformity
  - compliance (unanimous q-panel)
  - disinhibitory contagion

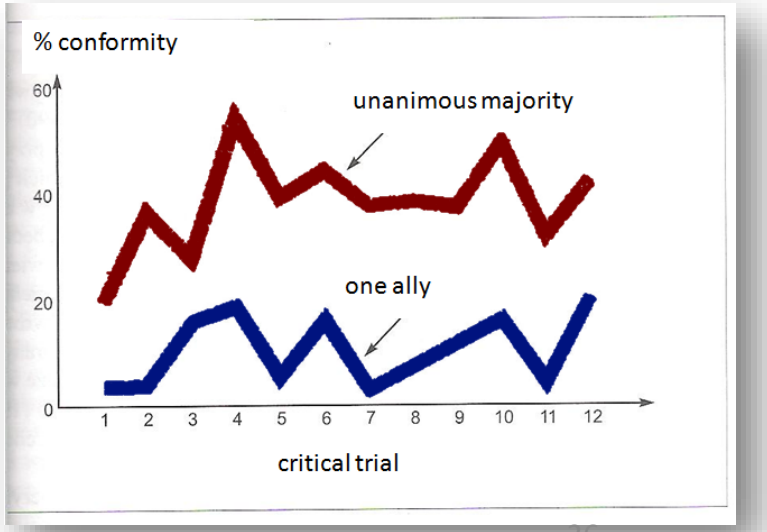
PUBLIC (EXTERNAL) \ PRIVATE (INTERNAL)	$\sigma_i(t) = +1$	$\sigma_i(t) = -1$
$S_i(t) = +1$		
$S_i(t) = -1$		

Two types of conformity

- Compliance: public conformity without private acceptance
  - Asch experiment
  - Increases with the size of the group
  - Unanimity is crucial







Wrocław University of Science and Technology

Two types of conformity

- Disinhibitory contagion
  - Appears in the case of the internal intra-psychic conflict
  - Single person can influence

PLOS ONE

RESEARCH ARTICLE

Think then act or act then think?

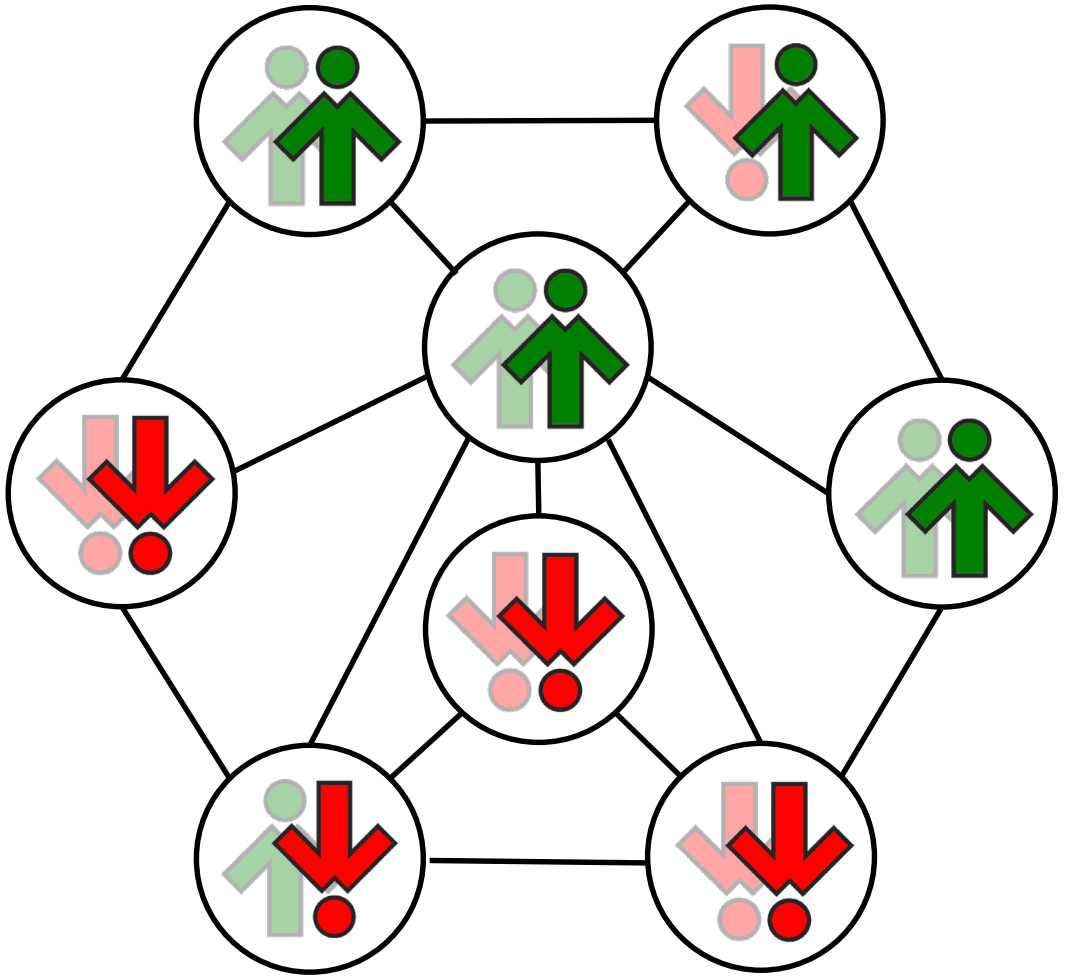
Arkadiusz Jędrzejewski[1], Grzegorz Marcjasz[2], Paul R. Nail[3], Katarzyna Sznajd-Weron[1]*

1 Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, Wrocław, Poland, 2 Faculty of Pure and Applied Mathematics, Wrocław University of Science and Technology, Wrocław, Poland, 3 Faculty of Psychology and Counseling, University of Central Arkansas, Conway, Arkansas, United States of America

