

# Cooperation, Norms and Conflict: Towards Simulating the Foundations of Society

Dirk Helbing,

with Wenjian Yu, Anders Johansson, Carlos Roca, Thomas Chadeaux  
and other collaborators in Zurich, Dresden, and all over the world



## Sociology - The Queen of Sciences?



**Auguste Comte** (1798-1857)

is often called the “father” of sociology. He proposed a rational (“positivistic”) approach to the study of society, based on observation and experiment. In the beginning, he called his approach “**social physics**”, but later he used the term “**sociology**” (meaning knowledge of society).

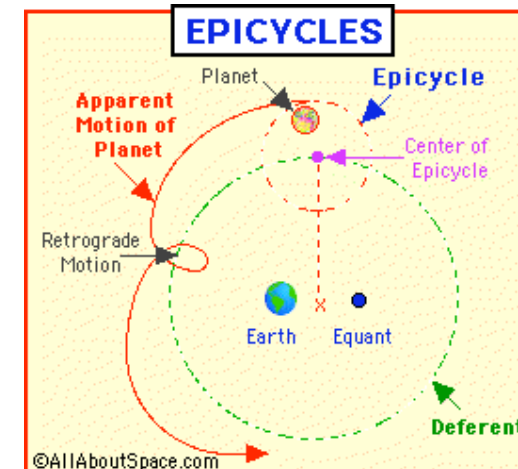
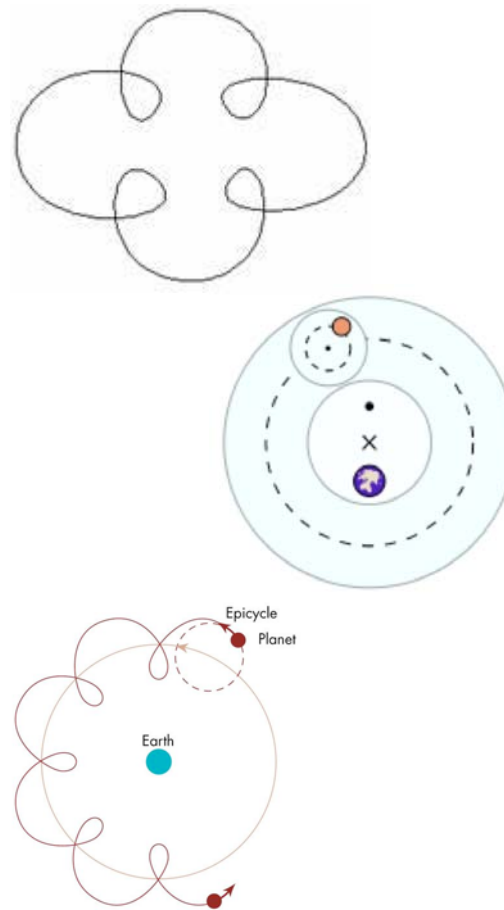
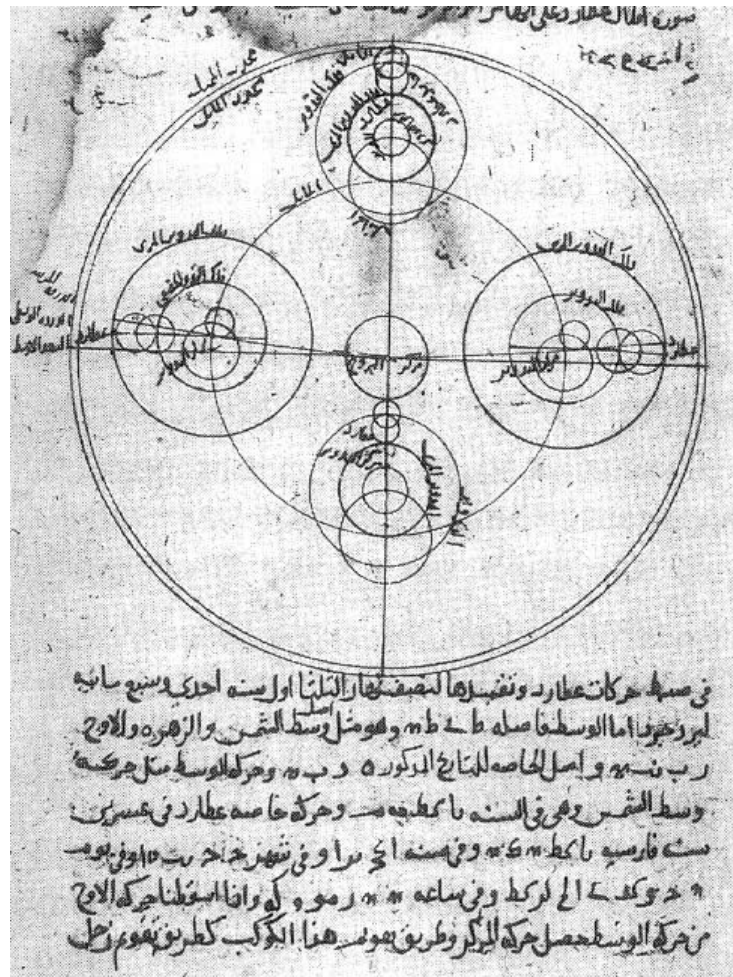
Auguste Comte considered sociology to be the **queen of sciences**. Comparing, for example, sociology with biology and physics, the systems it deals with are the most complex ones.

## What Makes Quantitative Theoretical Progress Difficult

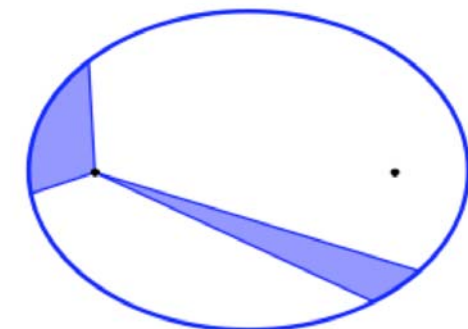
- Some of the reasons are
  - the **huge number of variables** involved,
  - the relevant variables and parameters are **often unknown**,
  - **empirical studies are limited** by technical, financial, and ethical issues,
  - factors such as **memory, anticipation, decision-making, communication**, interpretation of **intentions** and **meanings** complicate the situation a lot.
- The non-linear dependence of many variables leads to **complex dynamics and structures**, and often **paradoxical effects**. Linear statistical methods do not **reveal mechanisms of self-organization!**
- Furthermore, **heterogeneity** (due to individuality, social difference and specialization), and the fact that the **observer participates and modifies social reality**, imply additional difficulties.
- Conclusion: It seems worth trying to **start with simple, well measurable systems** such as crowds or traffic, and only then proceed with more complex phenomena.

## A Note on Simple Models

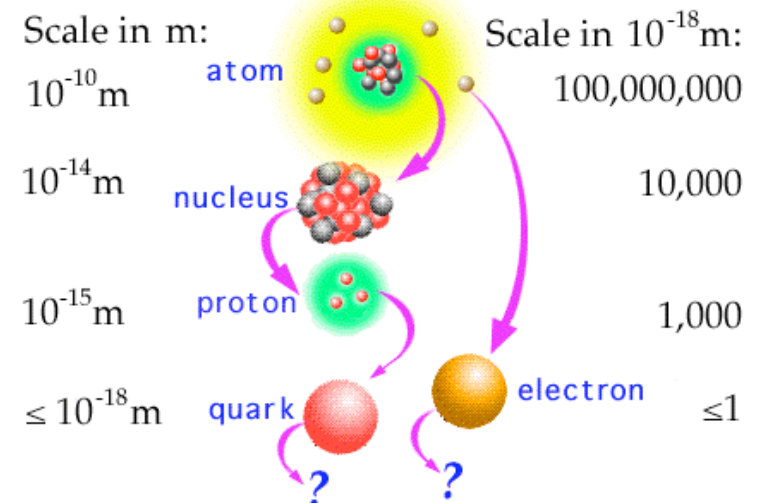
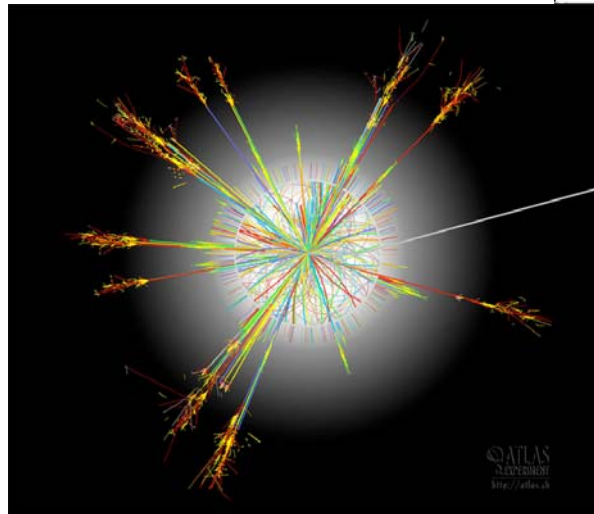
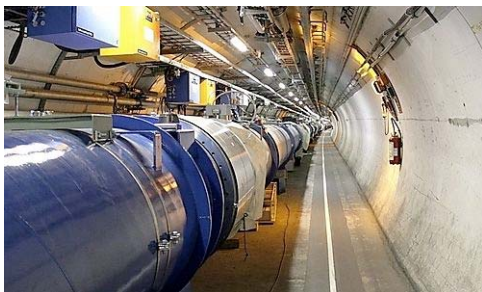
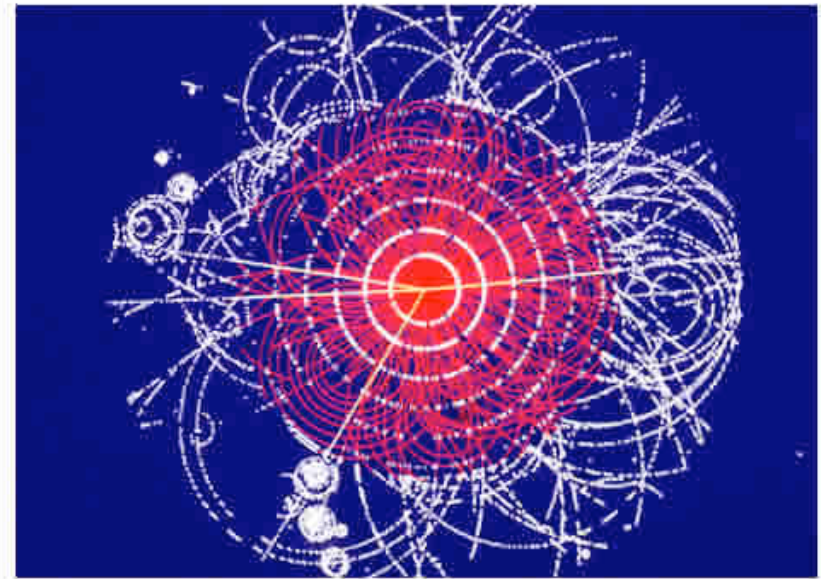
### Geocentric Picture: Epicycles around the Earth



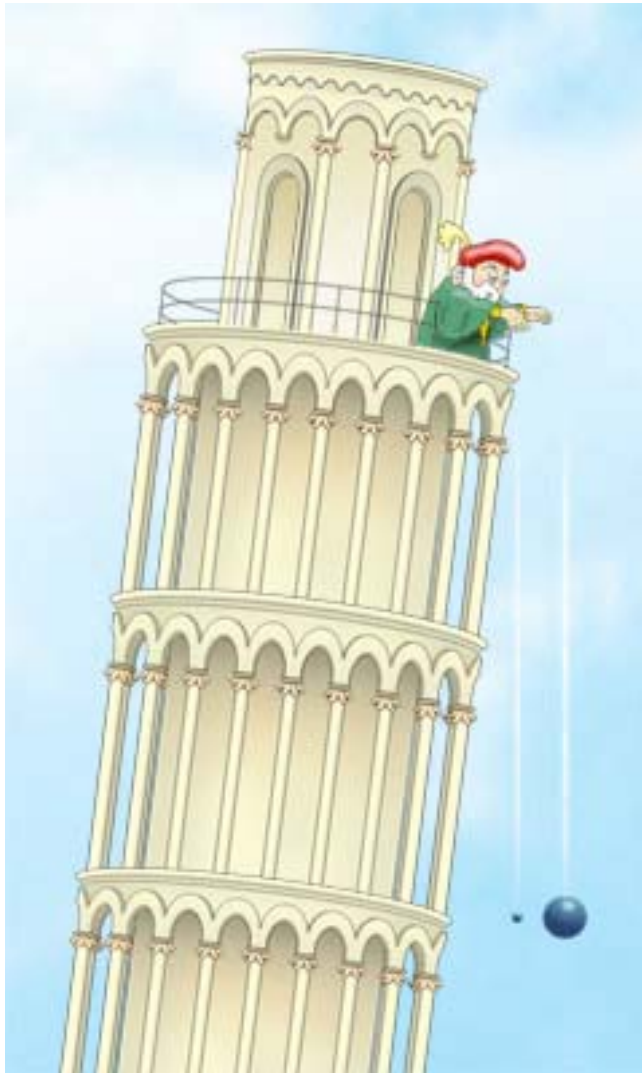
### Heliocentric Picture: Elliptical paths around the sun



# Can We Understand a System from Elementary Processes?



# The Need of Simplification and Abstraction



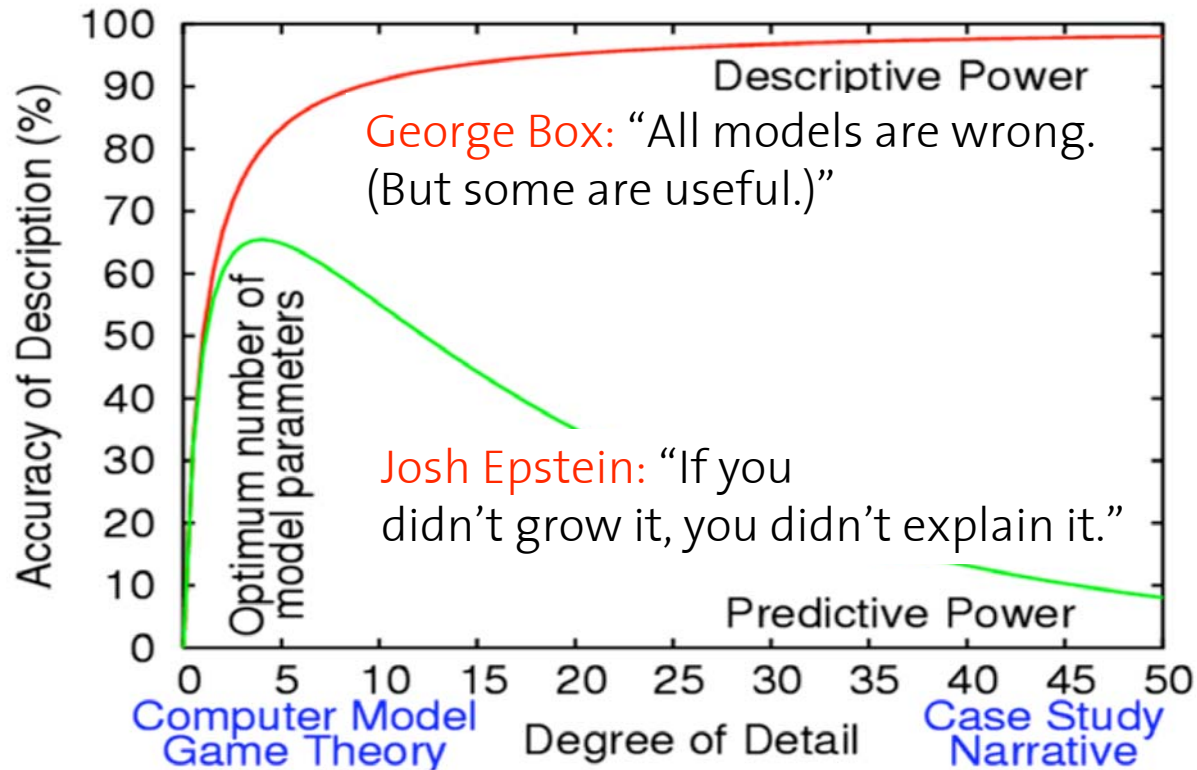
## Equations For A Falling Body



"Y'know, Henry, I had no idea it would be so fun to go skydiving with a physicist."

