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Modeling Social Systems, Self-Organized Coordination, and the Emergence of Cooperation

Dirk Helbing,

with Anders Johansson and Sergi Lozano

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).

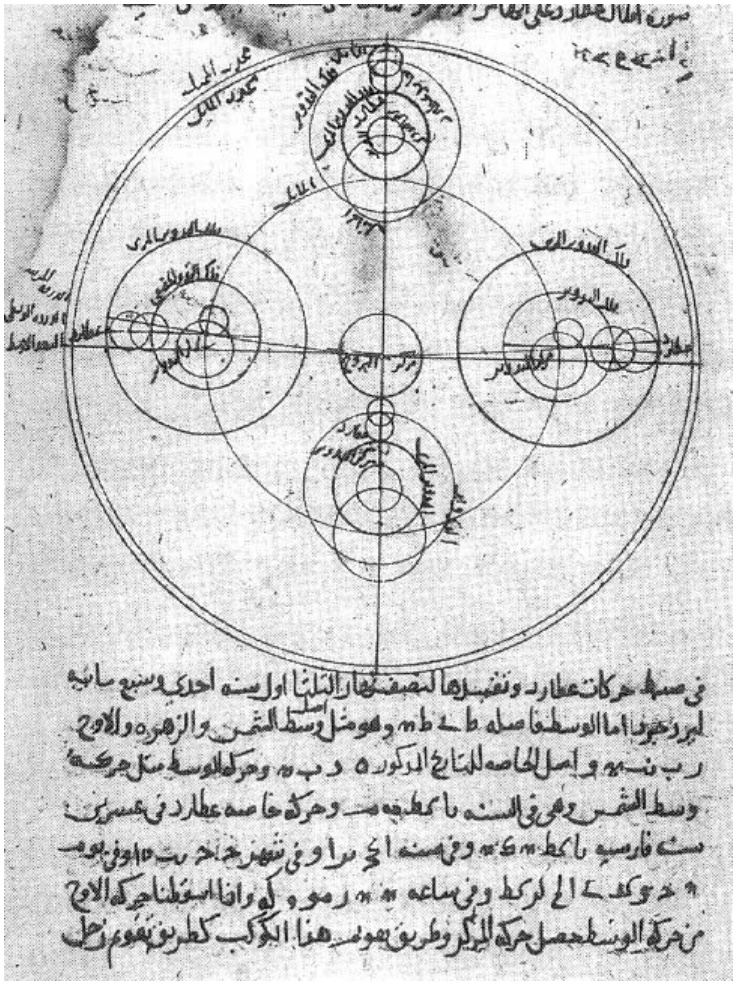
Auguste Comte considered sociology to be the queen of sciences. Comparing, for example, sociology with biology and physics, the systems it deals with are the most complex ones.

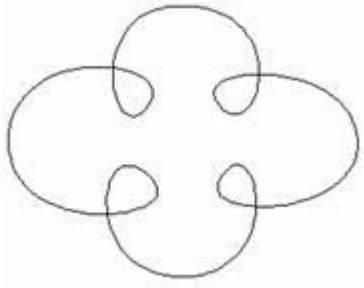
What Makes Quantitative Theoretical Progress Difficult

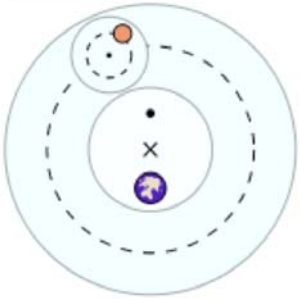
- Some of the reasons are
  - the huge number of variables involved,
  - the relevant variables and parameters are often unknown,
  - empirical studies are limited by technical, financial, and ethical issues,
  - factors such as memory, anticipation, decision-making, communication, interpretation of 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.

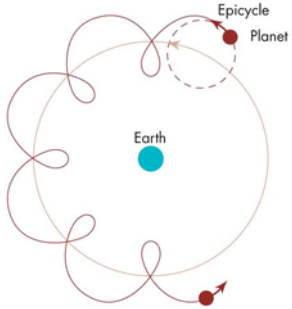
A Note on Simple Models

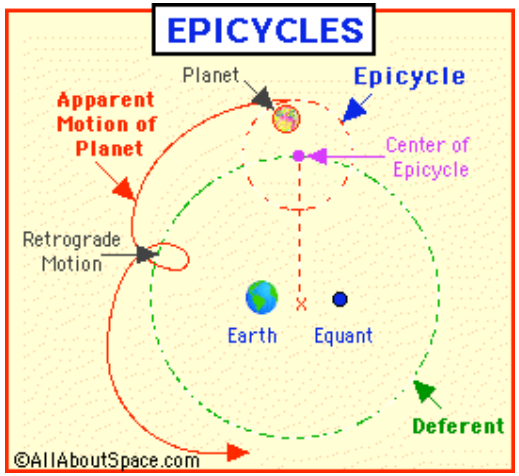
Geocentric Picture: Epicycles around the Earth