Wrocław
University
of Science
and Technology

Act then Think (AT) model

- choose one voter at random, located at site i

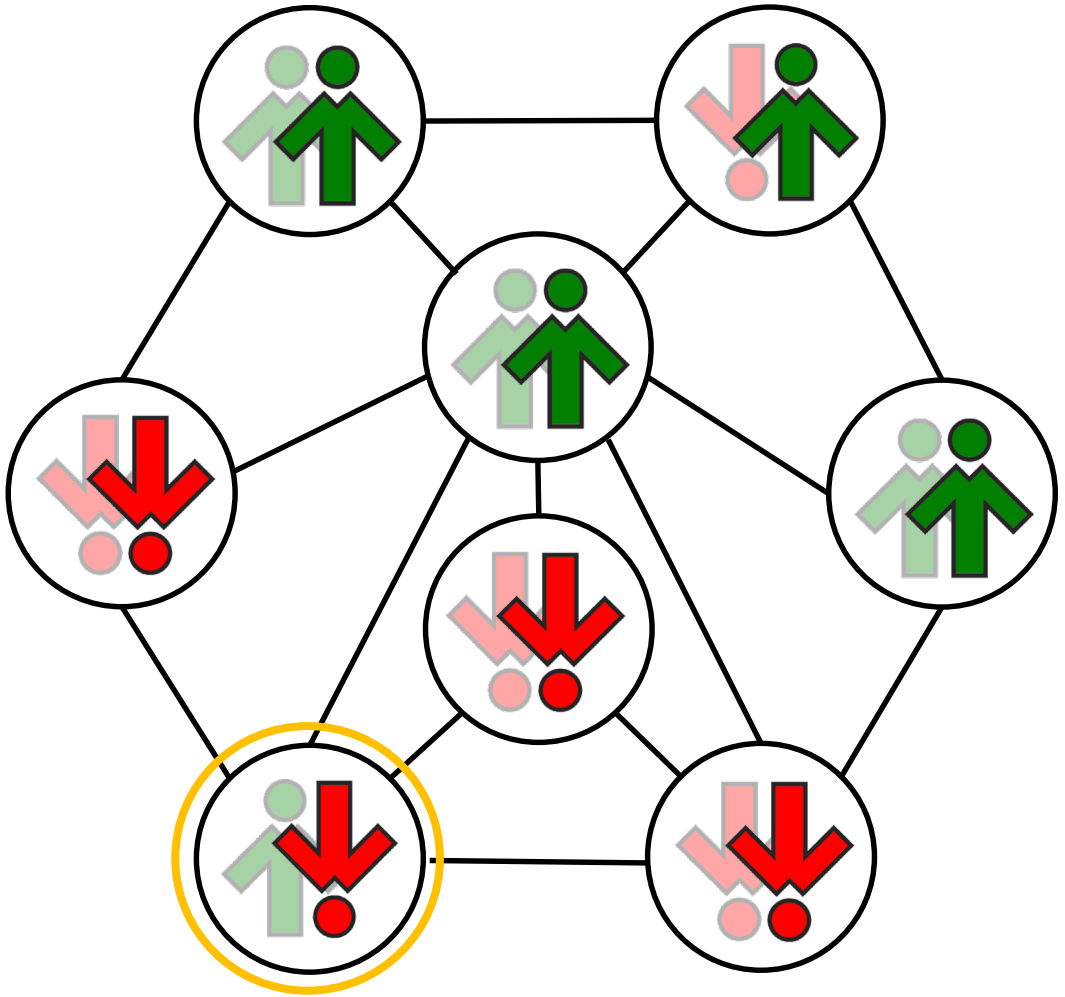


Wrocław
University
of Science
and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
  - **Independence with prob p**: replace public opinion by the private one

$$S_i \to \sigma_i$$

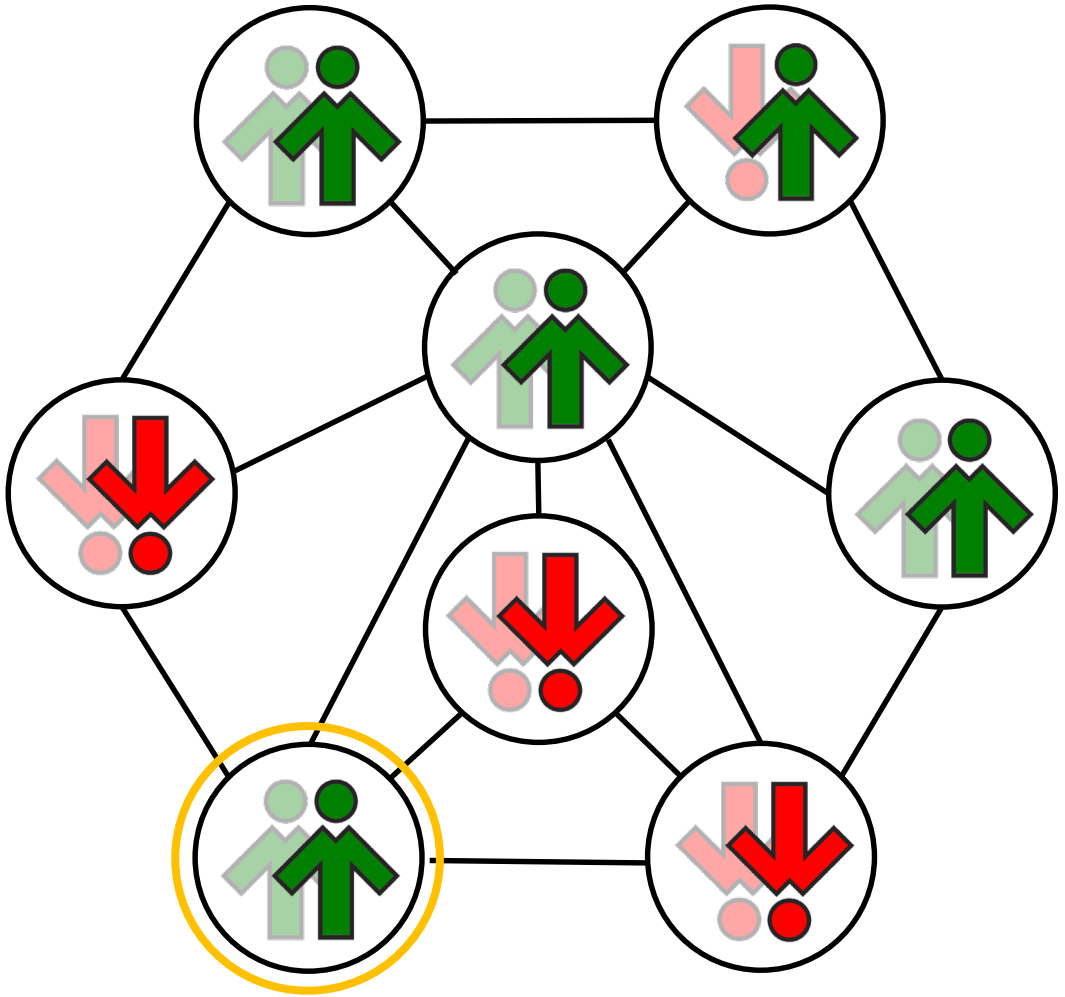


Wrocław
University
of Science
and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
  - **Independence with prob p**: replace public opinion by the private one

$$S_i \to \sigma_i$$



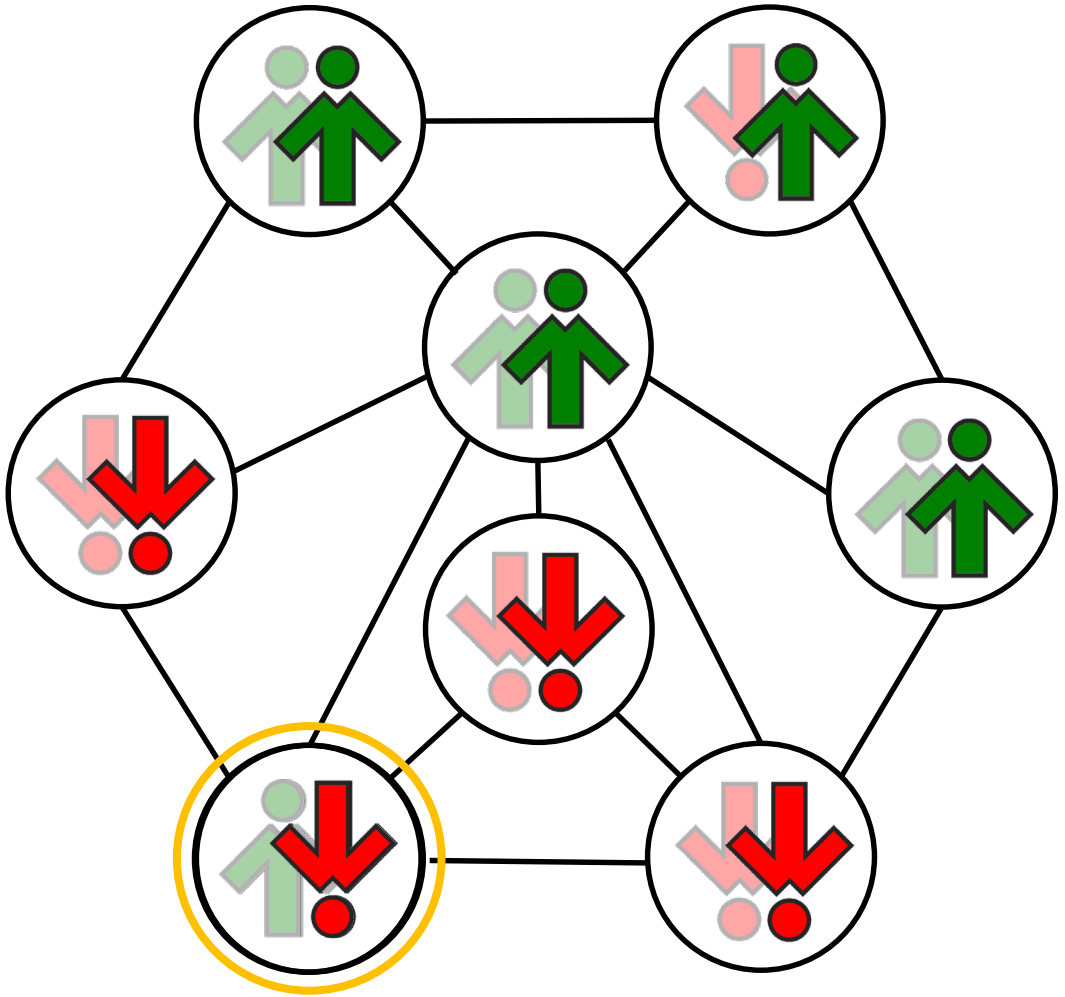
Wrocław
University
of Science
and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
  - **Independence with prob p**: replace public opinion by the private one

$$S_i \rightarrow \sigma_i$$

  - **Conformity with prob $1-p$**:
    1) pick randomly q neighbours without repetition