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## On Simple and Detailed Models



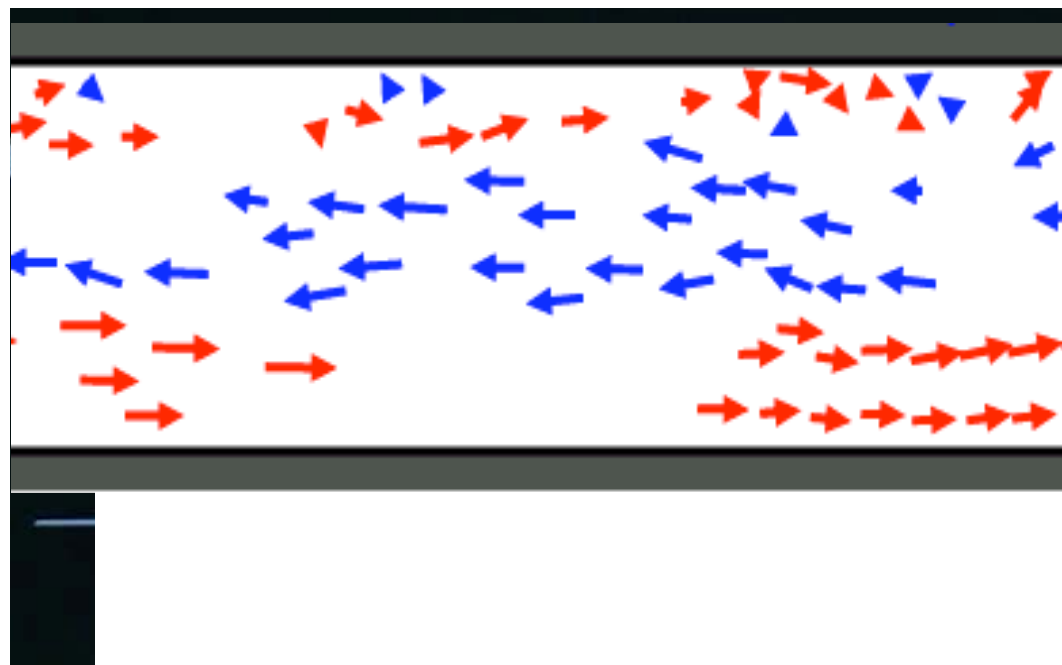
The more parameters a model has, the more difficult it is to fit them all exactly. This may affect the accuracy of predictions.

Many social systems are so complex, that the relevant variables and parameters involved are hard to identify and to measure. I will, therefore, study a few simple, measurable systems (leaving, for the time being, complex issues like meanings, values, historical aspects, and other behavioral dimensions aside), hoping that one can learn something more general from the principles observed in these examples.

## Emergence of Coordination in Pedestrian Counterflows



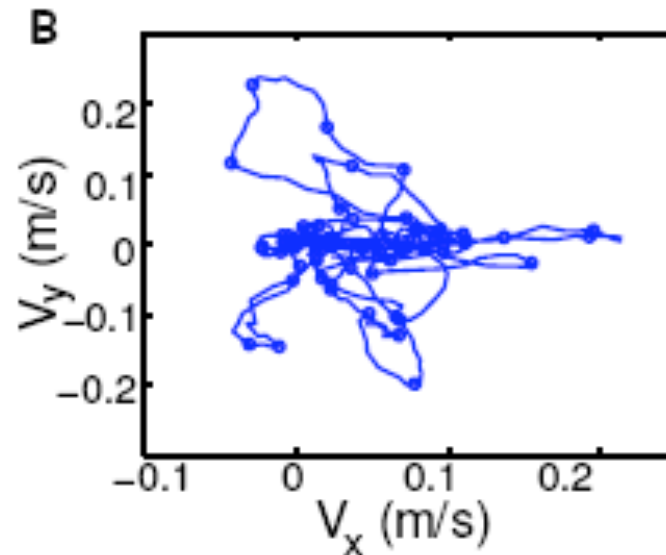
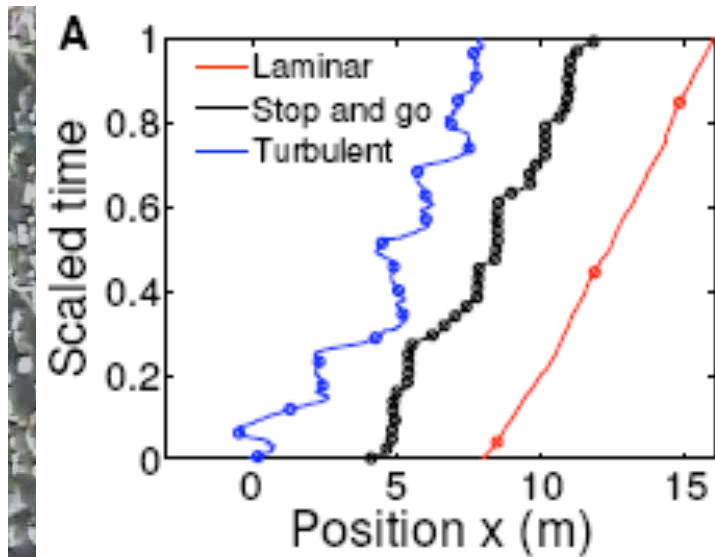
Acts like Adam Smith's "invisible hand"



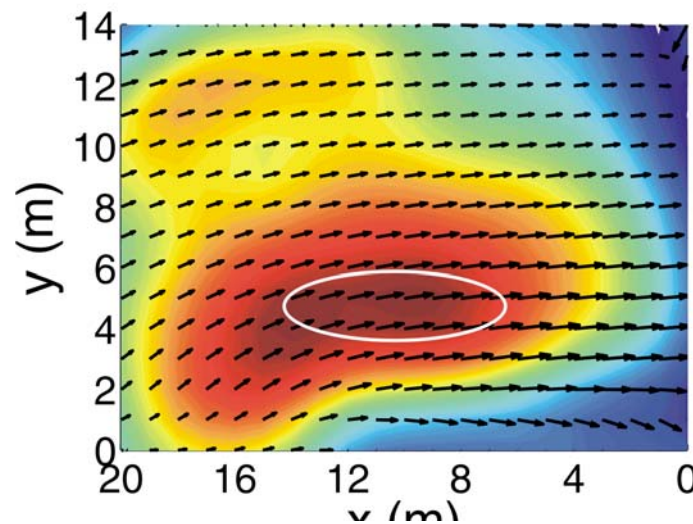
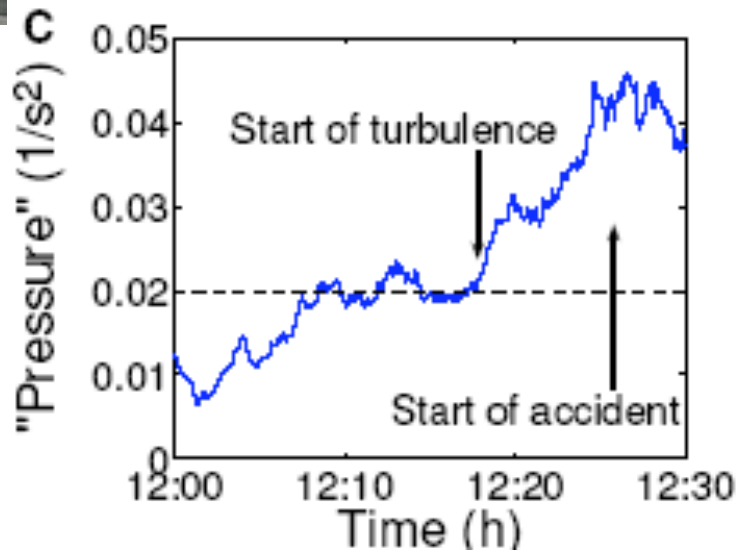
Based on individual interactions, lanes of uniform walking directions **emerge** in pedestrian crowds by **self-organization**. This constitutes a „**macroscopic**“ **social structure**. Nobody orchestrates this collective behavior, and most people are not even aware of it. A behavioral **convention** „**institutionalizes**“ a **side preference**.



# Breakdown of Coordination: Stop-and-Go and Turbulence Flow



The density times the variation in speeds constitutes the hazard! Pressure fluctuations cause turbulent motion and potentially the falling and trampling of people.



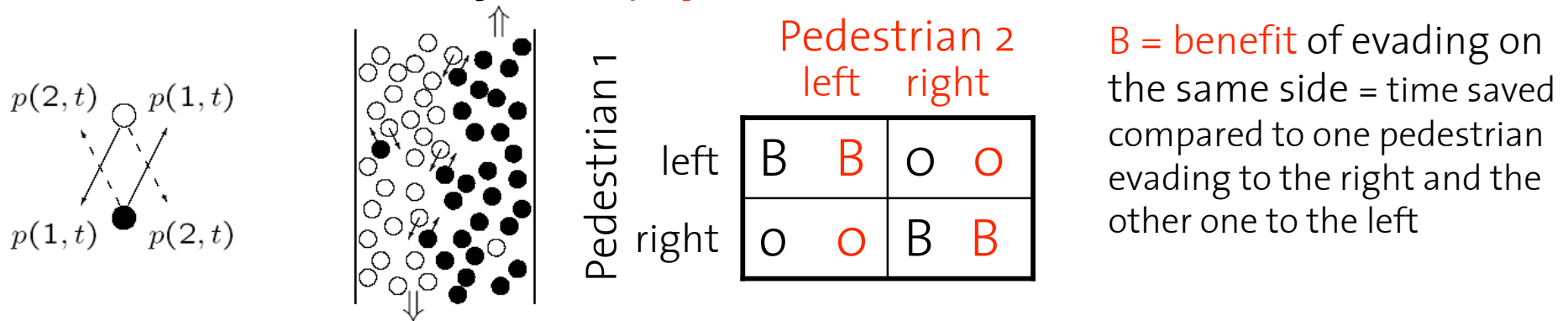
Increased driving forces occur in crowded areas when trying to gain space, particularly during "crowd panic"

# Evolutionary Game Theory: How Spatial Interactions, Migration, and Heterogeneous Preferences Can Change the World in Surprising Ways



## Self-Organization of A Behavioral Convention

The result of a social interaction between two individuals is characterized by the “payoff”



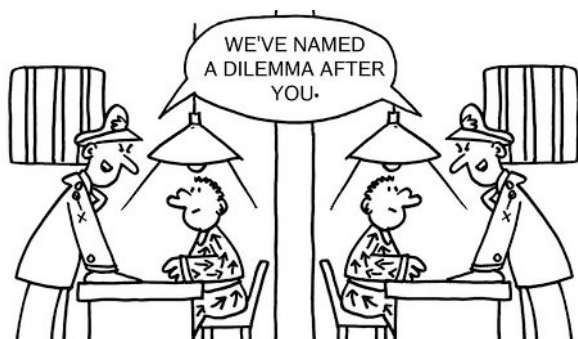
If  $p(1,t)$  denotes the probability of pedestrians to evade on the right and  $p(2,t)$  to the left, the **expected payoff** (“success”) is  $S(i,t) = Bp(i,t)$ , when using strategy  $i$ . The **average success** of pedestrians is  $A(t) = p(1,t)Bp(1,t) + p(2,t)Bp(2,t)$ , where  $p(2,t) = 1 - p(1,t)$ . Due to strategy changes (**success-driven imitation**), the proportion of strategy  $i$  grows proportionally to the difference between the expected success and the *average* expected success:  $dp(i,t)/dt = r [S(i,t) - A(t)]p(i,t)$

$$dp(i,t)/dt = -2rB[p(i,t)-1/2] p(i,t) [1-p(i,t)] \quad i=1: \text{right}, i=2: \text{left}$$

Only the stationary solutions  $P(i,t)=0$  or  $1$  are stable, i.e. one evading side will become a **behavioral convention** (Helbing, 1990, 1991, 1992; Young 1993)

## The Prisoner's Dilemma

The prisoner's dilemma game has served as prime example of strategic conflict among individuals. It assumes that, when two individuals cooperate, both get the “reward”  $R$ , while both receive the “punishment”  $P < R$ , if they defect. If one of them cooperates (“C”) and the other one defects (“D”), the cooperator suffers the “sucker’s payoff”  $S < P$ , while the payoff  $T > R$  for the second individual reflects the “temptation” to defect. Additionally, one typically assumes  $S+T < 2R$ .