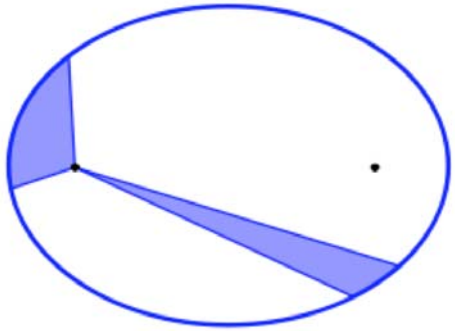




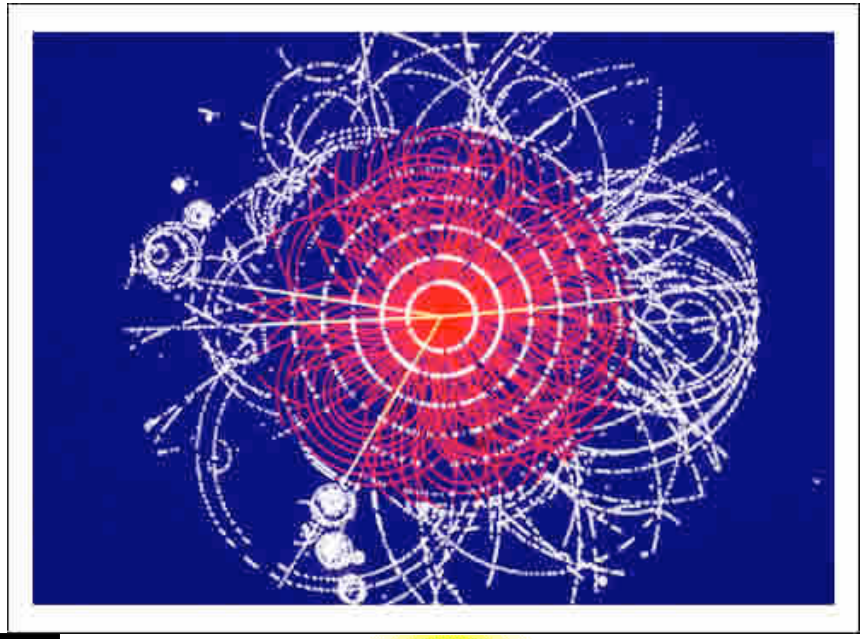


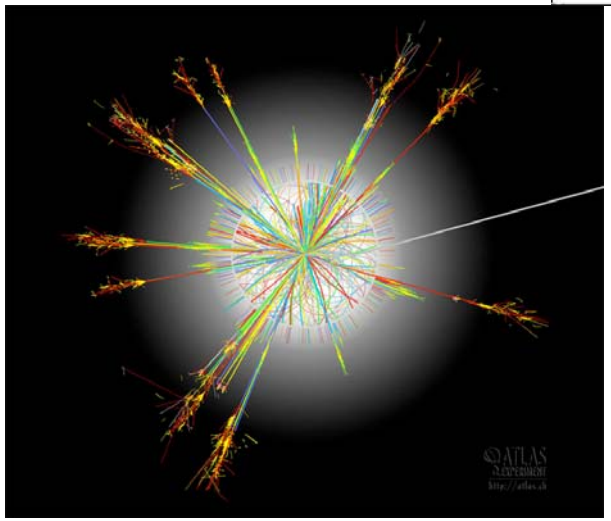


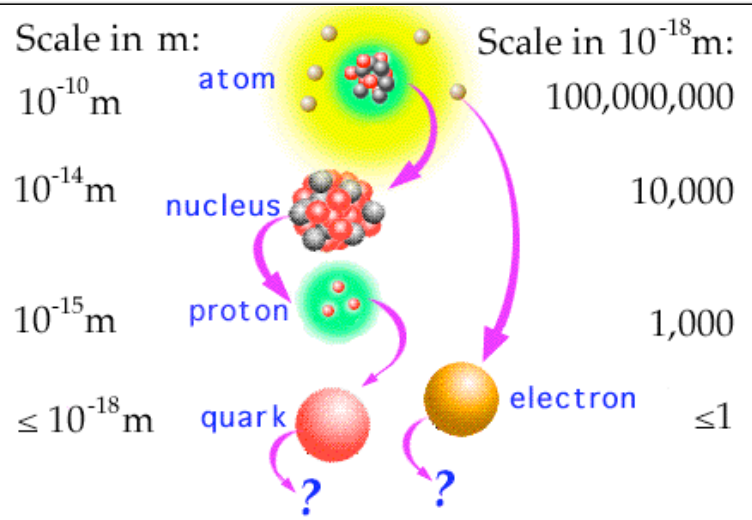
Heliocentric Picture: Elliptical paths around the sun



Can We Understand a System from Elementary Processes?