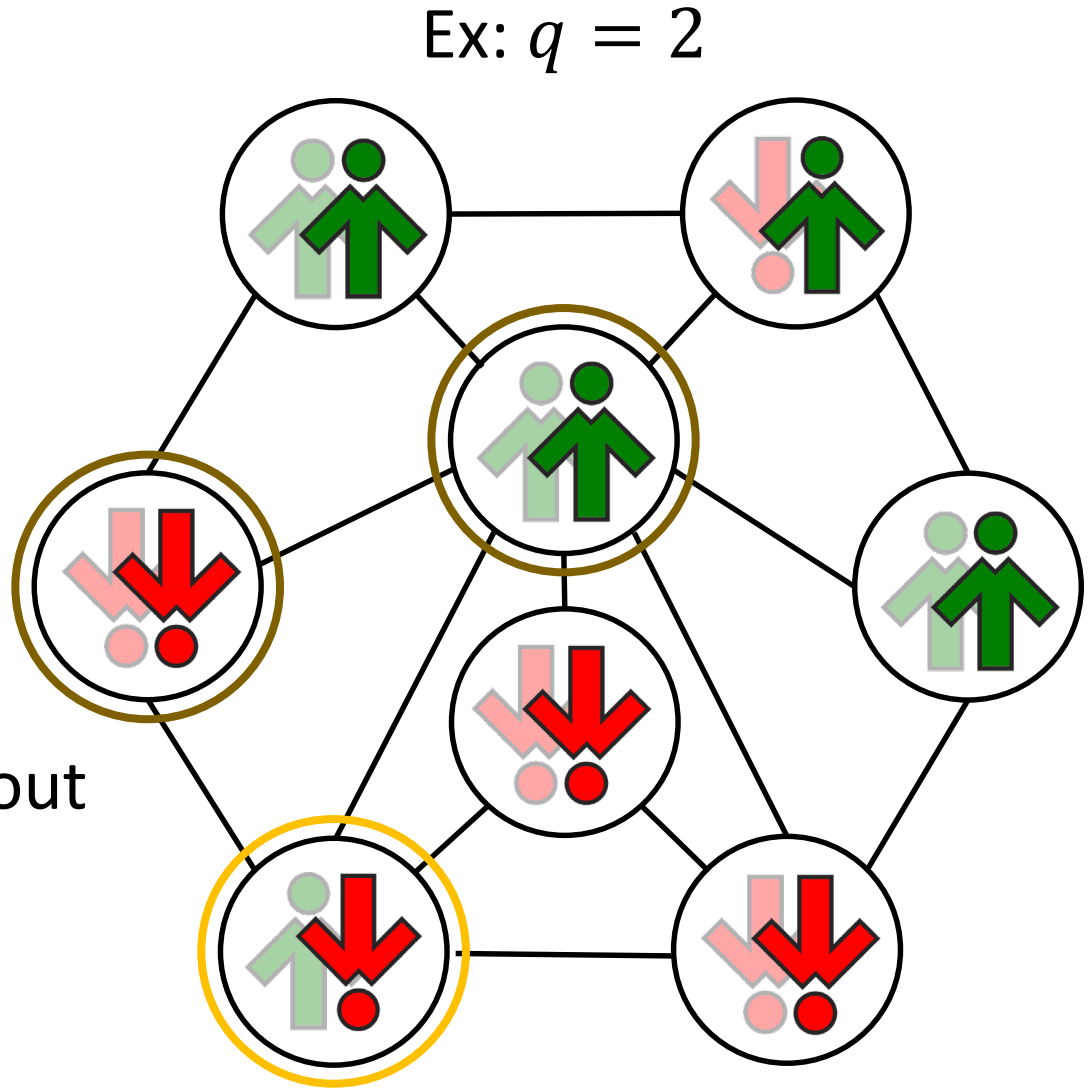
Wrocław University of Science and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
  - **Independence with prob p**: replace public opinion by the private one

$$S_i \to \sigma_i$$

  - **Conformity with prob $1-p$**:
    1) pick randomly q neighbours without repetition
    2) $S_i = \sigma_i$? NO: disinhibitory contagion $S_i \to \sigma_i$ if one $S_{ix} = \sigma_i$



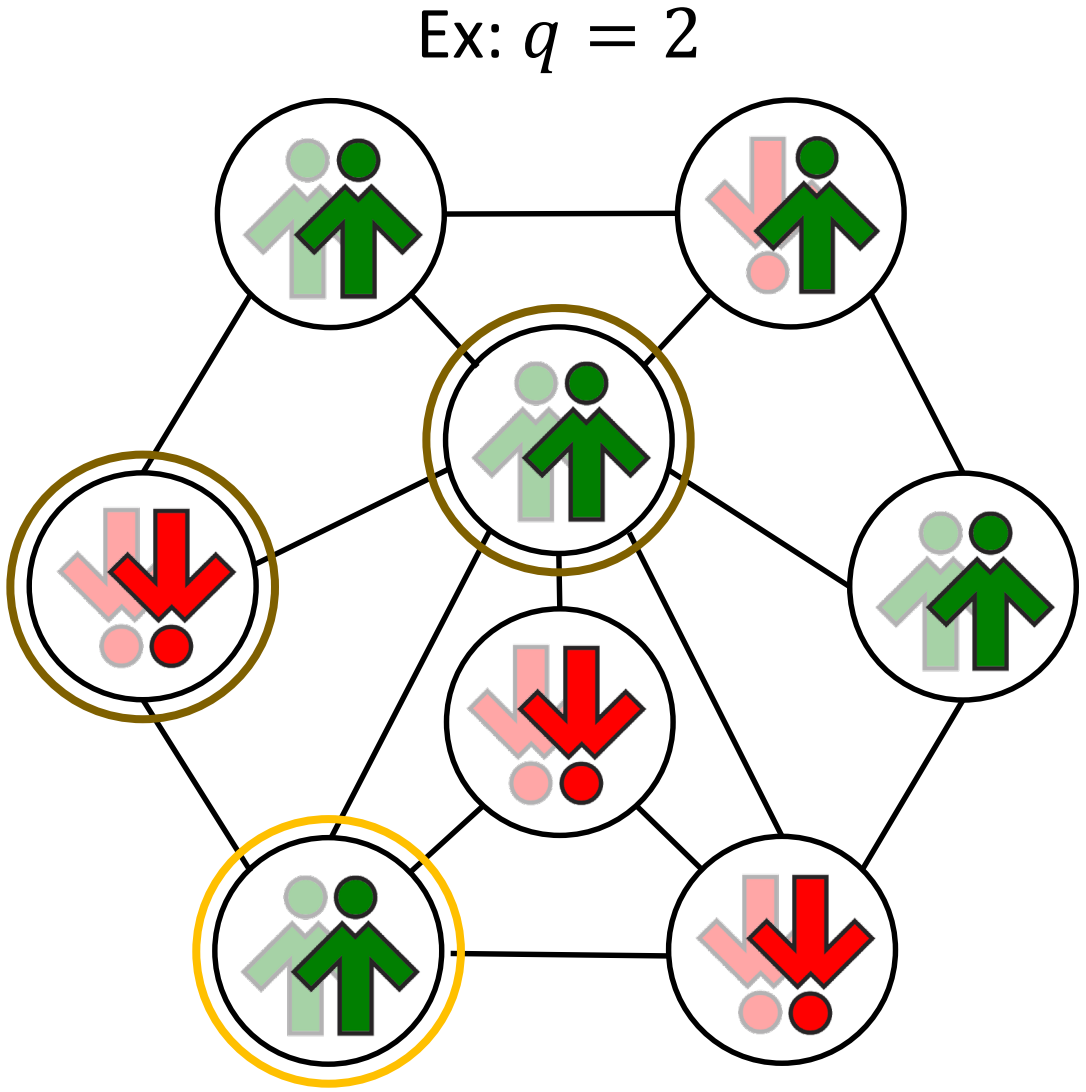
Wrocław University of Science and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
  - **Independence with prob p**: replace public opinion by the private one