		Player 2	
		Cooperate	Defect
Player 1	Cooperate	$R_1 \quad R_2$	$S_1 \quad T_2$
	Defect	$T_1 \quad S_2$	$P_1 \quad P_2$

For example:

$$S_1 = S_2 = S = -5$$

$$P_1 = P_2 = P = -2$$

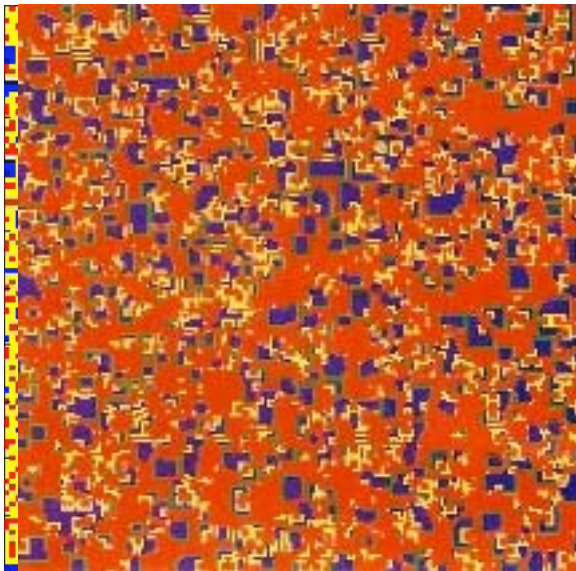
$$R_1 = R_2 = R = -1$$

$$T_1 = T_2 = T = 0$$

Many “social dilemmas” are of a similar kind (see public goods game)

## Start with the Spatial Prisoner's Dilemma...

Nowak and May (1992) have extended the prisoner's dilemma to simultaneous **spatial interactions** in an  $L \times L$  grid involving  $L^2$  players, assuming that each player would have binary **interactions with  $m=8$  nearest neighbors**, and would afterwards **imitate the strategy C or D of the most successful neighbor**, if he or she performed better. Computer simulations for  $R=1$  and  $P=S=0$  show **“chaotic” pattern formation phenomena** in a certain parameter range of  $T$ .

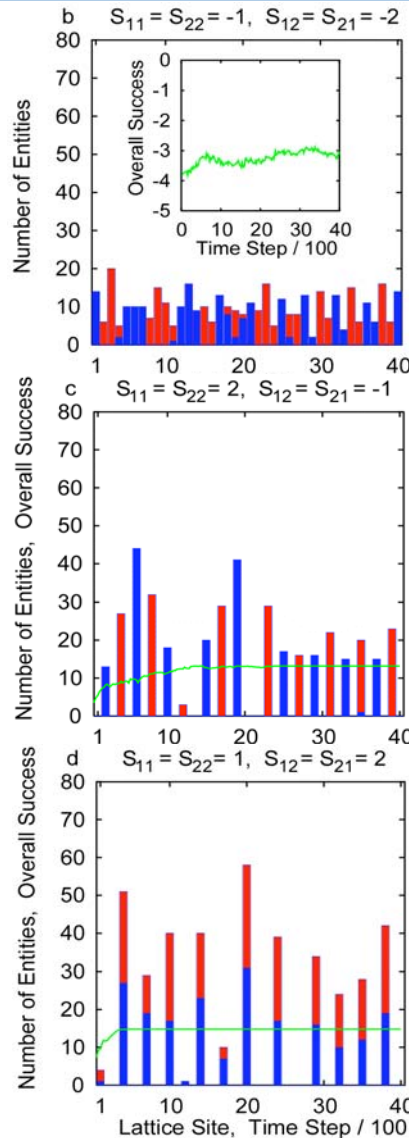


For  $R=1$  and  $P=S=0$  Nowak and May have found that big clusters of defection shrink for  $T < 1.8$ , while for  $T > 2$ , cooperative clusters do not grow, and in between, both **cooperative and defective clusters would expand, collide, and fragment**.

Source: M. A. Nowak and R. M. May, Nature 359, 826 (1992).

blue = cooperator, red = defector, yellow = turned to defection, green = turned to cooperation

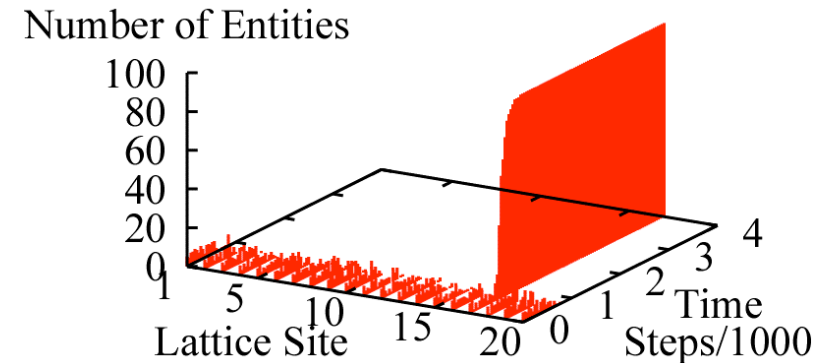
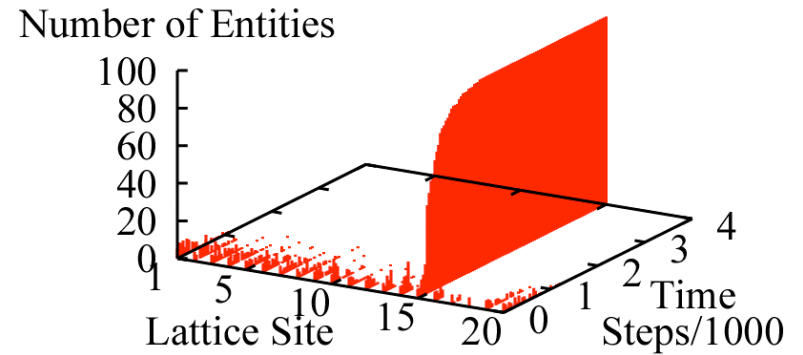
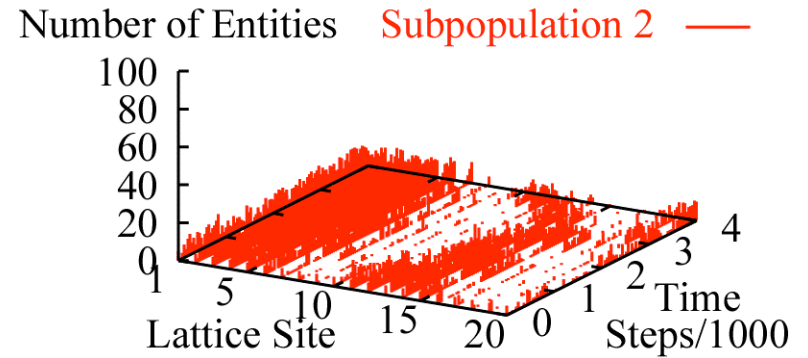
# Spatio-Temporal Pattern Formation Due to Success-Driven Migration



Segregation  
("Lane Formation")

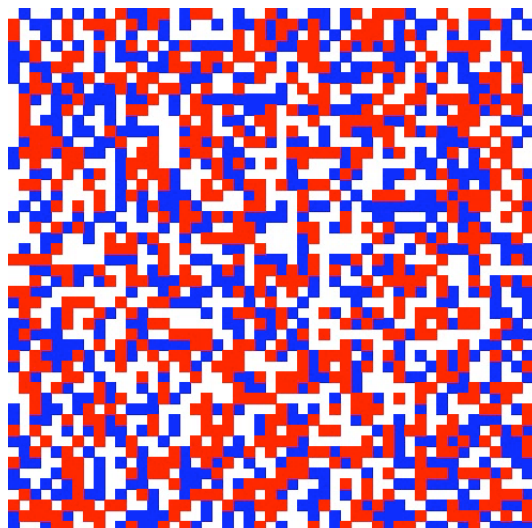
Repulsive Agglomeration  
("Ghetto Formation")

Attractive Agglomeration  
("Clustering")

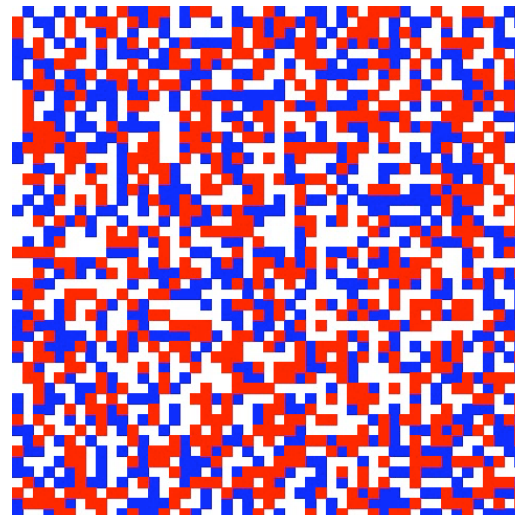


# Imitation and Success-Driven Motion, Separately and Together

$P = 0$   
 $R = 1$   
 $S = 0$   
 $T = 1.4$



imitation only

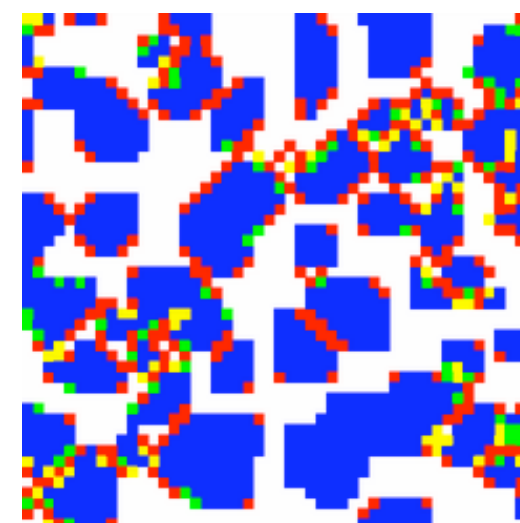
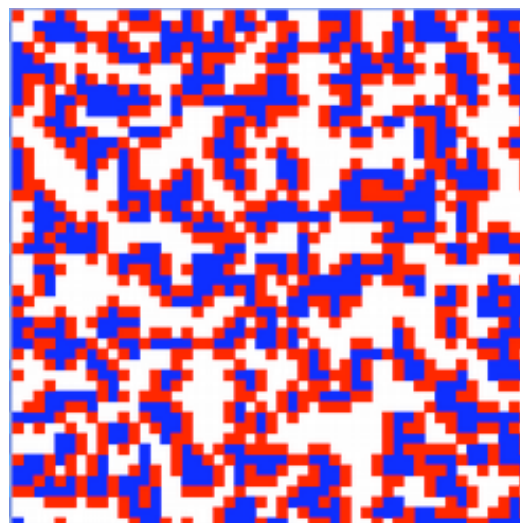
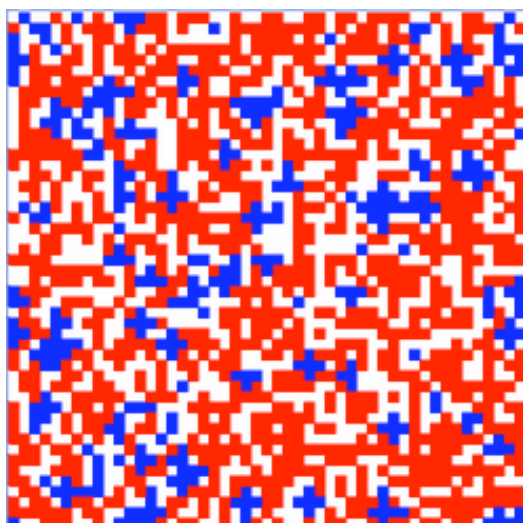