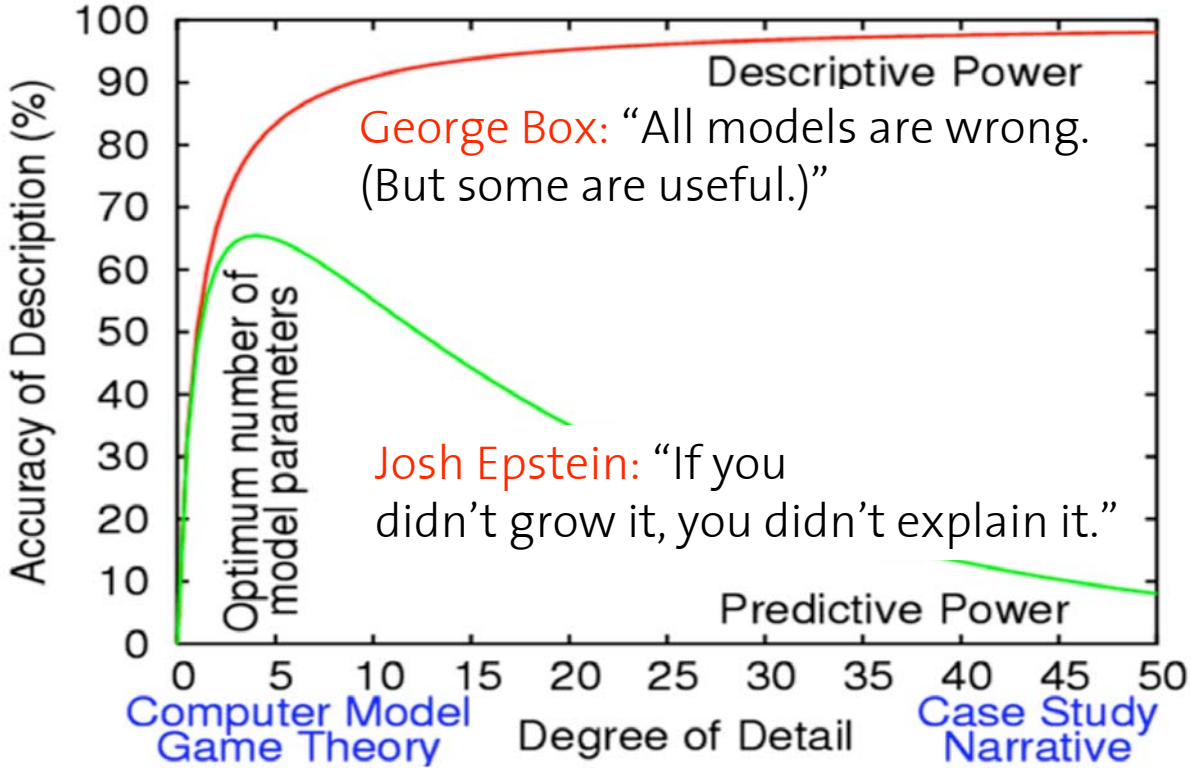




The Need of Simplification and Abstraction

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

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.

Some Fundamental Phenomena in Social Systems

- Homophily (interaction with similar people) and social agglomeration
- Social influence: Collective decision making and behavior, voting behavior
- Cooperation in social dilemma situations
- Group identity: Group formation, group and crowd dynamics, coalition formation, social movements, organizations
- Social norms and conventions, conformity, integration, social roles and socialization, social institutions, evolution of language and culture
- Social differentiation, inequality, and segregation
- Social structure, hierarchical organization, etc.
- Deviance and crime
- Social exchange, trading, market dynamics
- Conflicts, violence, and wars