$$S_i \to \sigma_i$$

  - **Conformity with prob $1-p$**:
    1) pick randomly q neighbours without repetition
    2) $S_i = \sigma_i$? NO: disinhibitory contagion $S_i \to \sigma_i$ if one $S_{ix} = \sigma_i$



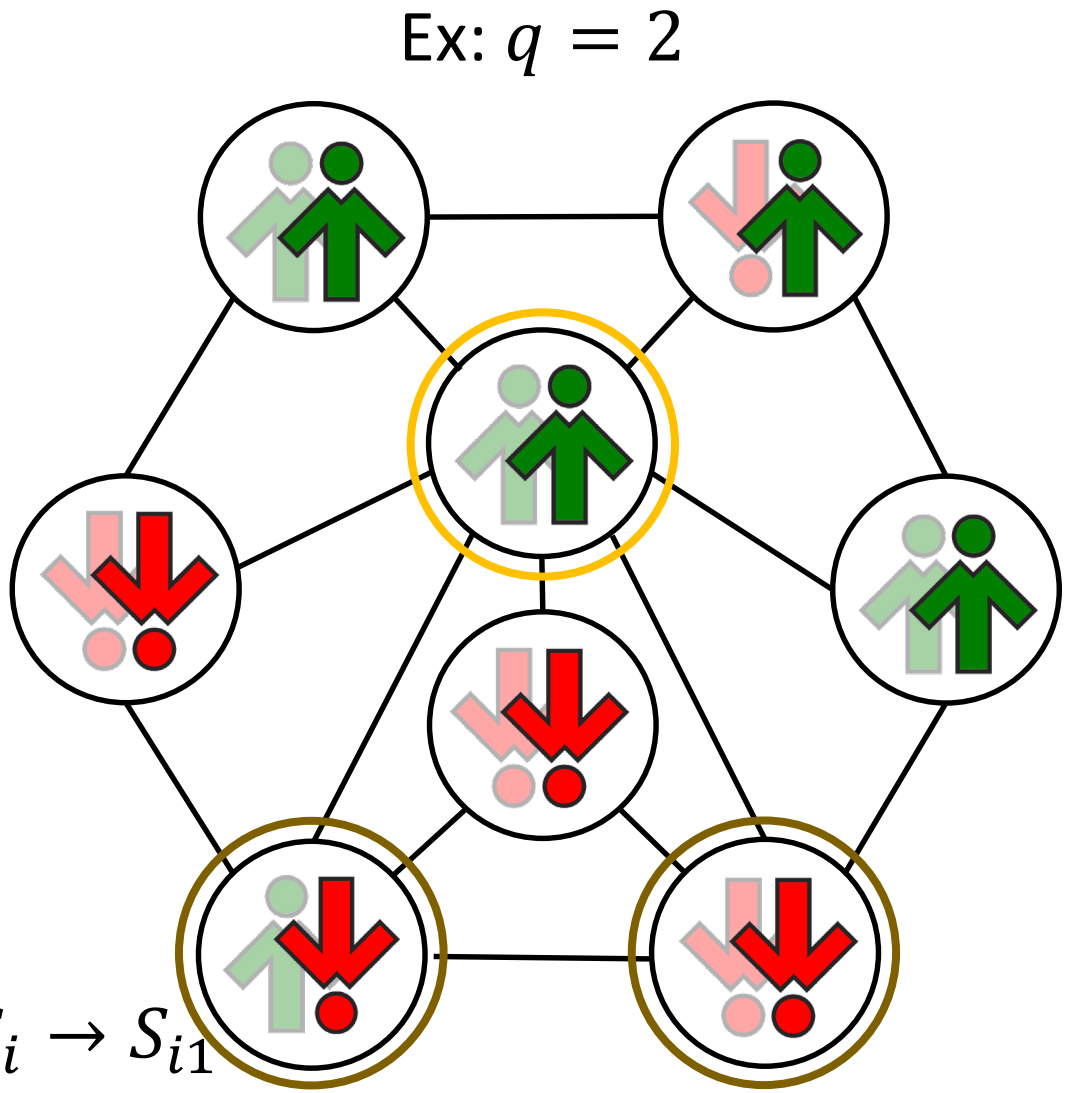
Wrocław University of Science and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
  - **Independence with prob p**: replace public opinion by the private one

$$S_i \to \sigma_i$$

  - **Conformity with prob $1-p$**:
    1) pick randomly q neighbours without repetition
    2) $S_i = \sigma_i$? YES
    3) unanimous: $S_{i1} = \ldots = S_{iq}$? YES: $S_i \to S_{i1}$



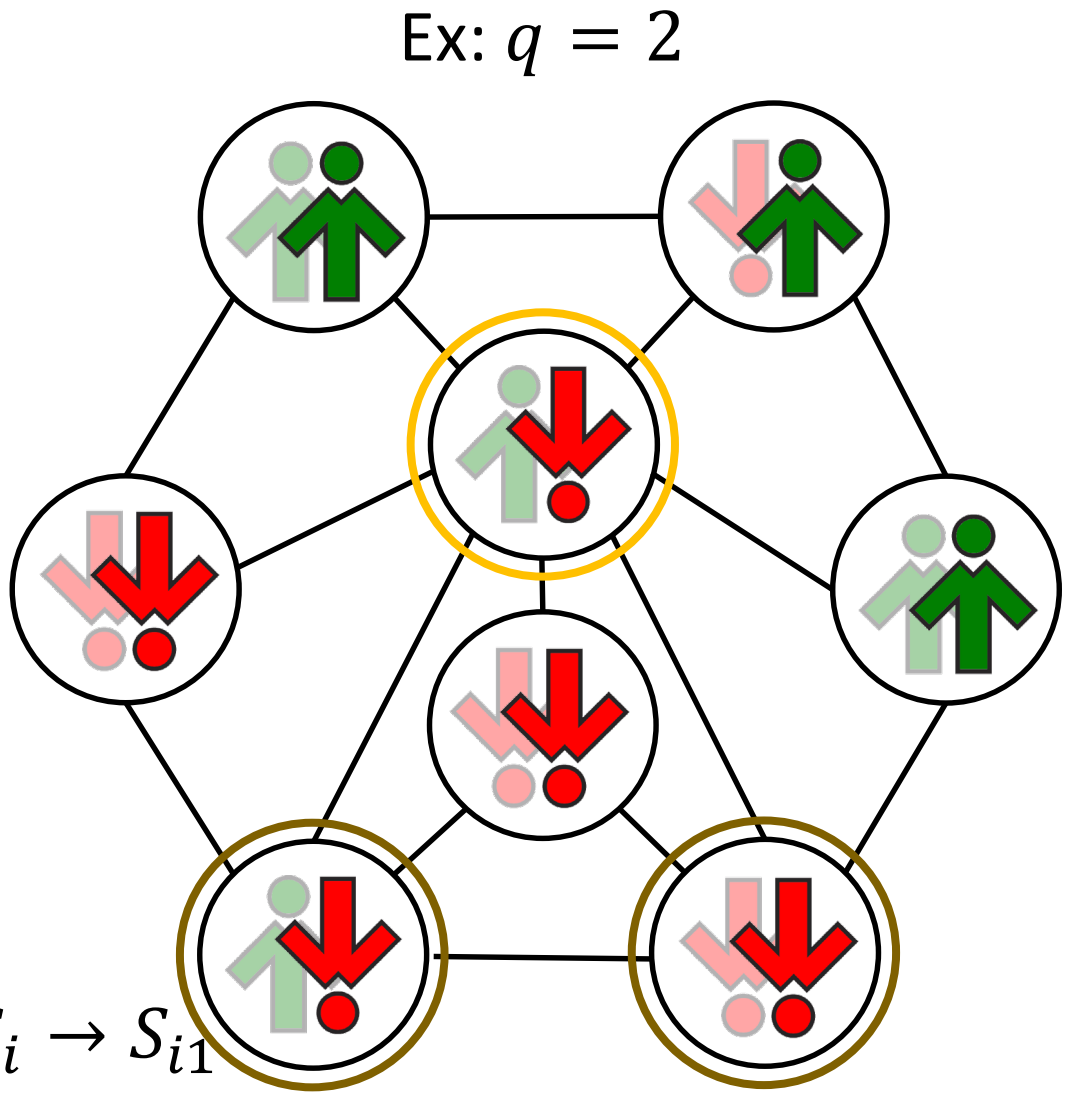
Wrocław University of Science and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
  - **Independence with prob p**: replace public opinion by the private one