migration only



imitation & migration

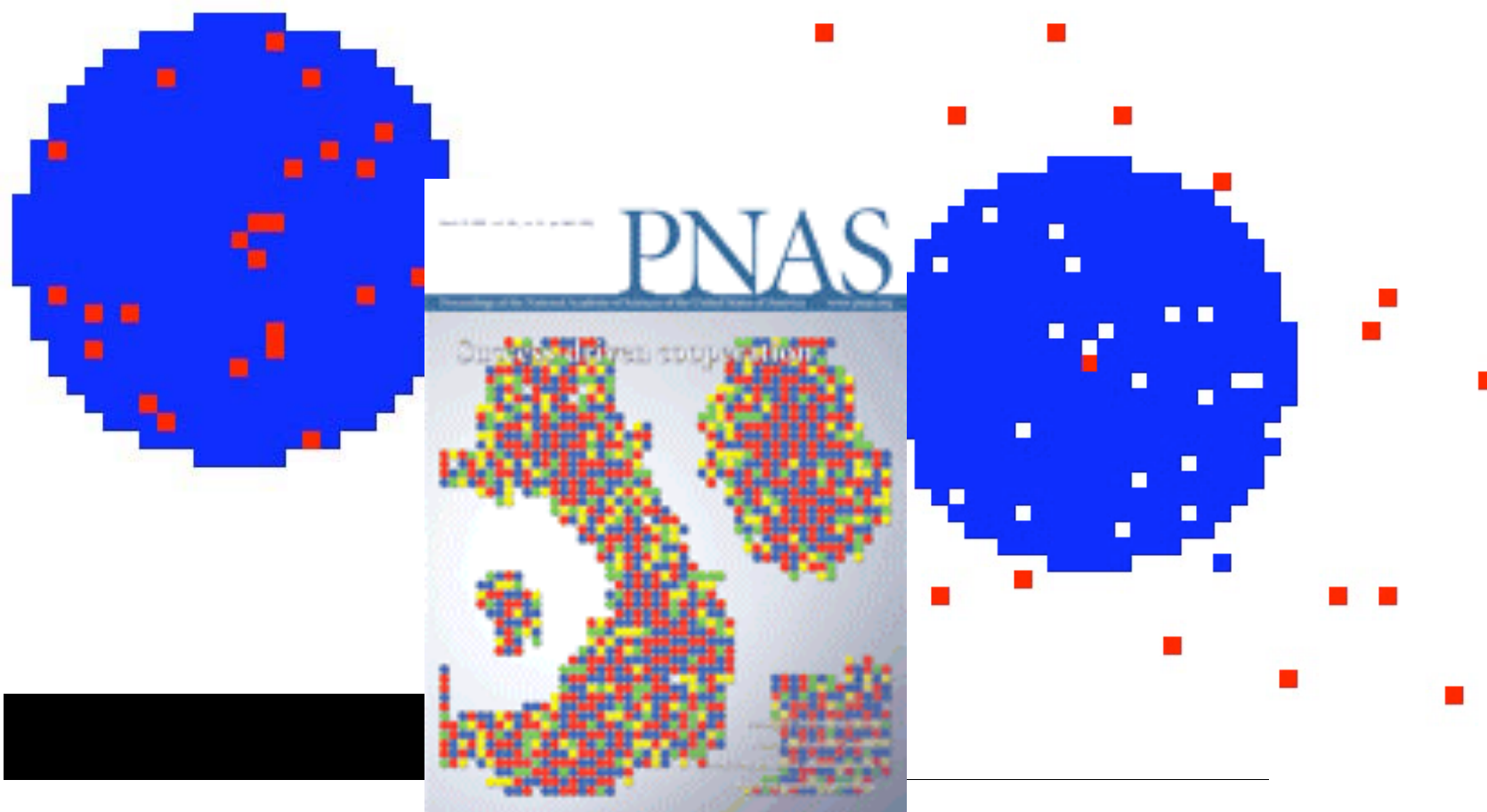
blue = C  
red = D



# The Breakdown and Outbreak of Cooperation

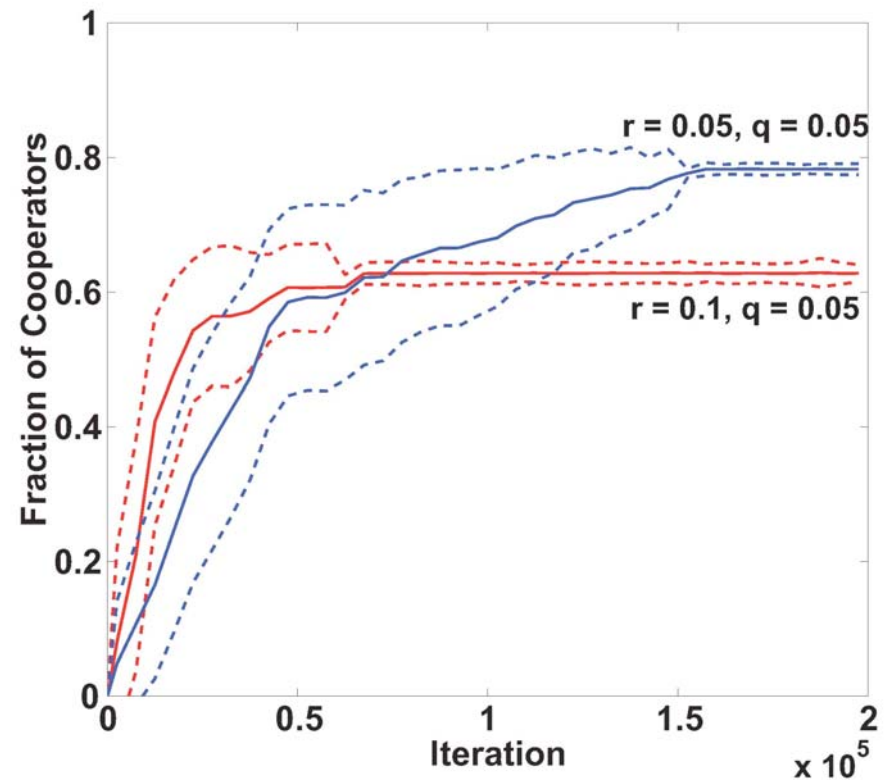
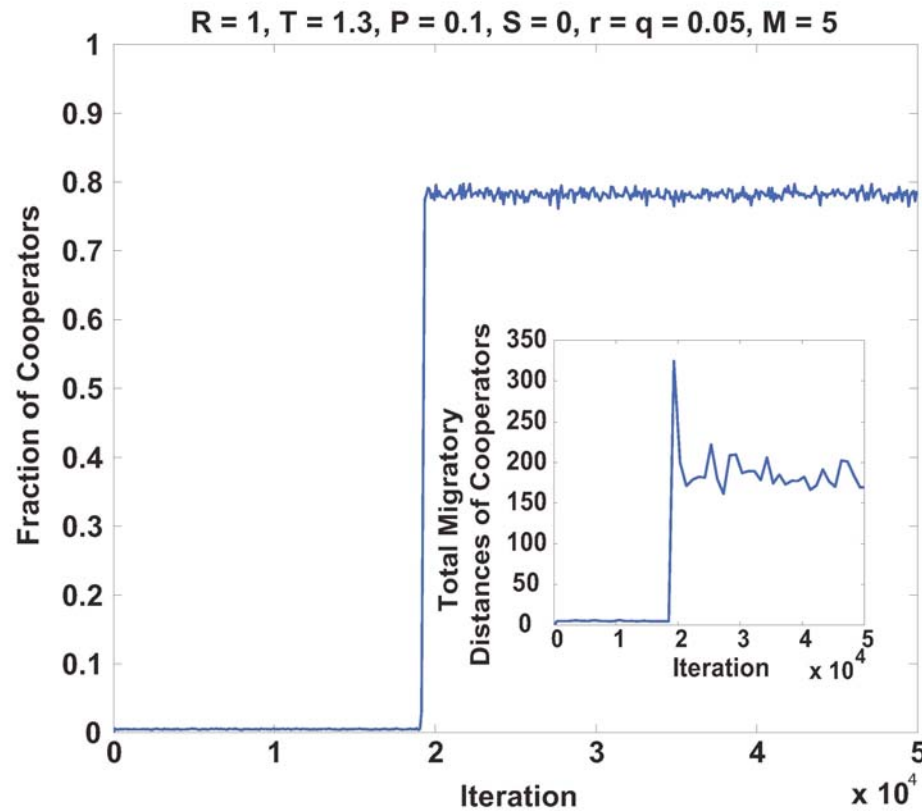
Red, yellow: defectors (cheaters)

Blue, green: cooperators





# Time-Dependence of Transition of Predominant Cooperation



## Intermediate Summary

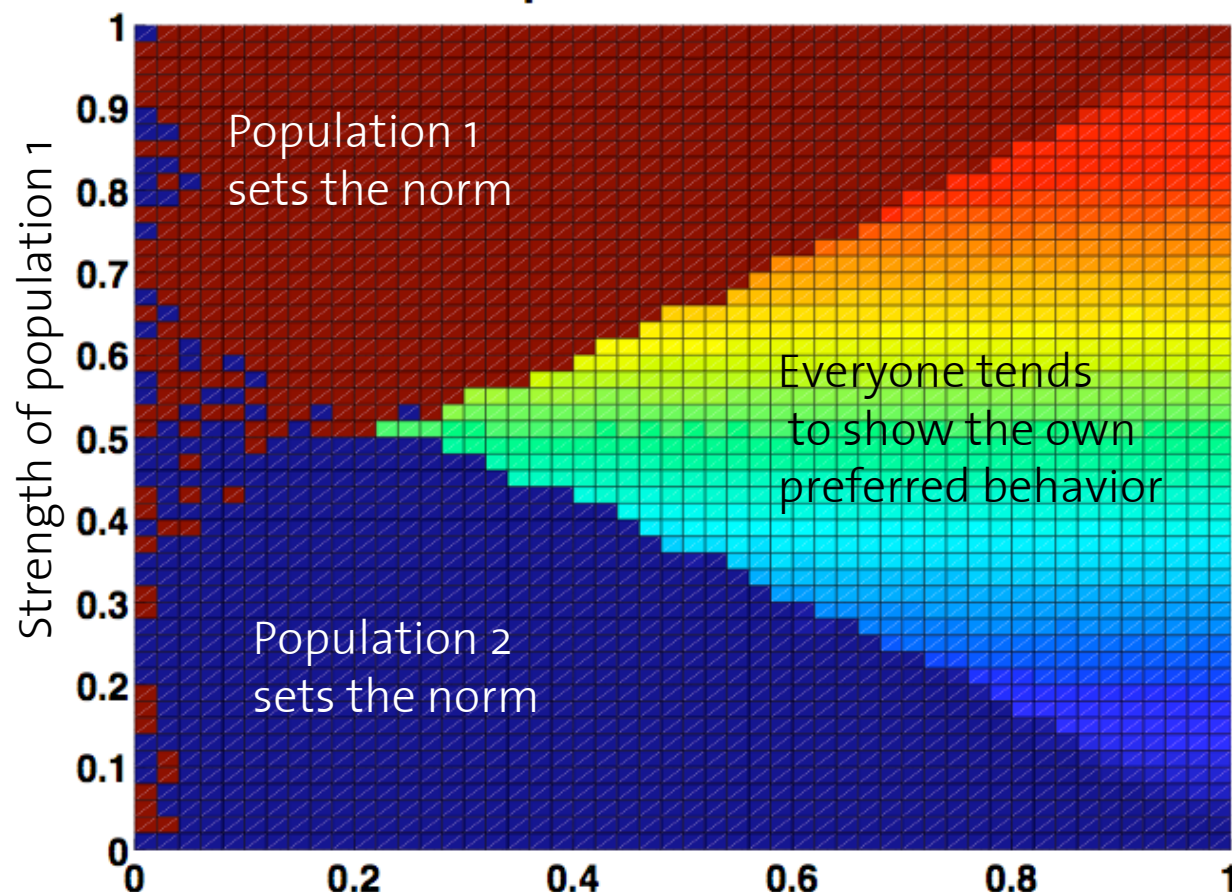
A simple model considering strategy and location changes and noise can reproduce various **stylized facts** of social systems:

1. Individuals like to **agglomerate** (form cities, groups, etc.)
2. Individuals with different behavioral strategies tend to **segregate** (--> see also Schelling)
3. **Levels of cooperation** in the prisoner's dilemma and in public goods games are **higher than expected**; they tend to break down, but may grow, if people can leave bad environments and choose more favorable ones
4. Individual **behaviors are partially determined by the social environment** they are contributing to (--> norms)
5. Social environments **persist** much longer than an average individual contributes to it (--> **social institutions**)
6. Social systems perform well by **continuous adaptation**

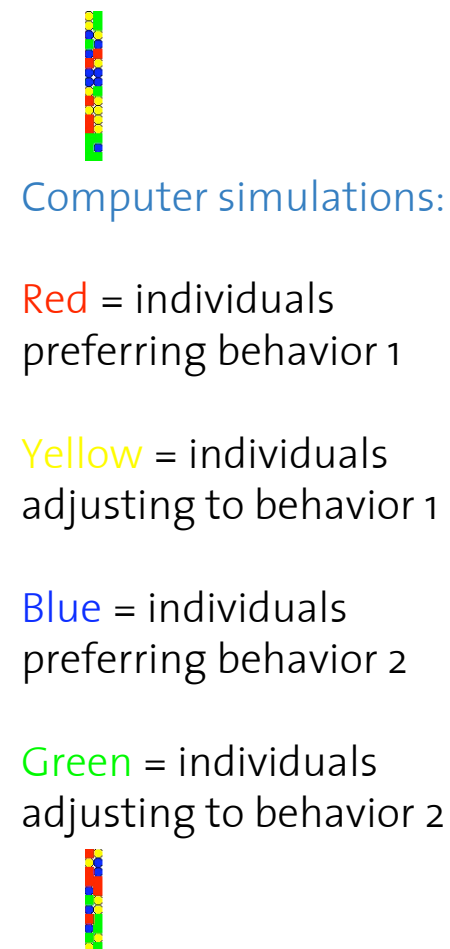
## Possible Outcomes in the Two-Population Norms Game

$\varepsilon = 0.01$ , Interaction Partner = 1,  $p_0 = p_1 = 0.5$

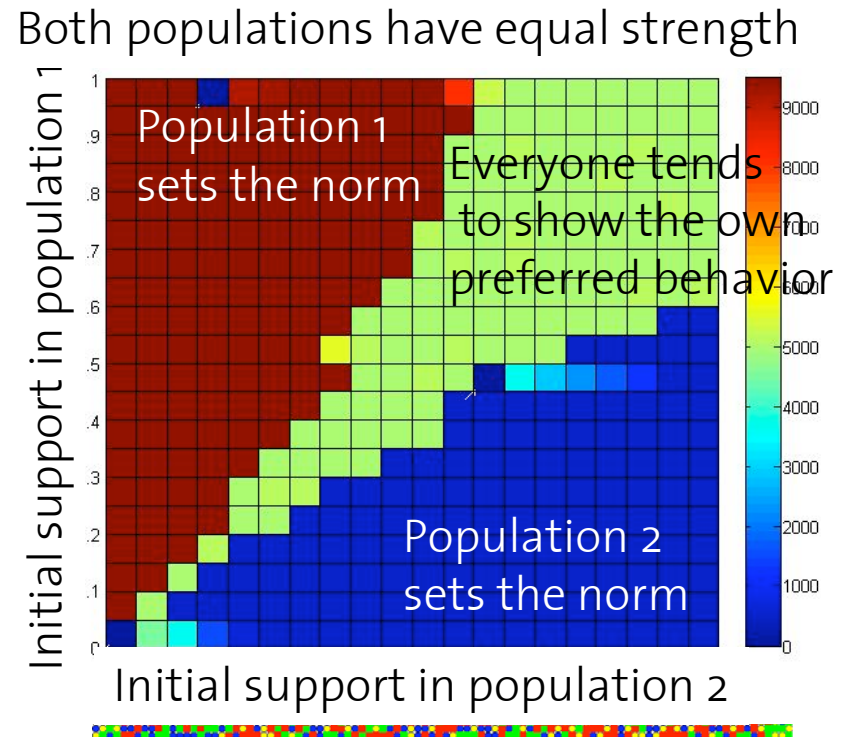
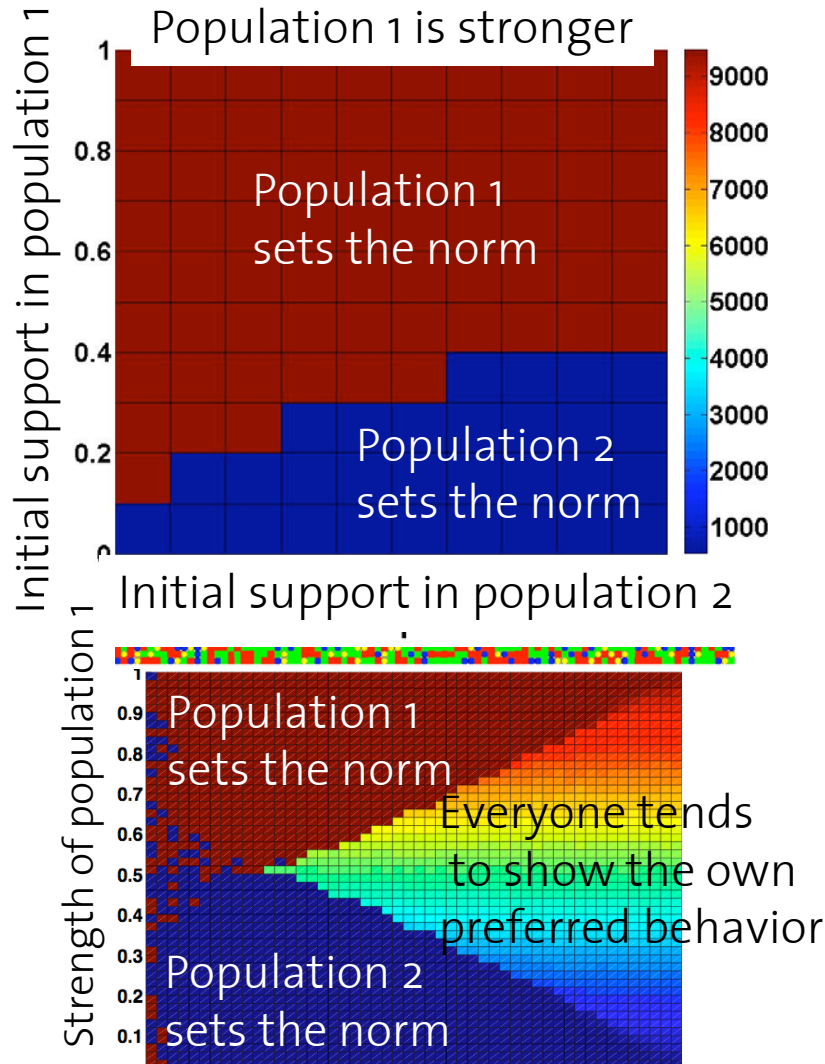
Proportional Imitation