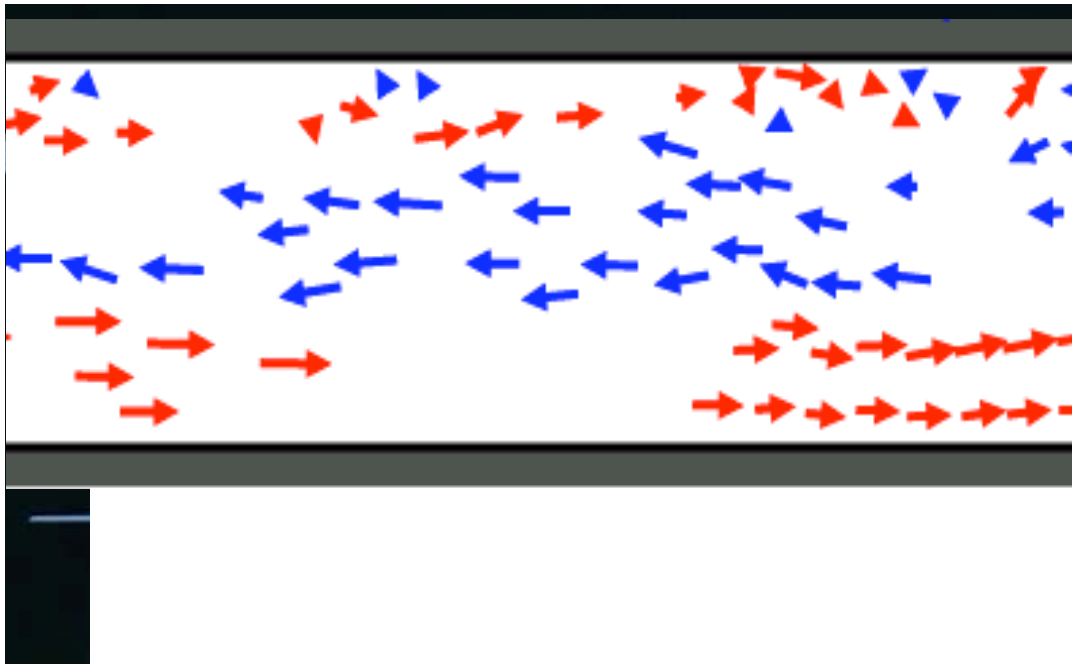
Model Ingredients: Elementary Properties of Individuals

- Birth, death, and reproduction
- Individuals need resources (e.g. eat and drink)
- Competition, fighting ability
- Toolmaking ability, possibility to grow food, hunt etc.
- Perception
- Curiosity, exploration behavior, ability for innovation
- Emotions
- Memory
- Mobility and carrying capacity
- Communication
- Teaching ability
- Possibility of trading and exchange

Goal: Derive the fundamental phenomena from these elementary properties

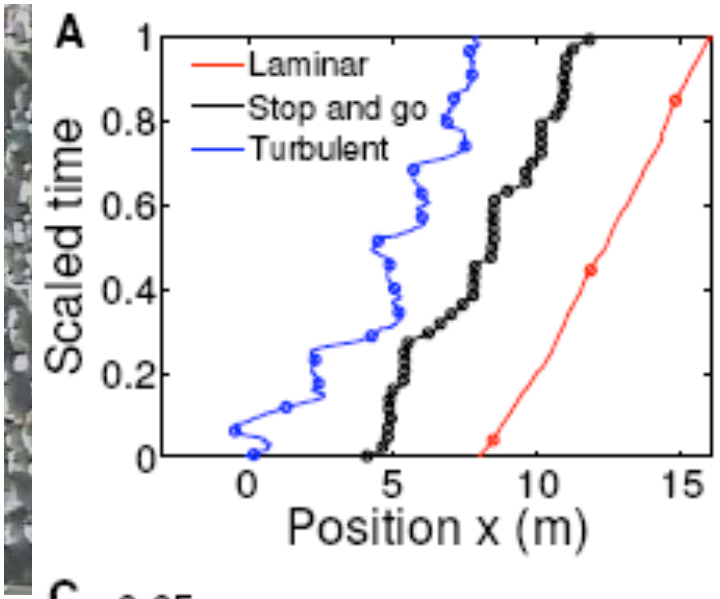
Emergence of Coordination in Pedestrian Counterflows

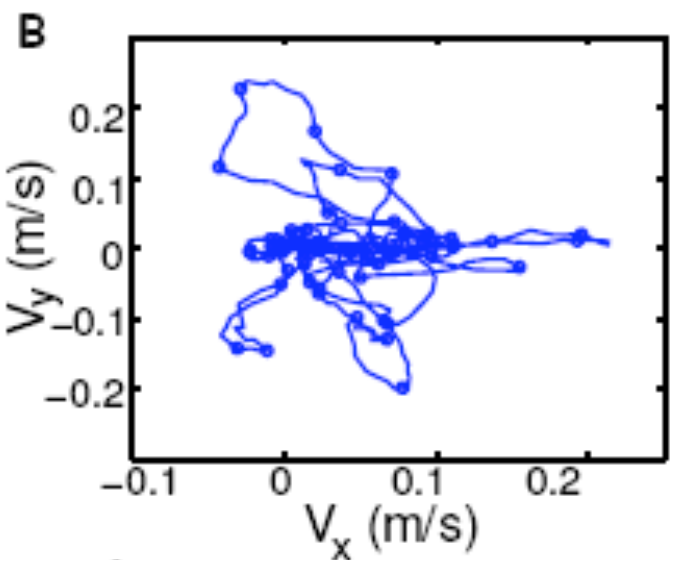
Acts like Adam Smith's "invisible hand"