$$S_i \to \sigma_i$$

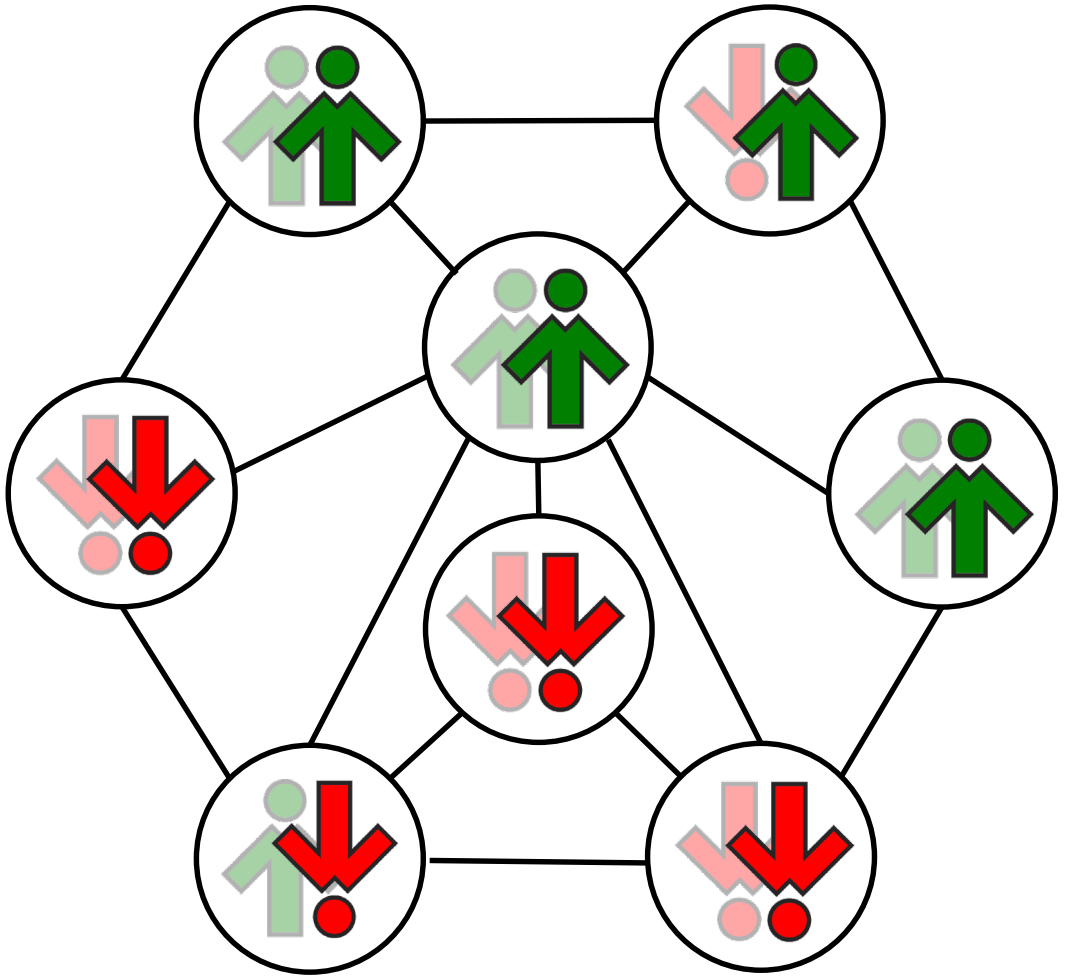
  - **Conformity with prob $1-p$**:
    1) pick randomly q neighbours without repetition
    2) $S_i = \sigma_i$? YES
    3) unanimous: $S_{i1} = \ldots = S_{iq}$? YES: $S_i \to S_{i1}$



Wrocław University of Science and Technology

Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
- Think: update the **private** opinion σ_i