Reward of showing preferred behavior / Reward of conforming

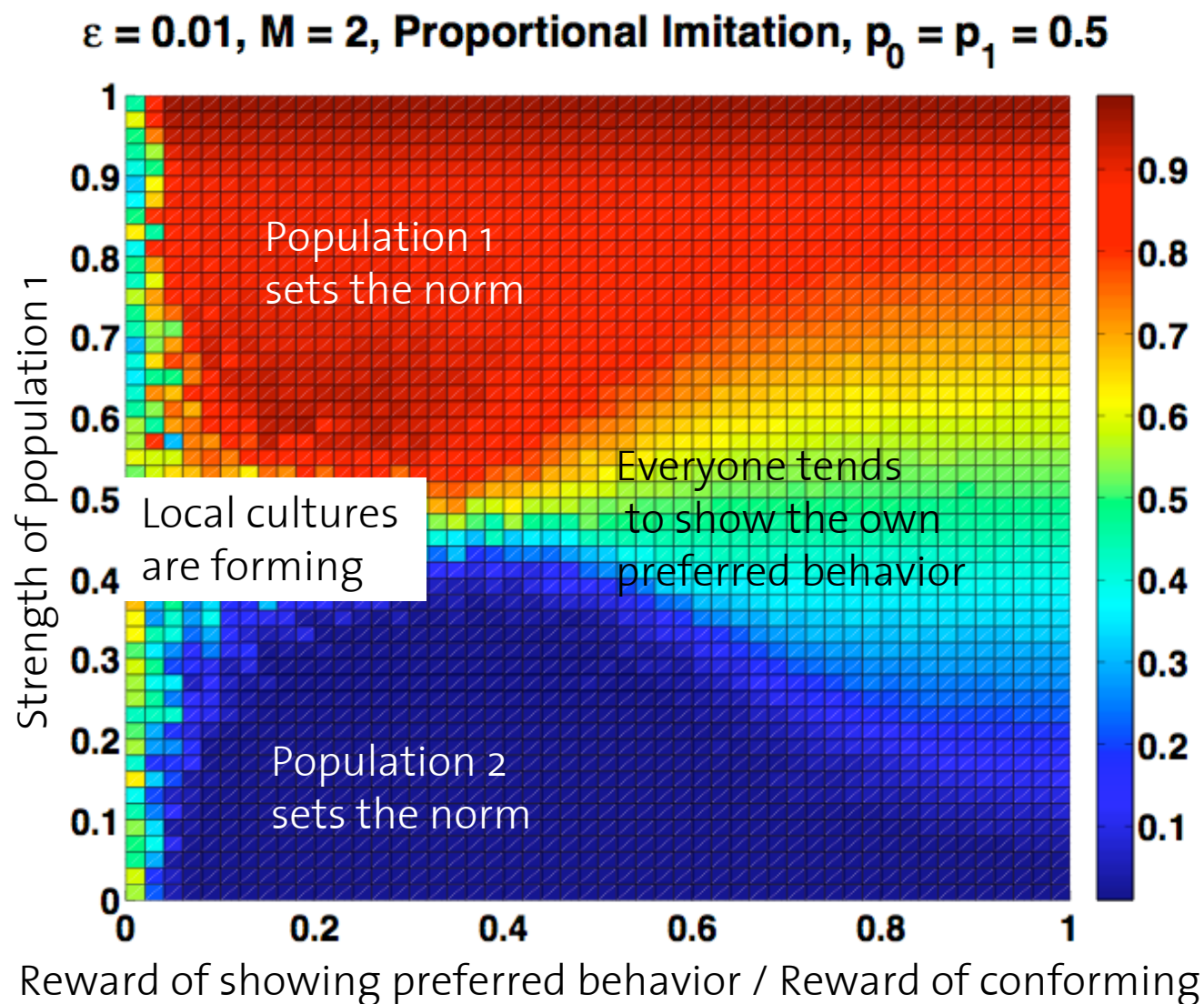
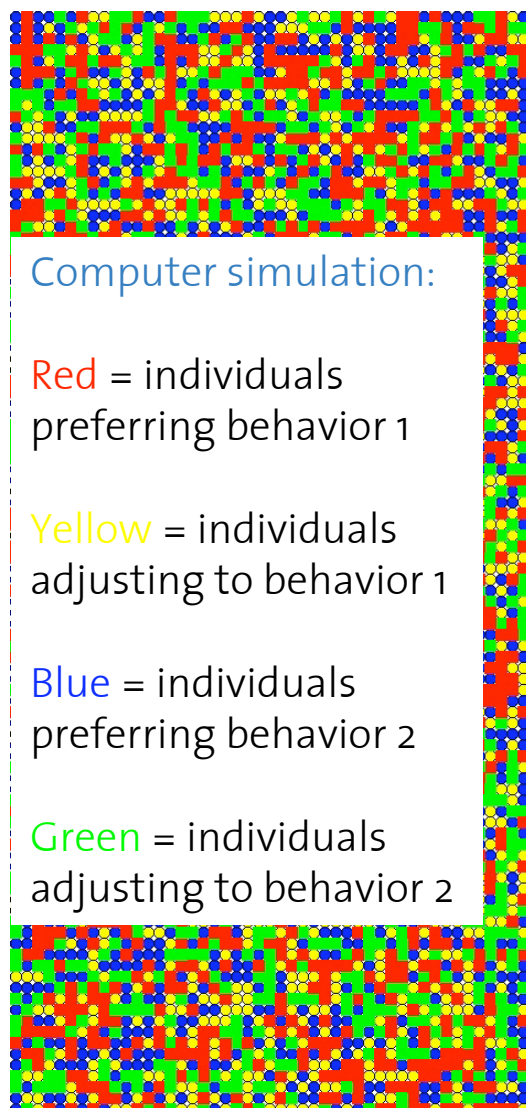


# History/Path Dependence - The Initial Condition Matters



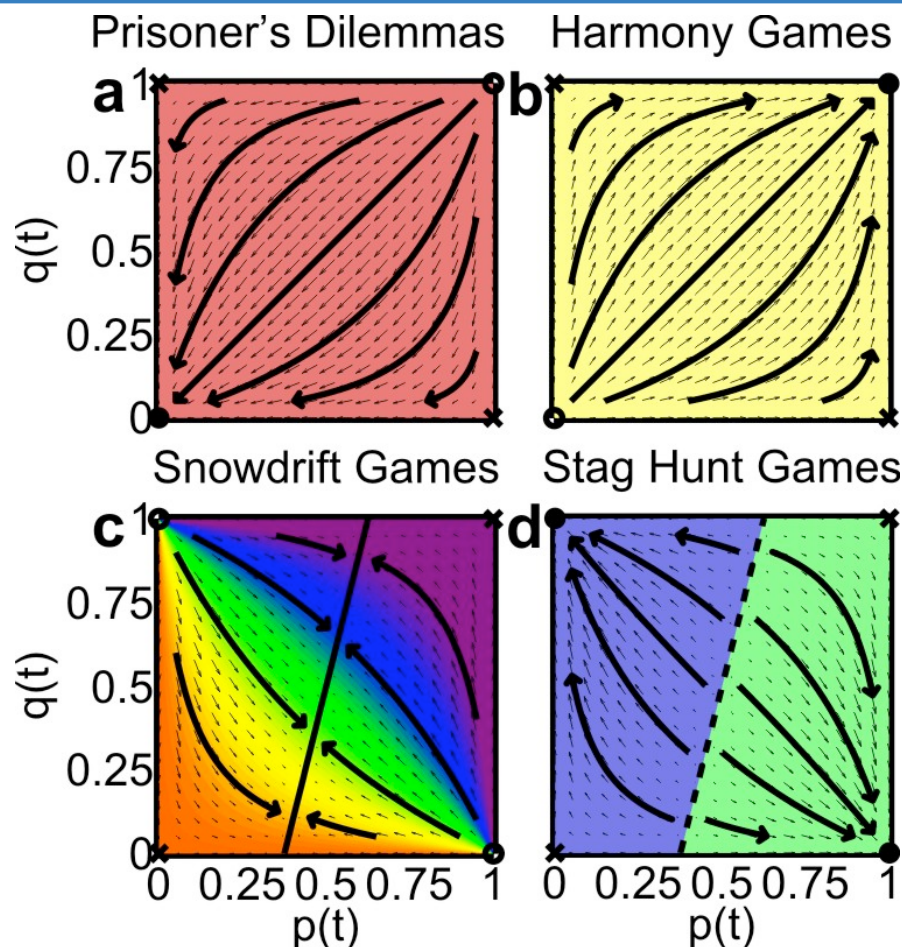
Reward of showing preferred behavior / Reward of conforming

## Possible Outcomes in the Norms Game with Local Interactions



## Two Populations with Incompatible Interests

Breakdown  
of cooperation



Formation of  
subcultures

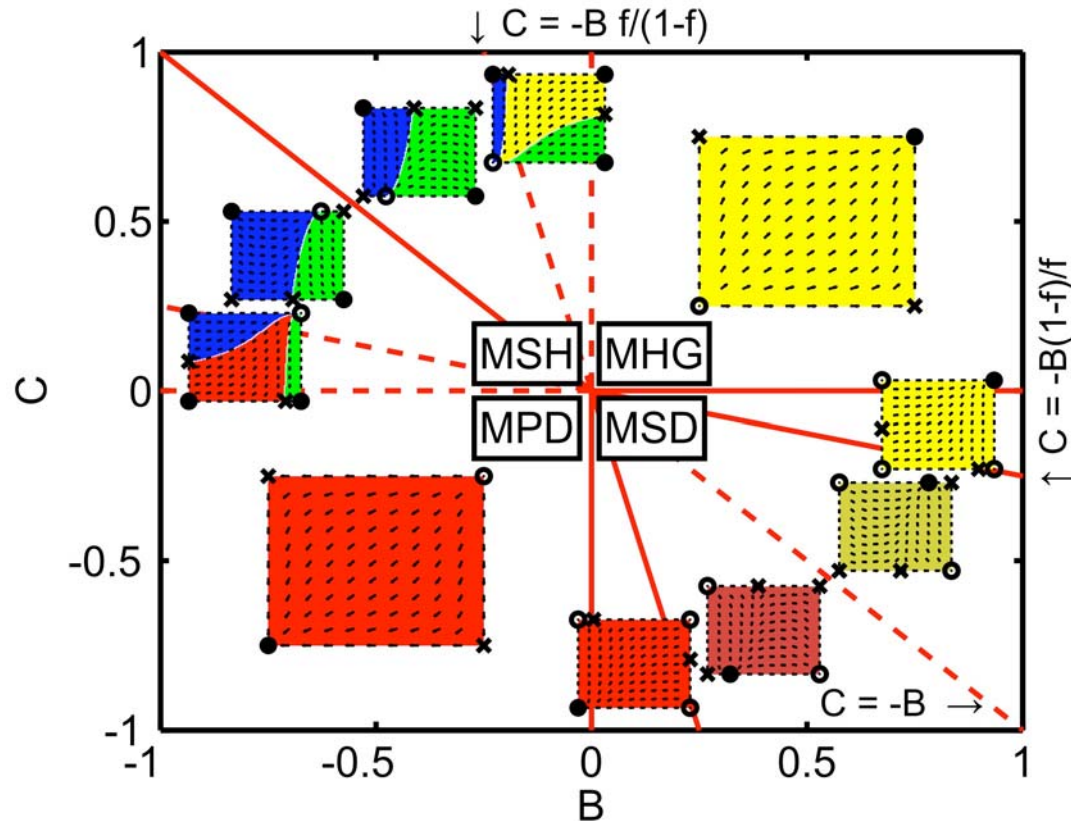
Polarization

Formation of shared  
behavioral norms

Only in the stag hunt game we find that both populations tend to use the same behavioral strategy, i.e. **a behavioral norm evolves!** The norm-creating mechanism is also important for the **evolution of language.**