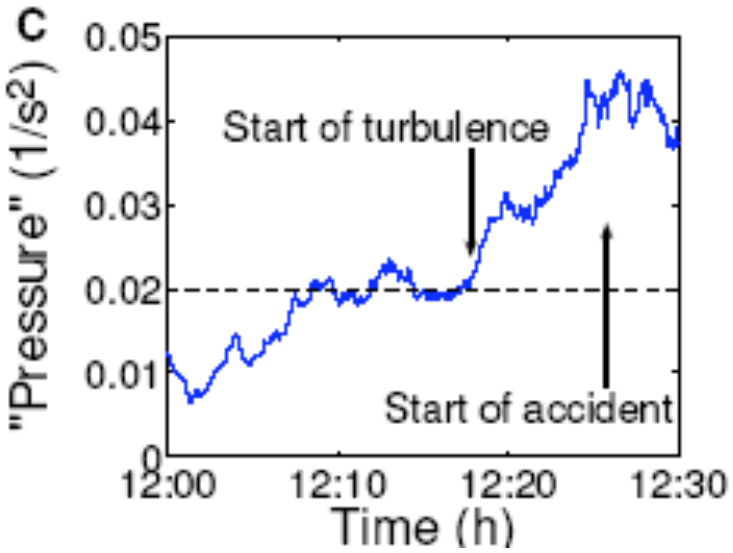
Based on individual interactions, lanes of uniform walking directions emerge in pedestrian crowds by self-organization. This constitutes a „macroscopic" social structure. Nobody orchestrates this collective behavior, and most people are not even aware of it. A behavioral convention „institutionalizes"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

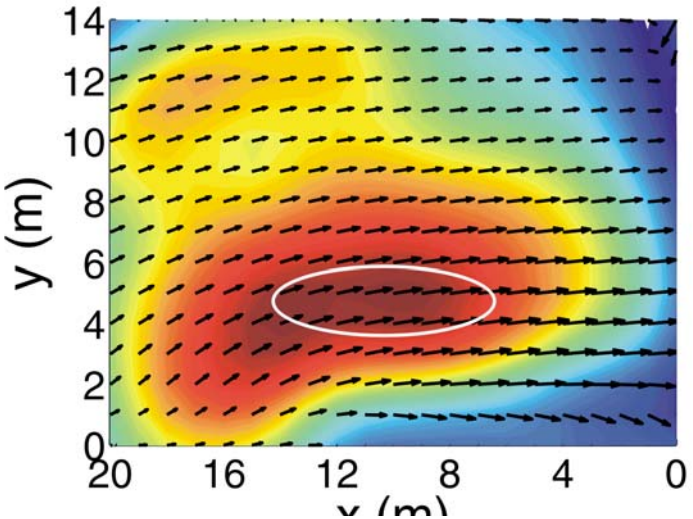
Breakdown of Coordination: Stop-and-Go and Turbulence Flow





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”

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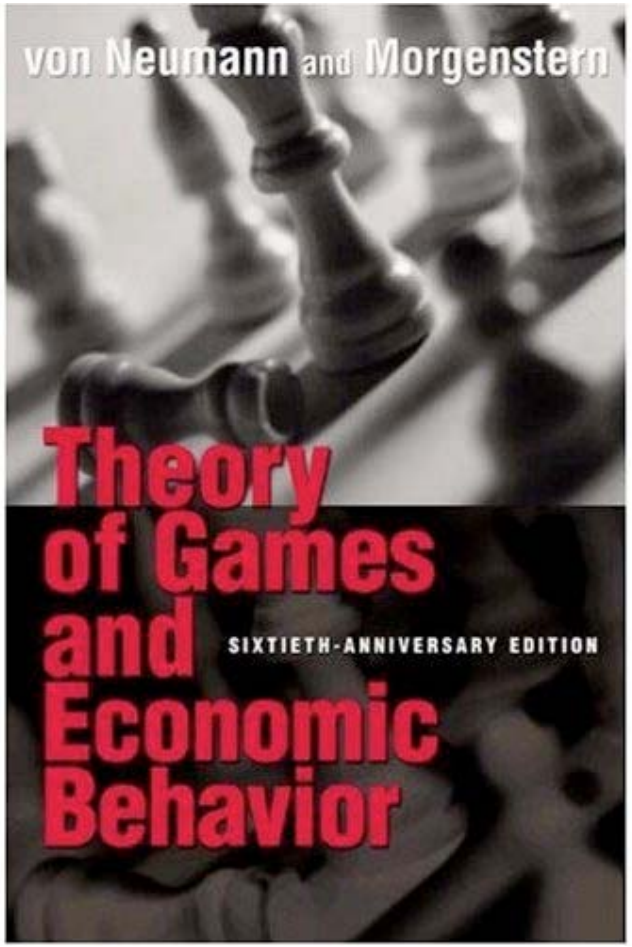
Evolutionary Game Theory:

How Spatial Interactions, Migration, Social Inequality, Globalization and Heterogeneous Preferences Can Change the World in Surprising Ways

What is Game Theory?