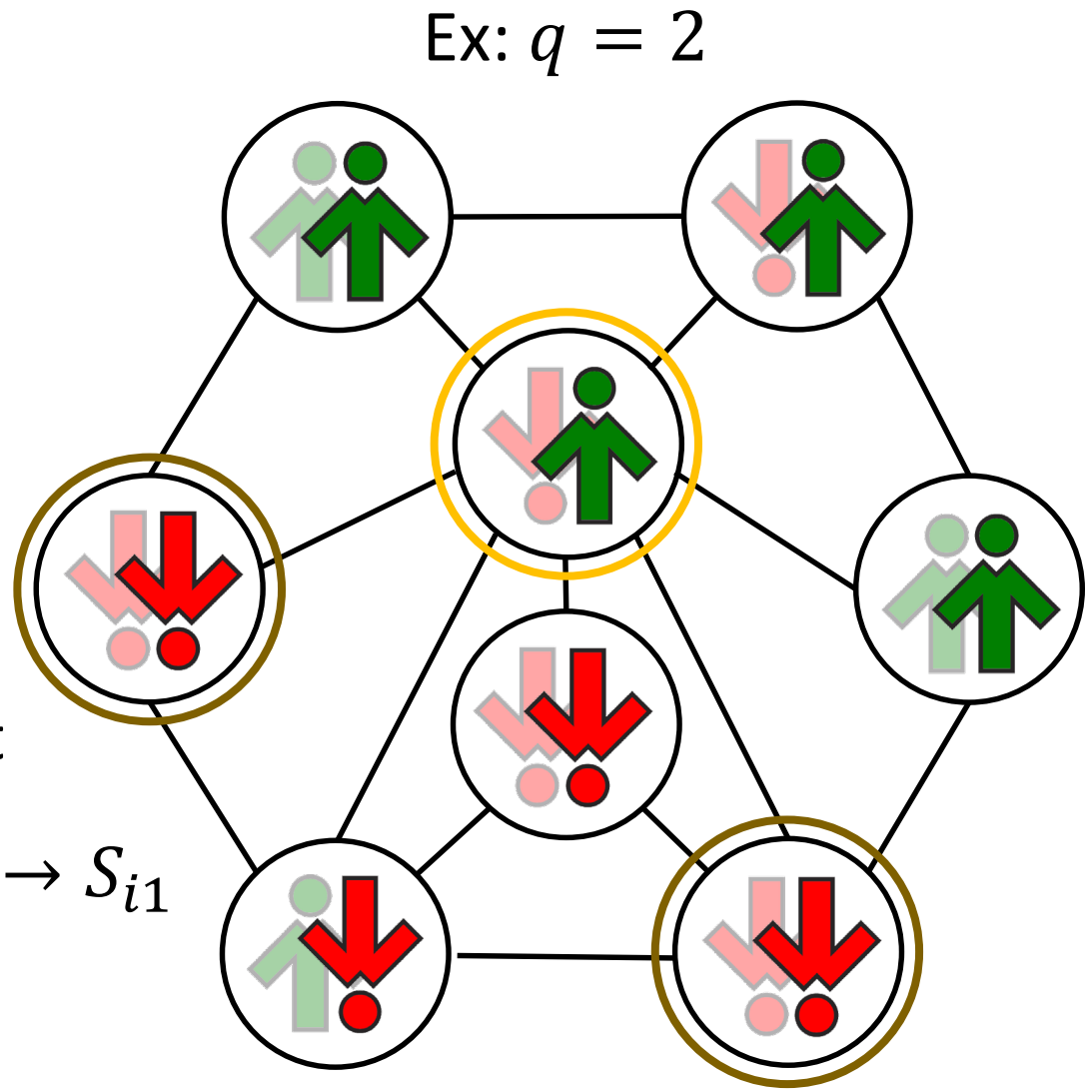


Act then Think (AT) model

- choose one voter at random, located at site i
- Act: update the **public** opinion S_i
- Think: update the **private** opinion σ_i
  - **Independence with prob p**

$$\sigma_i \xrightarrow{1/2} -\sigma_i$$

  - **Conformity with prob $1-p$**:
    1) pick randomly q neighbours without repetition
    2) unanimous: $S_{i1} = \ldots = S_{iq}$? YES: $\sigma_i \to S_{i1}$



Wrocław University of Science and Technology

Why „Act then Think (AT) model”?

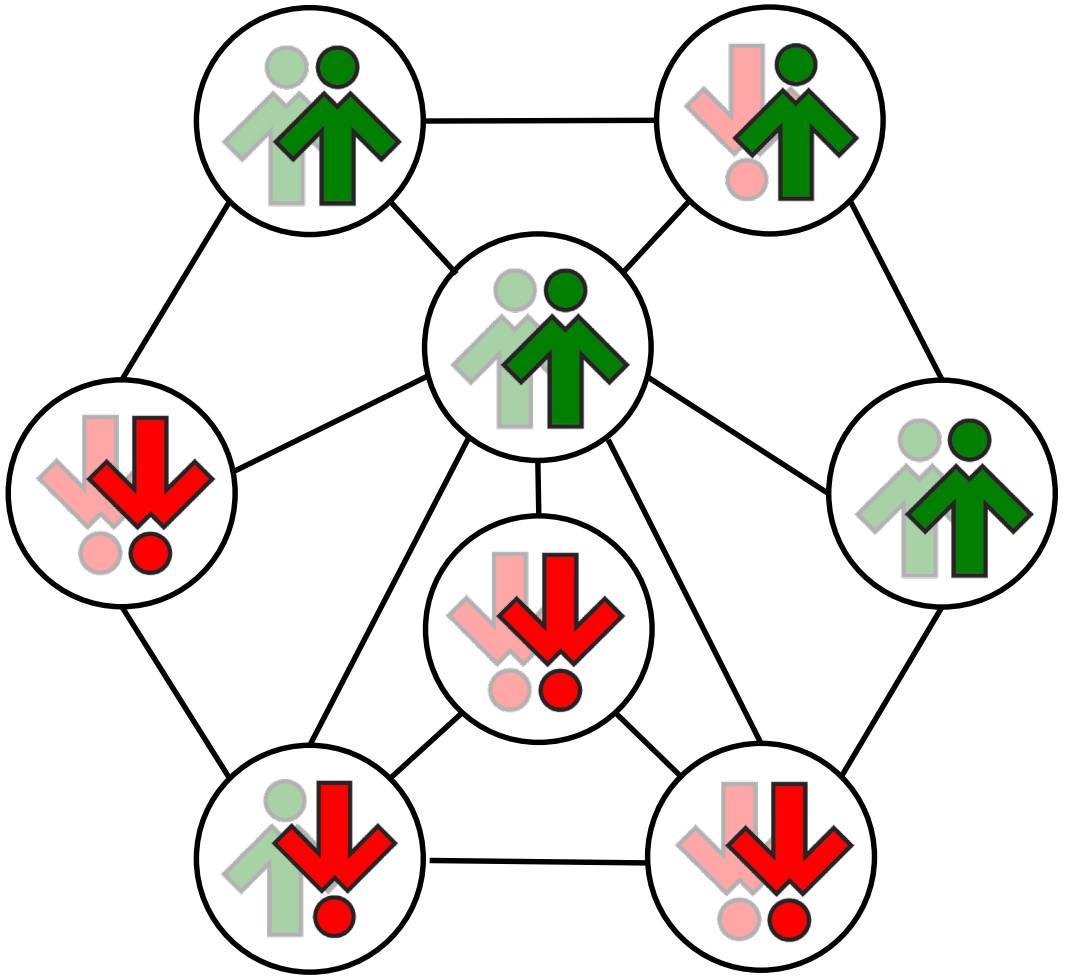
- *“If social psychology has taught us anything during the last 25 years, it is that we are likely not only to think ourselves into a way of acting but also to act ourselves into a way of thinking.”*
  [David G. Myers, Social Psychology 10th Ed. page 131]

- How to update opinions?
- What should be updated first?
- Does it matter for ABM?

Wrocław
University
of Science
and Technology

Two versions of the model: AT vs. TA

- **A**ct then **T**hink (AT) model
  - choose one voter at random, located at site i
  - Act: update the **public** opinion S_i
  - Think: update the **private** opinion σ_i
- **T**hink then **A**ct (TA) model
  - choose one voter at random, located at site i
  - Think: update the **private** opinion σ_i
  - Act: update the **public** opinion S_i

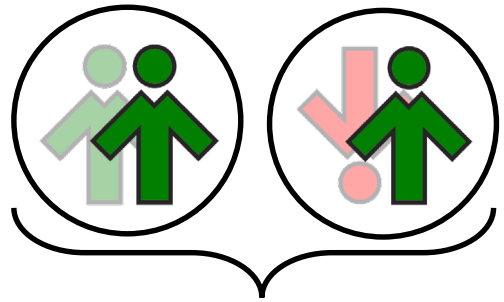


Wrocław University of Science and Technology

What do we measure?