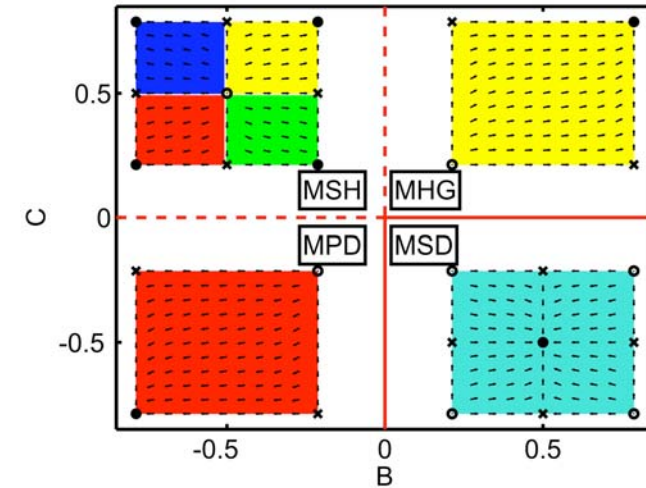
# Summary of System Dynamics in Multi-Population Games

with interactions and self-interactions

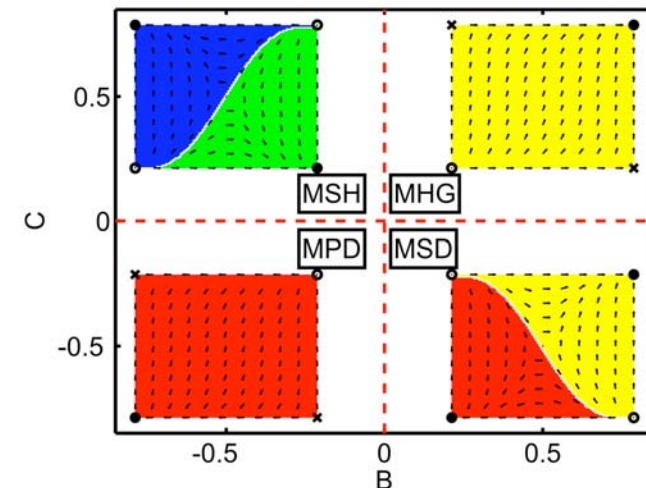


MSH = multi-population stag hunt game  
 MPD = multi-population prisoner's dilemma  
 MHG = multi-population harmony game  
 MSD = multi-population snowdrift game

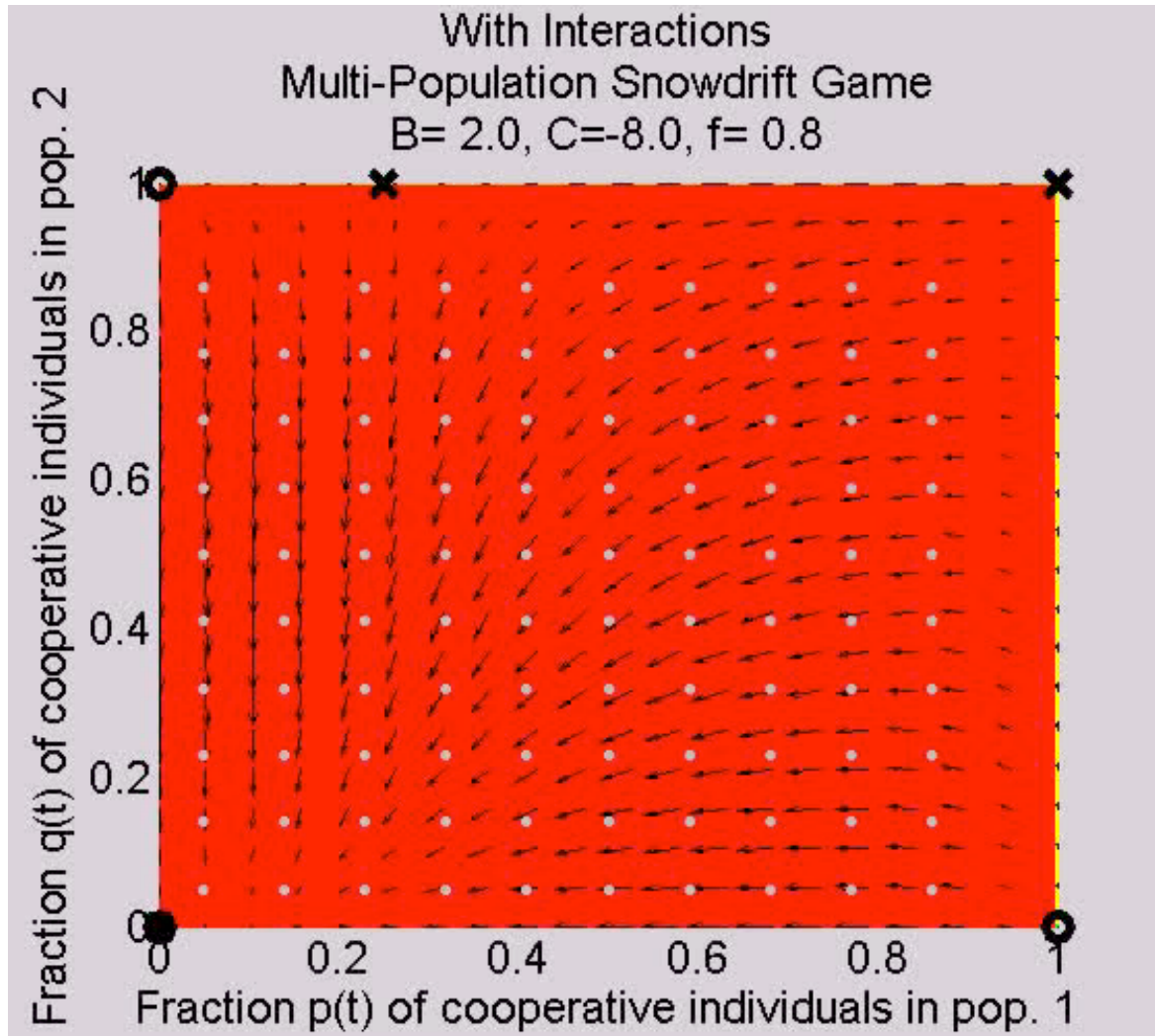
without interactions



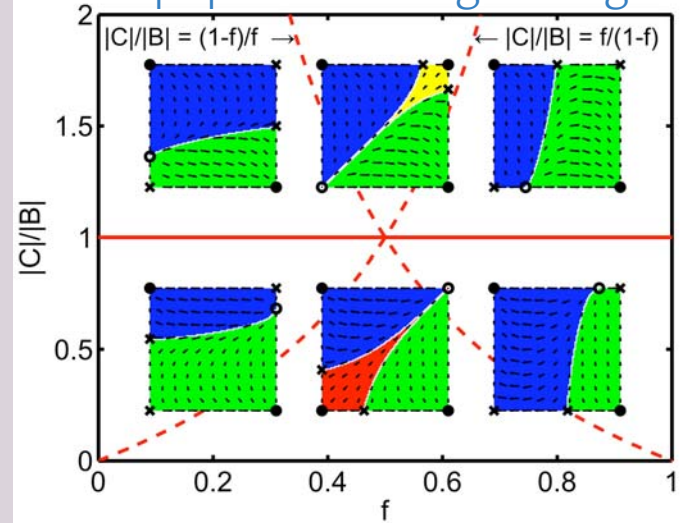
without self-interactions



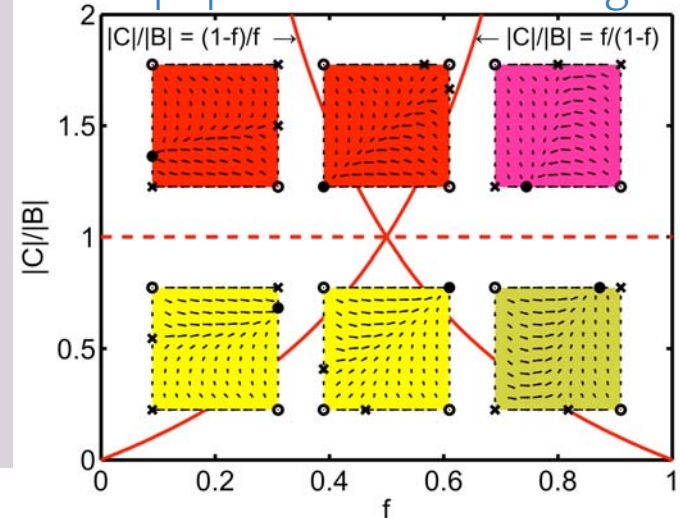
# Relevance of the Payoff Parameters and Power



multi-population stag hunt game



multi-population snowdrift game





## Intermediate Summary II

- Simple models can produce complex behavior and promise to gain surprisingly interesting insights into the mechanisms underlying socio-economic systems
- Linear models do not allow to explain emergent self-organization phenomena
- The representative agent (mean field) approach is misleading
- Considering time-dependence, spatial interactions, and heterogeneity lead to different conclusions regarding the behavior of socio-economic systems
- Puzzles such as the occurrence of cooperation among selfish individuals (the victory of cooperators over free-riders) or the establishment of costly punishment (or the disappearance of second-order free-riders) are naturally resolved
- Mobility is essential for the co-evolution of social environment and social behavior
- It seems possible to formulate a unified model describing (1) the breakdown of cooperation, (2) the coexistence of different behaviors (subcultures), (3) the evolution of commonly shared behaviors (norms), and (4) the occurrence of social polarization or of revolutions.
- Globalization seems to endanger social cooperation. Are we on the way to a punishment society or to a reputation society?

## Challenges to Address

- Social and economic systems are rapidly changing, are in a **transformation process**, not in equilibrium
- Scientists need to be put in a better position to address the **increasing number of socio-economic problems**



As president of New York's Columbia University, Lee C. Bollinger formulated the issue as follows: "The forces affecting societies around the world ... are powerful and novel. The spread of global market systems ... are ... reshaping our world ..., raising profound questions. These questions call for the kinds of analyses and understandings that academic institutions are uniquely capable of providing. Too many policy failures are fundamentally failures of knowledge."

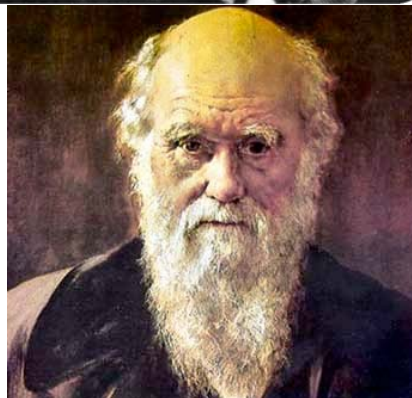
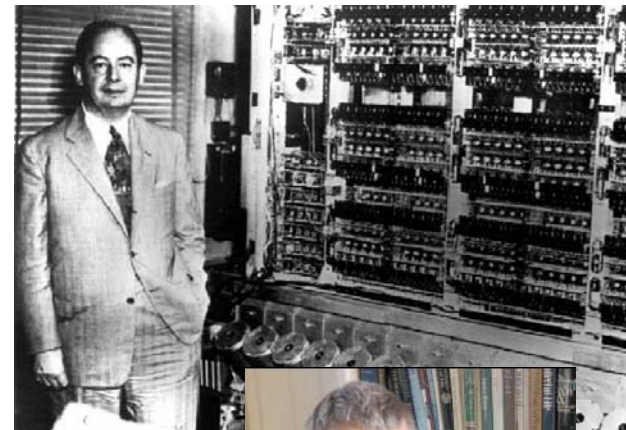
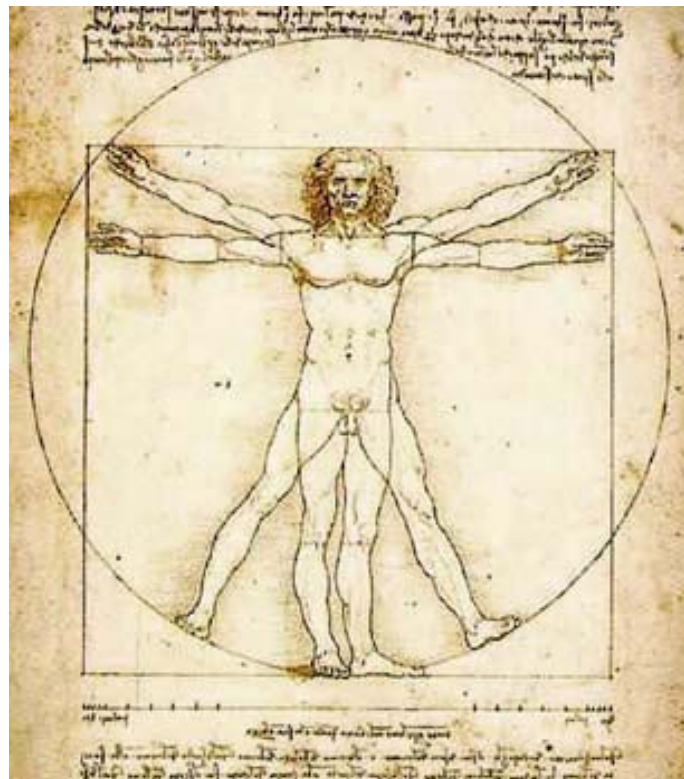
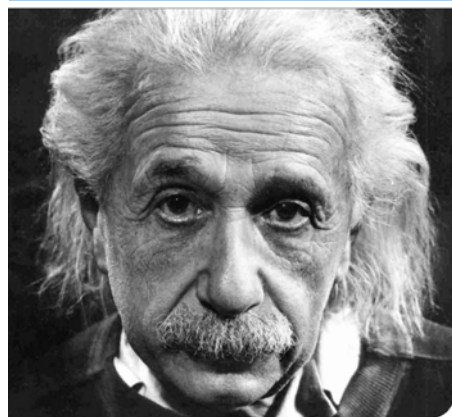


- We must **close the gap** between existing socio-economic problems and solutions, and get into a position to come up with solutions **before** a problem occurs
- The goal is to **support politicians and business people** in addressing practical problems