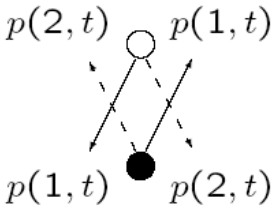
Game theory is a mathematical discipline providing a set of analytical tools and solutions concepts, which have explanatory and predictive power in interactive decision situations, when the goals and preferences of the participating players are potentially in conflict.

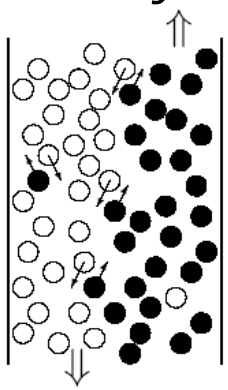


J. von Neumann, O. Morgenstern, *Theory of Games and Economic Behaviour* (Princeton University, Princeton, 1944).

Self-Organization of A Behavioral Convention

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





Pedestrian 1 \ Pedestrian 2	left	right
left	B B	o o
right	o o	B B

B = benefit of evading on the same side = time saved compared to one pedestrian evading to the right and the other one to the left

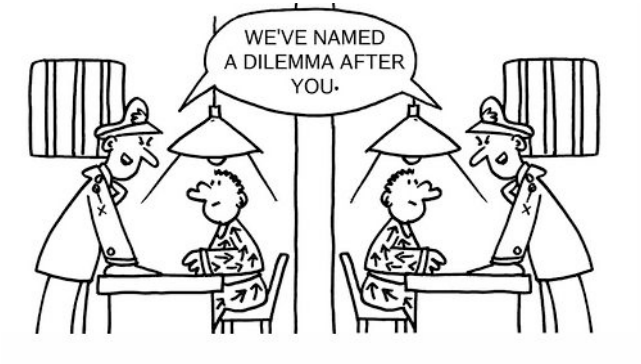
If p(1,t) denotes the probability of pedestrians to evade on the right and p(2,t) to the left, the expected payoff ("success") is S(i,t) = Bp(i,t), when using strategy i. The average success of pedestrians is A(t) = p(1,t)Bp(1,t) + p(2,t)Bp(2,t), where p(2,t) = 1 - p(1,t). Due to strategy changes (success-driven 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)

$$dp(i,t)/dt = -2rB[p(i,t)-1/2]\, p(i,t)\, [1-p(i,t)]$$ i=1: right, i=2: 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 "tempation" to defect. Additionally, one typically assumes S+T < 2R.



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

For example:

$S_1 = S_2 = S = -5$

$P_1 = P_2 = P = -2$

$R_1 = R_2 = R = -1$

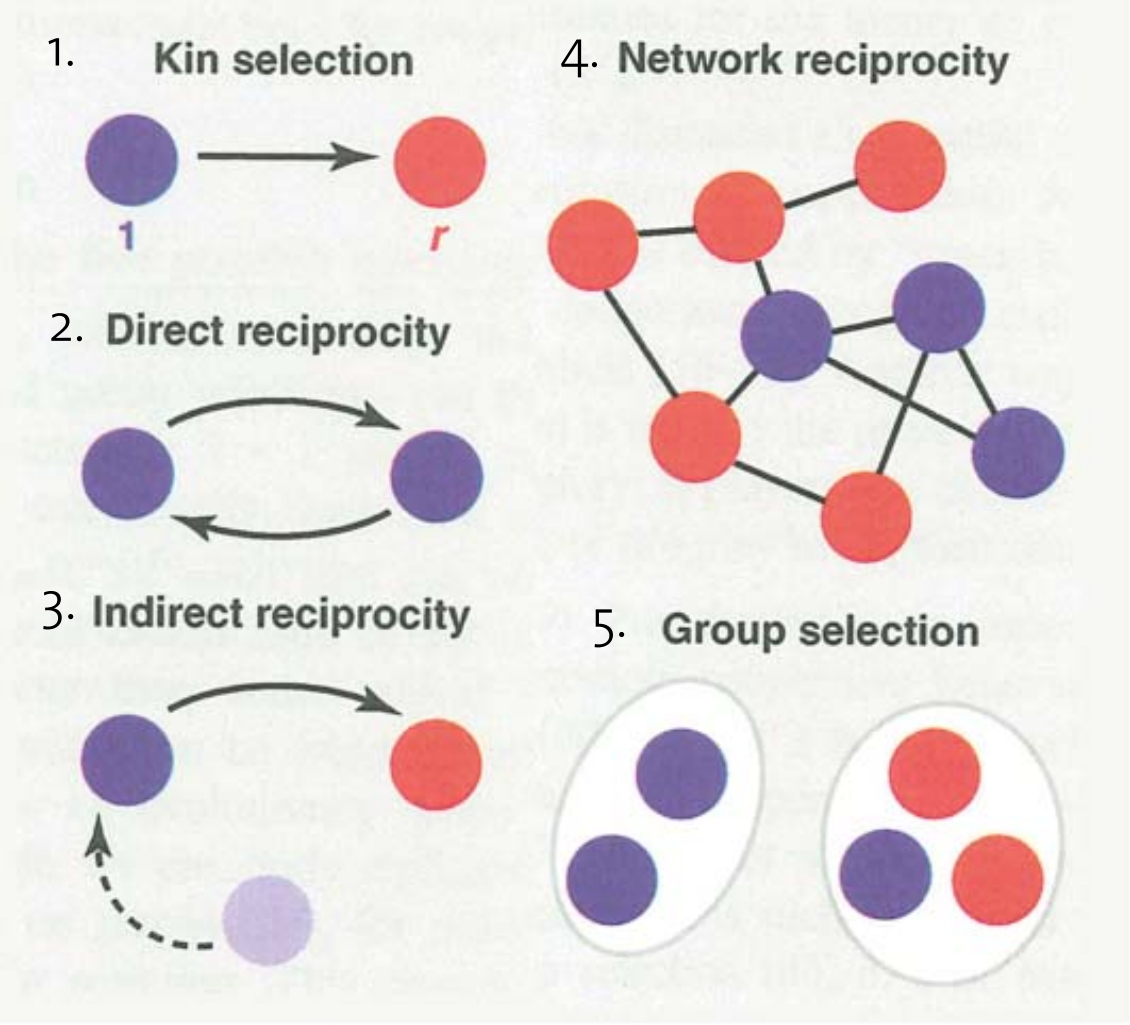
$T_1 = T_2 = T = 0$

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

Overview of Mechanisms Supporting Cooperation

Mechanisms:

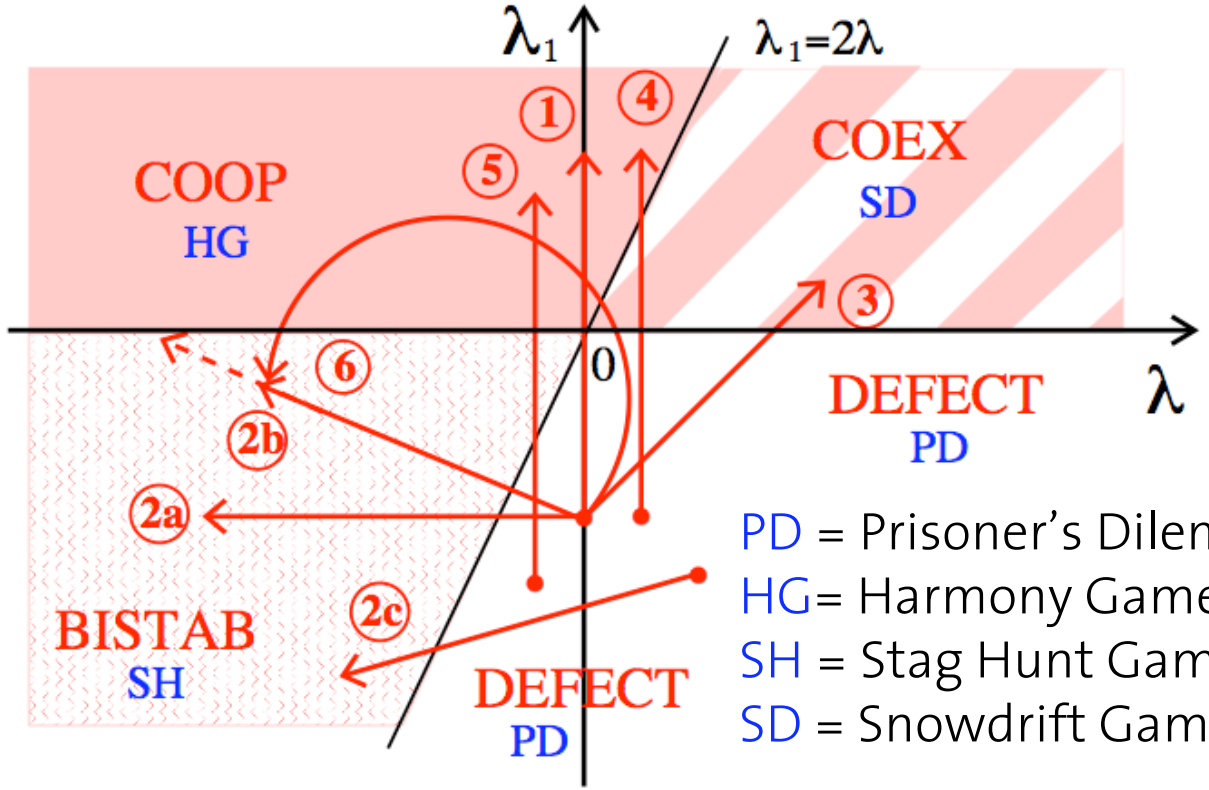
1. Genetic relatedness
2. Repeated interaction
3. Reputation
4. Clustering
5. Competition also *between* groups



Source:
M. A. Nowak,
Science **314**,
1560 (2006).