- The fraction of individuals with the positive public opinion:

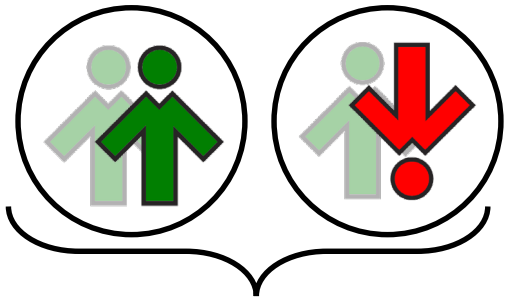
$$c_S(t) = \frac{N_{S=1}(t)}{N}$$



$S_i(t) = 1$

- The fraction of individuals with the positive private opinion:

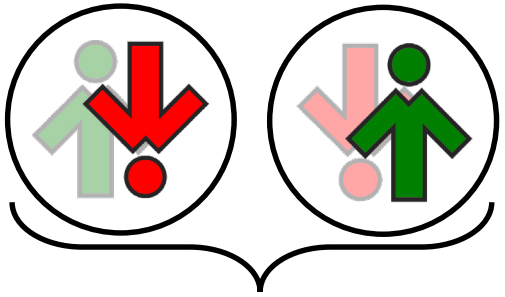
$$c_\sigma(t) = \frac{N_{\sigma=1}(t)}{N}$$



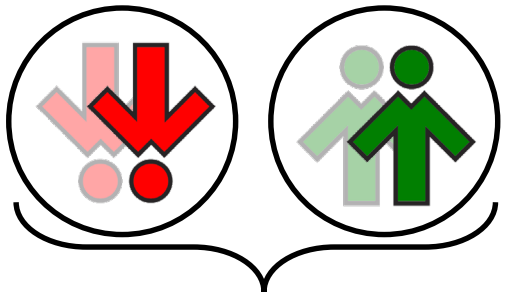
$\sigma_i(t) = 1$

- The level of dissonance = the fraction of individuals that have different public and private opinions:

$$d(t) = \frac{1}{2N}\sum_{i=1}^{N}(1 - S_i(t)\sigma_i(t))$$

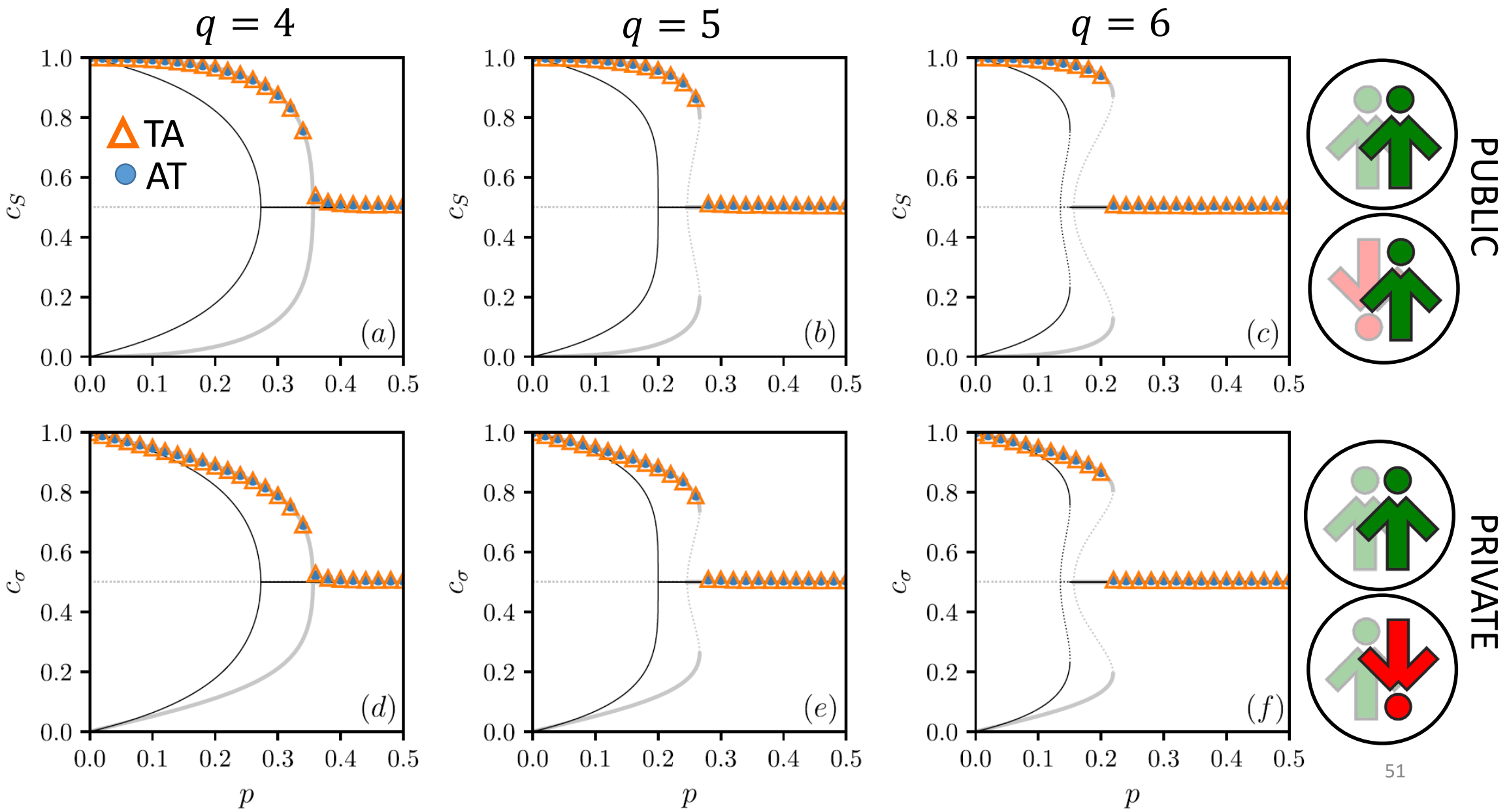


$S_i(t)\sigma_i(t) = -1$



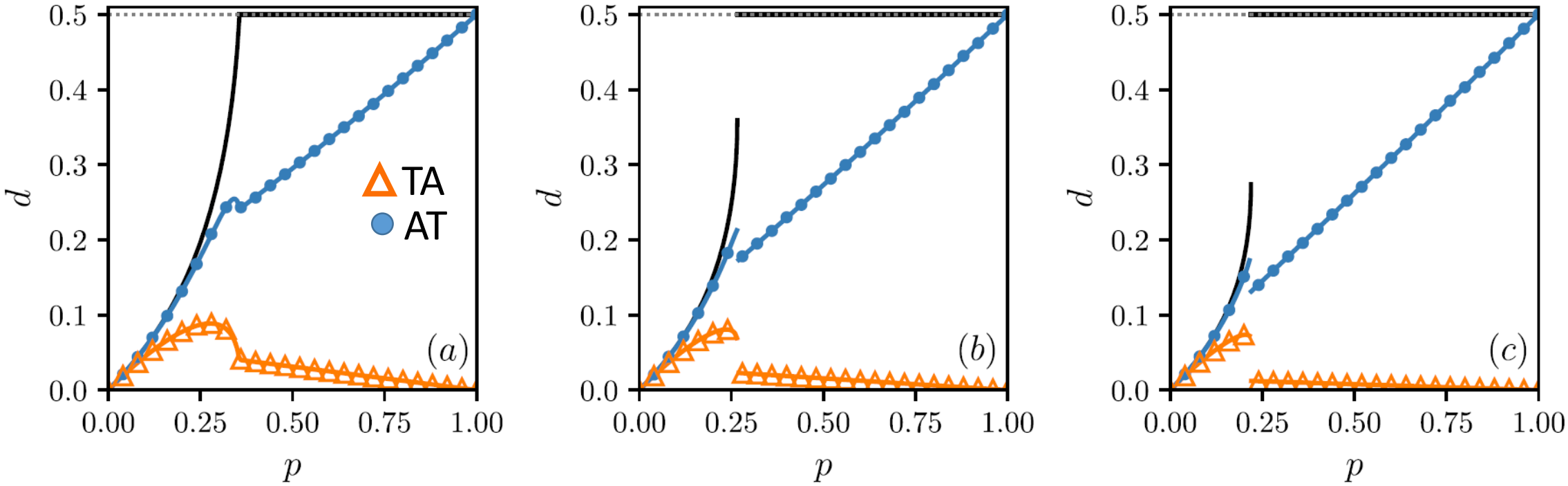
$S_i(t)\sigma_i(t) = 1$

Stationary concentrations of positive opinions

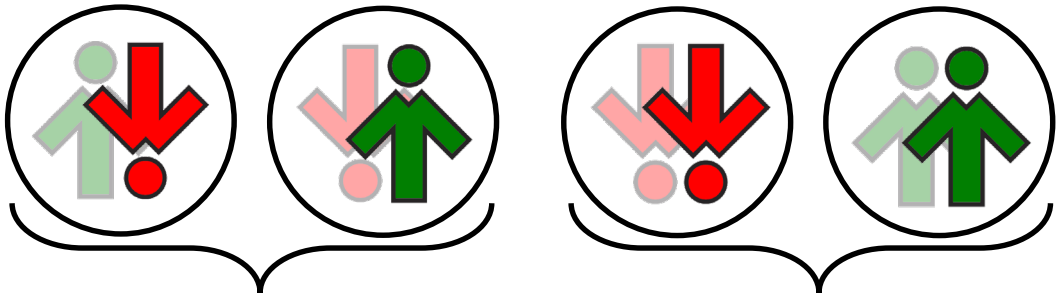


Stationary value of the dissonance

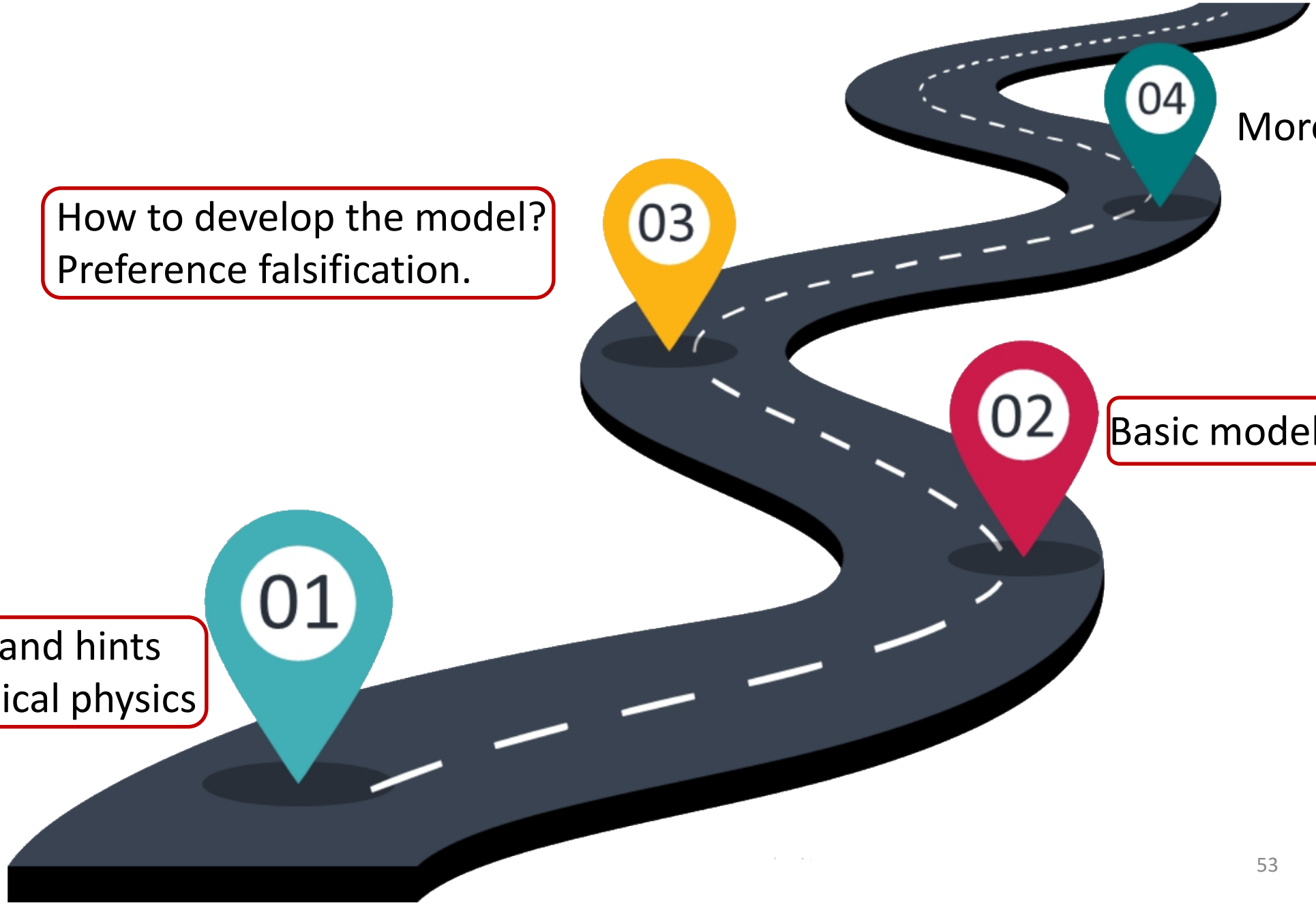
$q = 4$ $q = 5$ $q = 6$



$$d(t) = \frac{1}{2N}\sum_{i=1}^{N}(1 - S_i(t)\sigma_i(t))$$



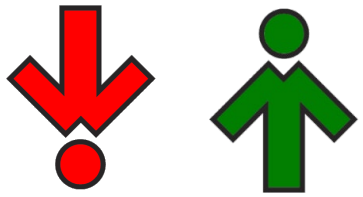
$S_i(t)\sigma_i(t) = -1$ $S_i(t)\sigma_i(t) = 1$

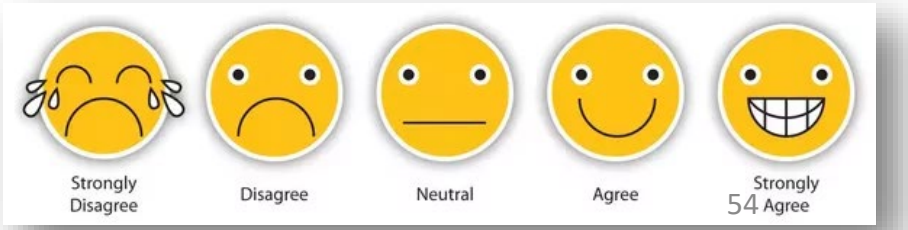

04
More?
How to develop the model?
Preference falsification.
03
02
Basic model
01
Inspiration and hints
from statistical physics

Wrocław University of Science and Technology

What factors promote social hysteresis in ABMs?
(not only in the q-voter model - universal)

- Larger size of the group of influence
- Super majority (simple majority is not enough)
- Higher level of independence in the society
- More layers in the social network (Face-to-face, Facebook)
- Situation over personality (person-situation debate)
- Larger number of individual states on the public level
- Preference falsification (internal and external opinion)
- …





Wrocław University of Science and Technology

Take-home messages

1. Memory can appear even in the society of memoryless agents.

2. More channels of communications, more independence and larger groups of influence promote social hysteresis.

Wrocław University of Science and Technology

Lecture based on:

1. B. Nowak, B. Stoń, KSW, Discontinuous phase transitions in the multi-state noisy q-voter model: quenched vs. annealed disorder, Scientific Reports (2021)
2. A Jędrzejewski, KSW, Statistical physics of opinion formation: Is it a SPOOF? Comptes Rendus Physique (2019)
3. B. Nowak and KSW, Homogeneous Symmetrical Threshold Model with Nonconformity: Independence versus Anticonformity, Complexity (2019)
4. P. Nyczka, K. Byrka, P. R. Nail and KSW, Conformity in numbers—Does criticality in social responses exist?, PLoS ONE (2018)
5. A. Jedrzejewski, G. Marcjasz, P. R. Nail, KSW, Think then act or act then think? PLoS ONE (2018)
6. A. Jedrzejewski, Pair approximation for the q-voter model with independence on complex networks, PRE (2017)
7. A Chmiel, KSW, Phase transitions in the q-voter model with noise on a duplex clique, PRE (2015)
8. P. Nyczka, KSW, *Anticonformity or Independence? -Insights from Statistical Physics,* J. Stat. Phys. (2013)
9. P. Nyczka, KSW, J. Cisło, *Phase transitions in the q-voter model with two types of stochastic driving*, PRE (2012)