## 10 Grand Socio-Economic Challenges

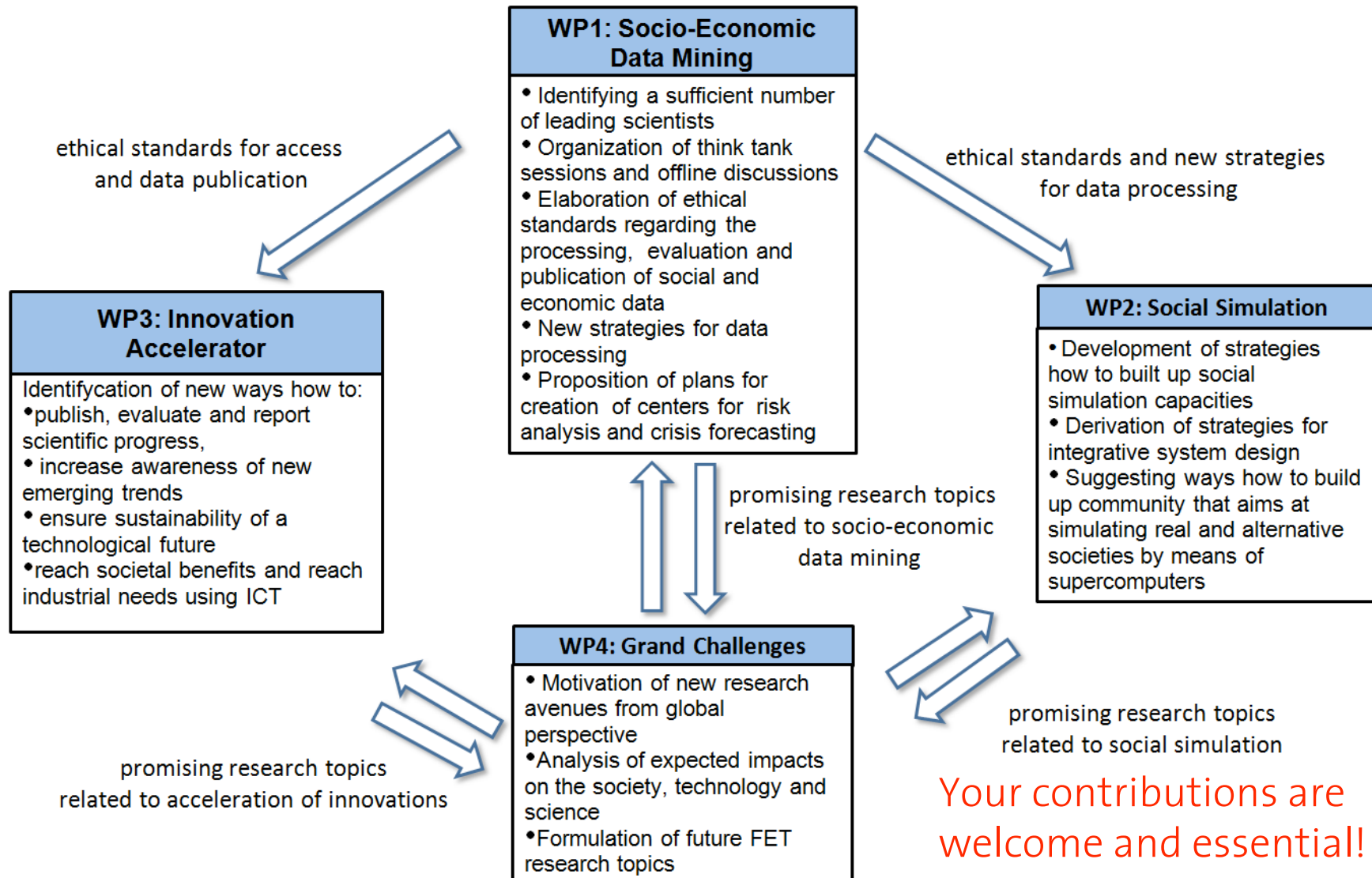
1. **Demographic change** of the population structure (change of birth rate, migration)
2. **Financial and economic stability** (trust, consumption and investments; government debts, taxation, and inflation/deflation; sustainability of social benefit systems...)
3. **Social, economic and political inclusion** (people of different gender, age, education, income, religion, culture, language, preferences,...; unemployment)
4. **Public health** (spreading of epidemics [flu, HIV], obesity, smoking, or healthy diets; incentives supporting food safety)
5. **Balance of power** (in a multi-polar world; also between individual and collective rights, political and company power; protection of pluralisms, individual freedom, and minorities...)
6. **Conflict** (terrorism, independence movements, social unrest, organized crime, war)
7. **Sustainability of communication and information systems** (education and inheritance of culture; cyber risks, violation of privacy, misuse of sensitive data, data deluge, spam, ...)
8. **Collective behavior and opinion dynamics** (social contagion, breakdown of trust, extremism, changing values, breakdown of cooperation, compliance, or solidarity)
9. **Institutional design** (over-regulation, compliance, corruption, balance between global and local, central and decentral, intellectual property rights,...)
10. **Sustainable use of resources and environment** (travel behavior, consumption habits, efficient use of energy and other resources, participation in recycling efforts)

# The Need of Integrative Systems Design + Complex Systems Science



We envision to create a **socio-economic knowledge accelerator** - a multi-disciplinary Apollo project for the social sciences, involving natural scientists and engineers

# Visioneer - Our Chance for the Future of Complexity Science



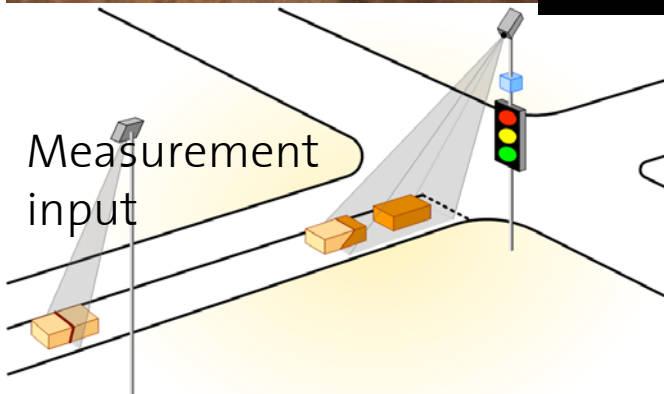
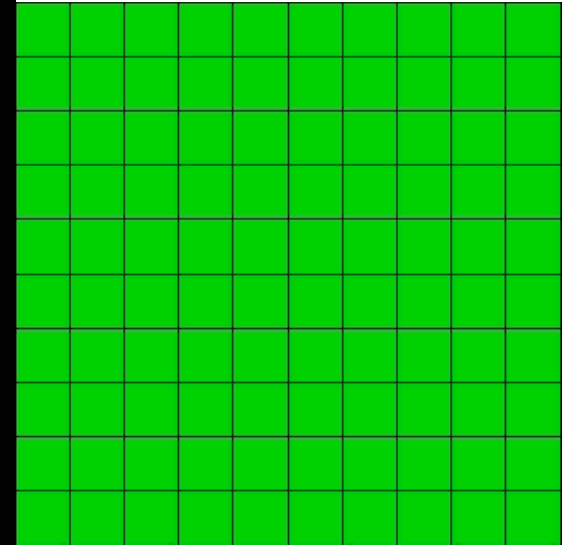
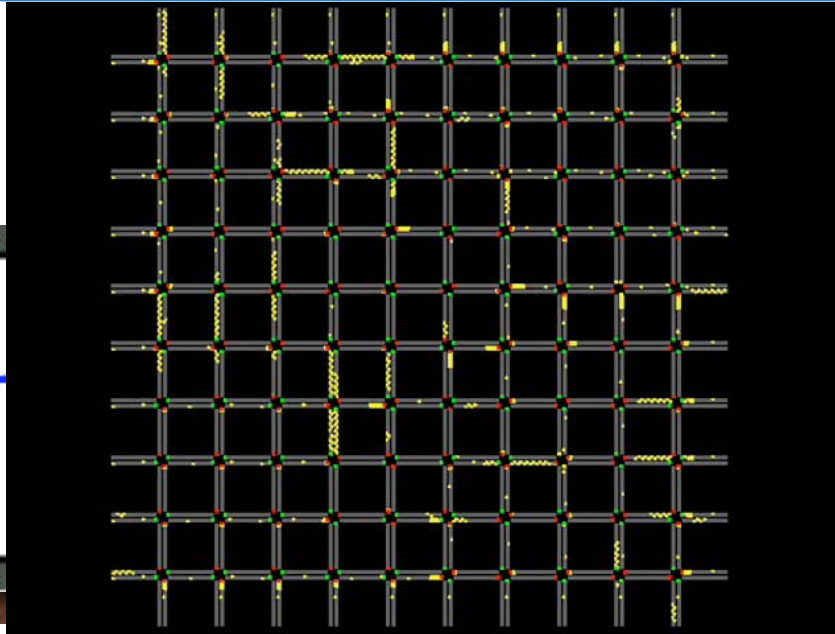
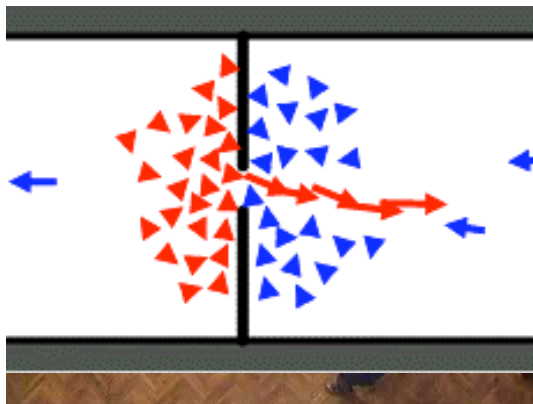
## Socio-Economic Systems Imply Major Risks

- Conflicts:** World War I (more than 15,000,000 victims); World War II (60,000,000 fatalities; cost of 1,000,000,000,000 1944 US\$; destruction of 1710 cities, 70,000 villages, 31,850 industrial establishments, 40,000 miles of railroad; 40,000 hospitals 84,000 schools); Vietnam, Korea, former Yugoslavia, Afghanistan, Irak, Darfur...
- Financial and Economic Crises:** estimated loss of 4-20 Trillion US\$
- Climate Change** will cause natural disasters conflicts for water, food, land; migration; social and political instability (estimated reduction of world gross domestic product by 0.6-12 Trillion US\$ per year)
- Epidemics:** Spanish Flu (20-40 Mio. Deaths), SARS (ca. 800 victims, 100 Billion US\$ losses)

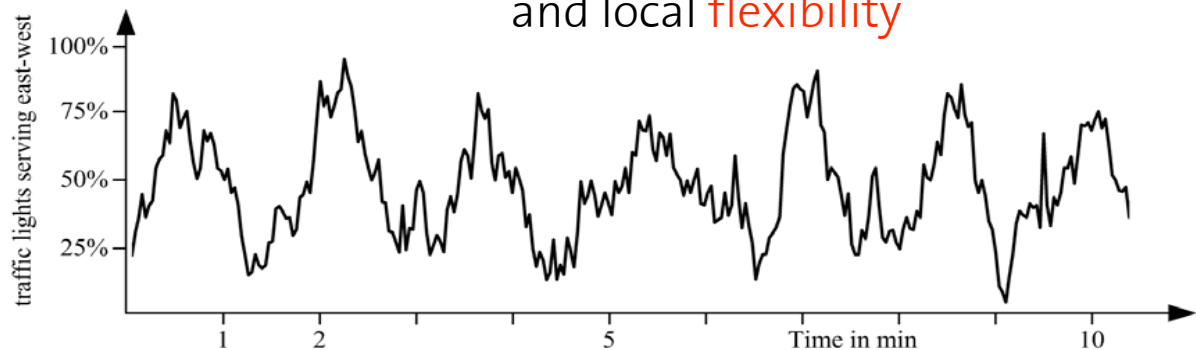


# Decentralized Concept of Self-Organized Traffic Light Control

Inspiration: Self-organized oscillations at bottlenecks

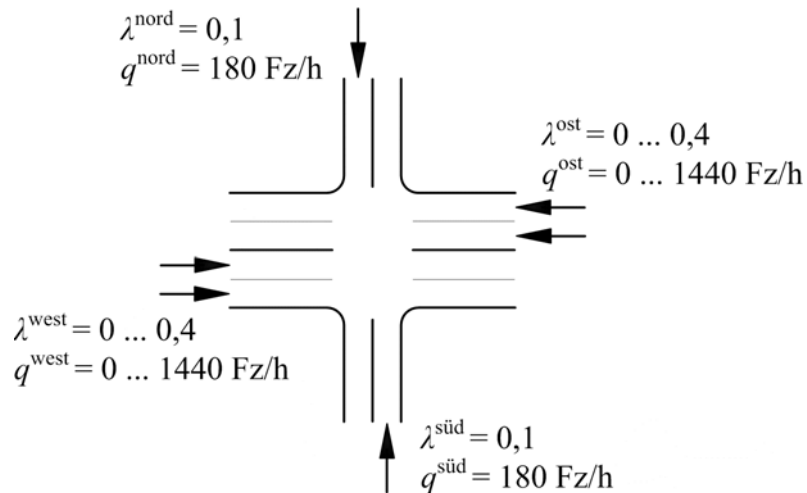


Published in *JSTAT* (2008)

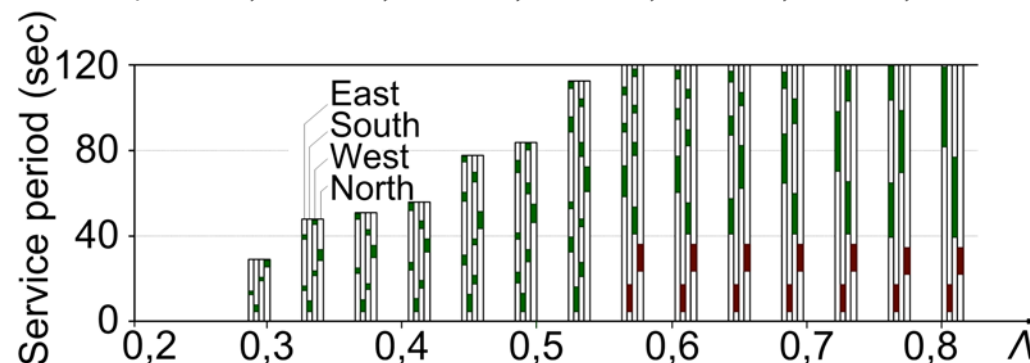
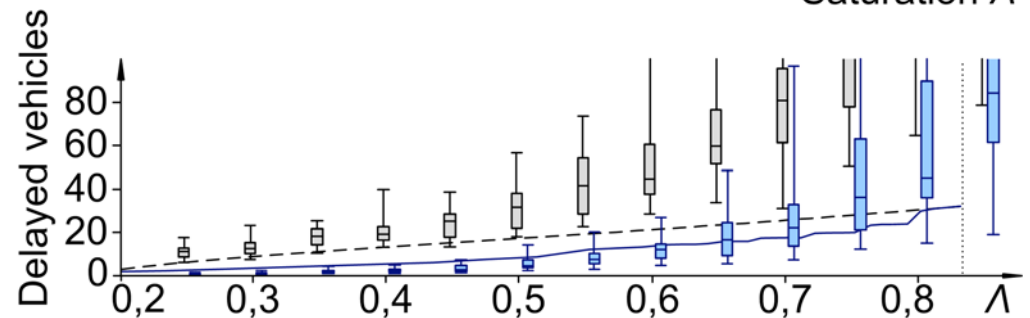
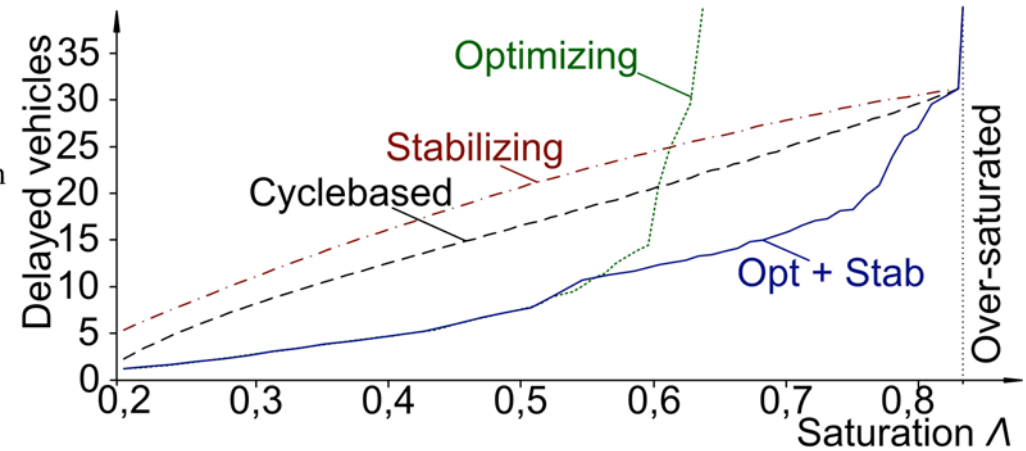


Optimal compromise between **coordination** and local **flexibility**

# Self-Organized Control of a Single Intersection

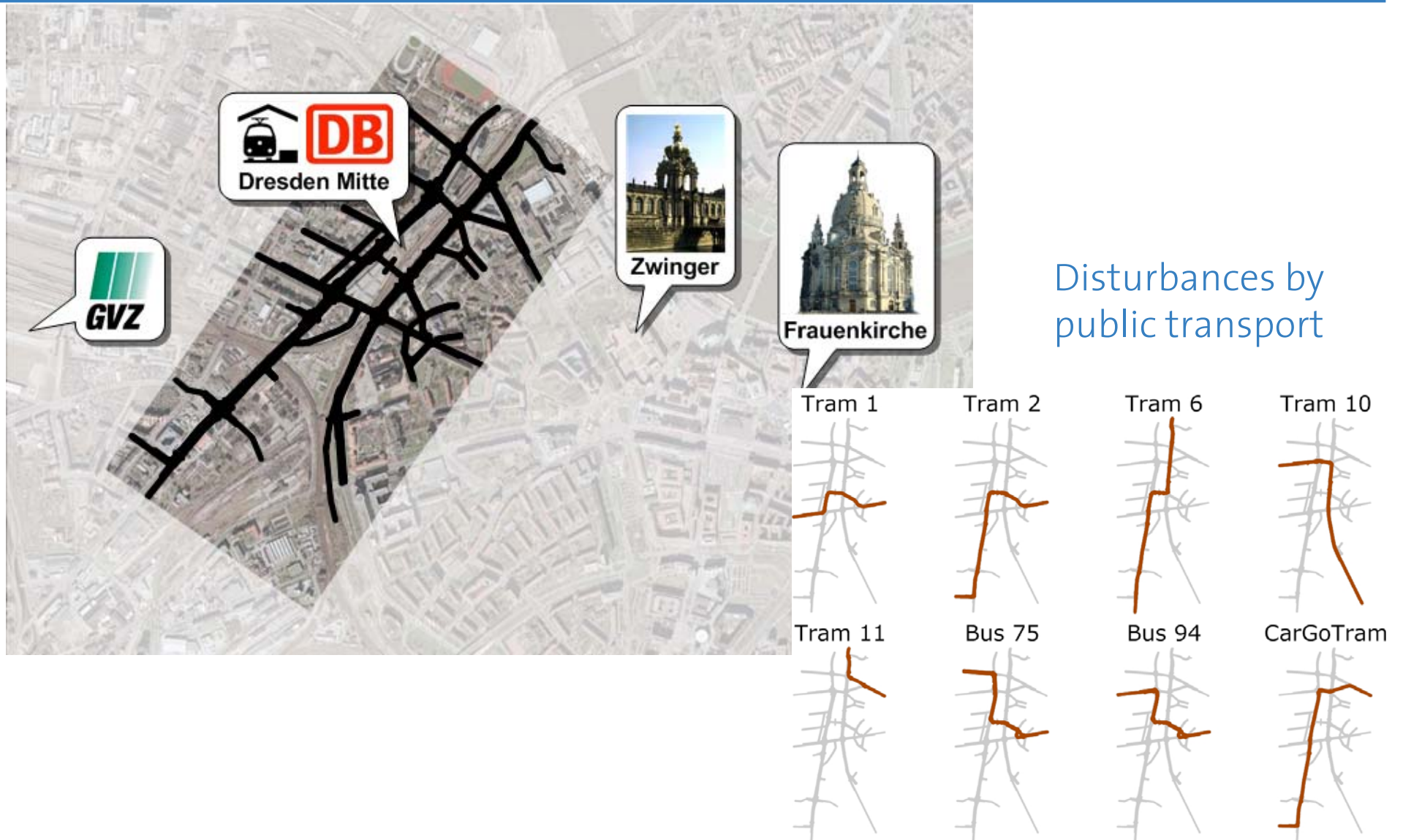


- The switching sequence adapts to the arrival patterns.
- We reach **flexible switching** with a **maximum red time duration**.
- Due to the flexibility, we observe a reduction in both, the total **waiting time** and its **variance**.
- Stabilization mechanism **avoids “social dilemmas”** based on local optimization



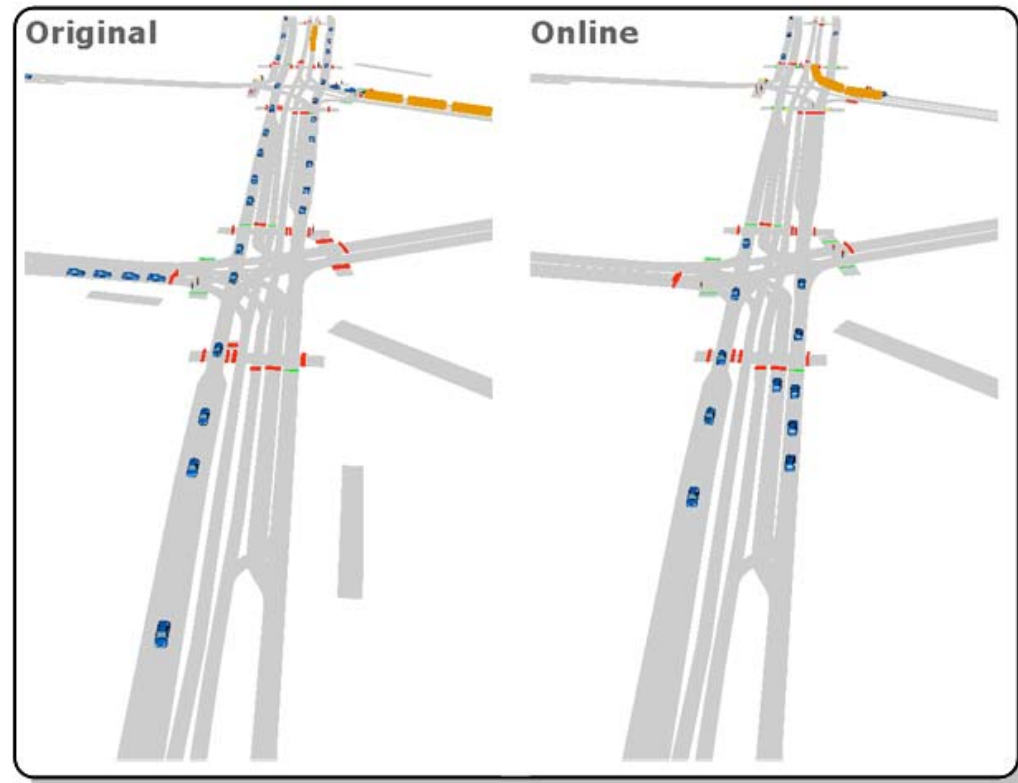


# The Measurement and Control Area



Disturbances by public transport

# Comparison of Current and Self-Organized Traffic Light Control



1000.20

1000.20

## Gain in Performance



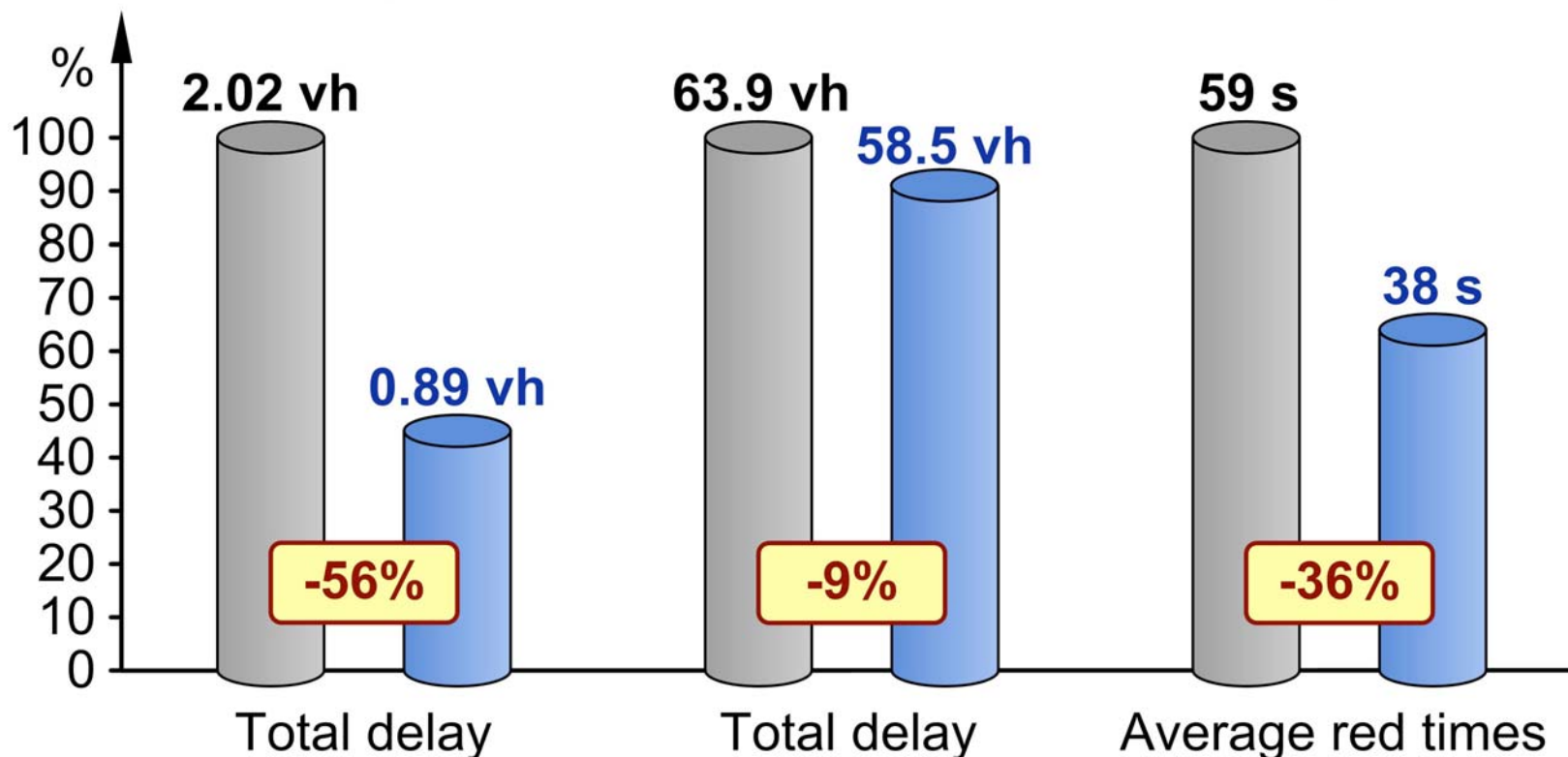
**Public transport**



**Motorized traffic**

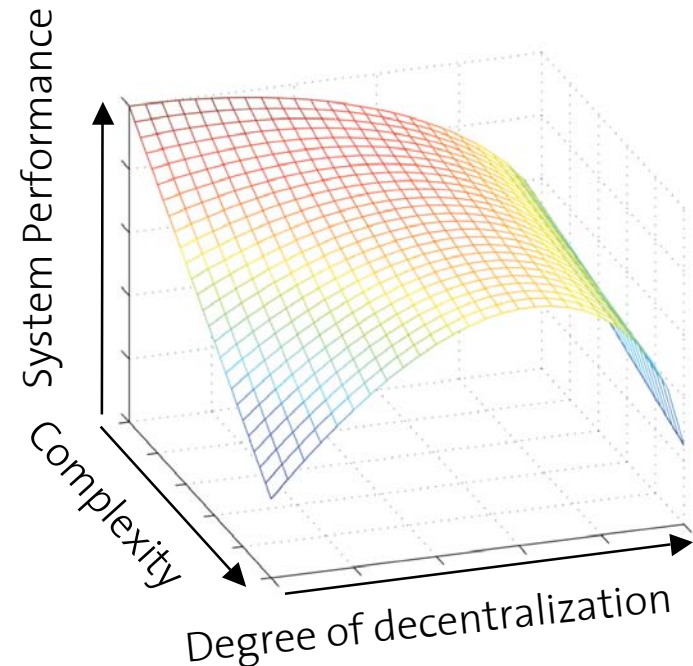


**Pedestrians and Cyclists**



## Centralized Control and Its Limits

- Advantage of centralized control is large-scale coordination
- Disadvantages are due to
  - vulnerability of the network
  - information overload
  - wrong selection of control parameters
  - delays in adaptive feedback control
- Decentralized control can perform better in complex systems with heterogeneous elements, large degree of fluctuations, and short-term predictability, because of greater flexibility to local conditions and greater robustness to perturbations



(Windt, Böse, Philipp, 2006)

# ETH Zurich's Competence Center Coping with Crises in Complex Socio- Economic Systems

Kay Axhausen, Lars-Erik Cederman,  
Dirk Helbing, Hans Herrmann,  
Frank Schweitzer, Didier Sornette

## CCSS

COPING WITH CRISES  
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A Competence Center of ETH Zurich