Routes to Cooperation

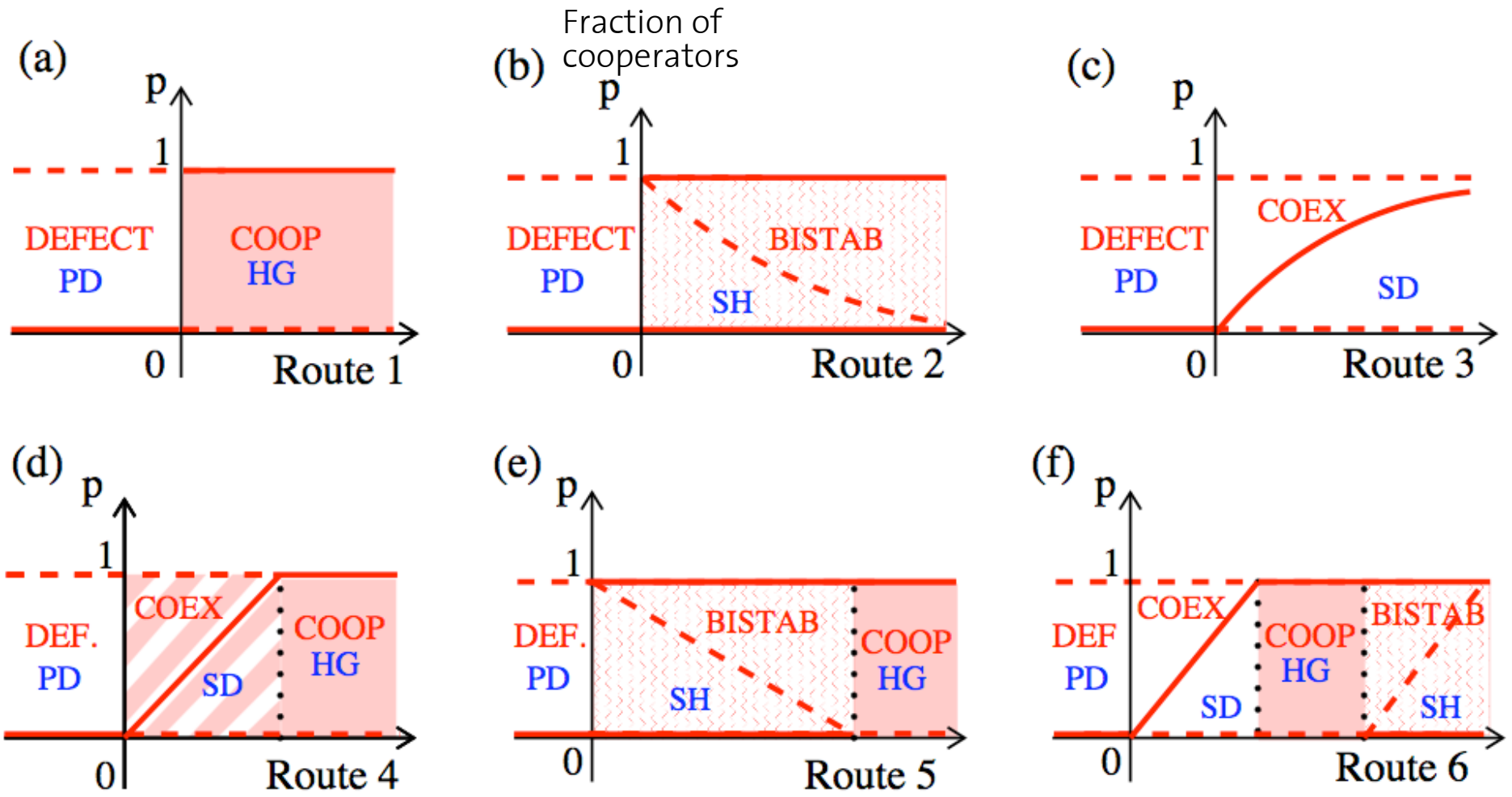
Routes to cooperation require to destabilize defection (PD --> SD)
or to stabilize cooperation (PD -->SH) or both (PD -->HG)



PD = Prisoner's Dilemma
HG= Harmony Game
SH = Stag Hunt Game
SD = Snowdrift Game

Route 1: Kin+group selection, network reciprocity, 2a: Direct reciprocity, 2b: Indirect reciprocity, 2c: Costly punishment, 3: Network interactions, 4+5: Kinship relations

Routes to Cooperation when Manipulating Payoffs

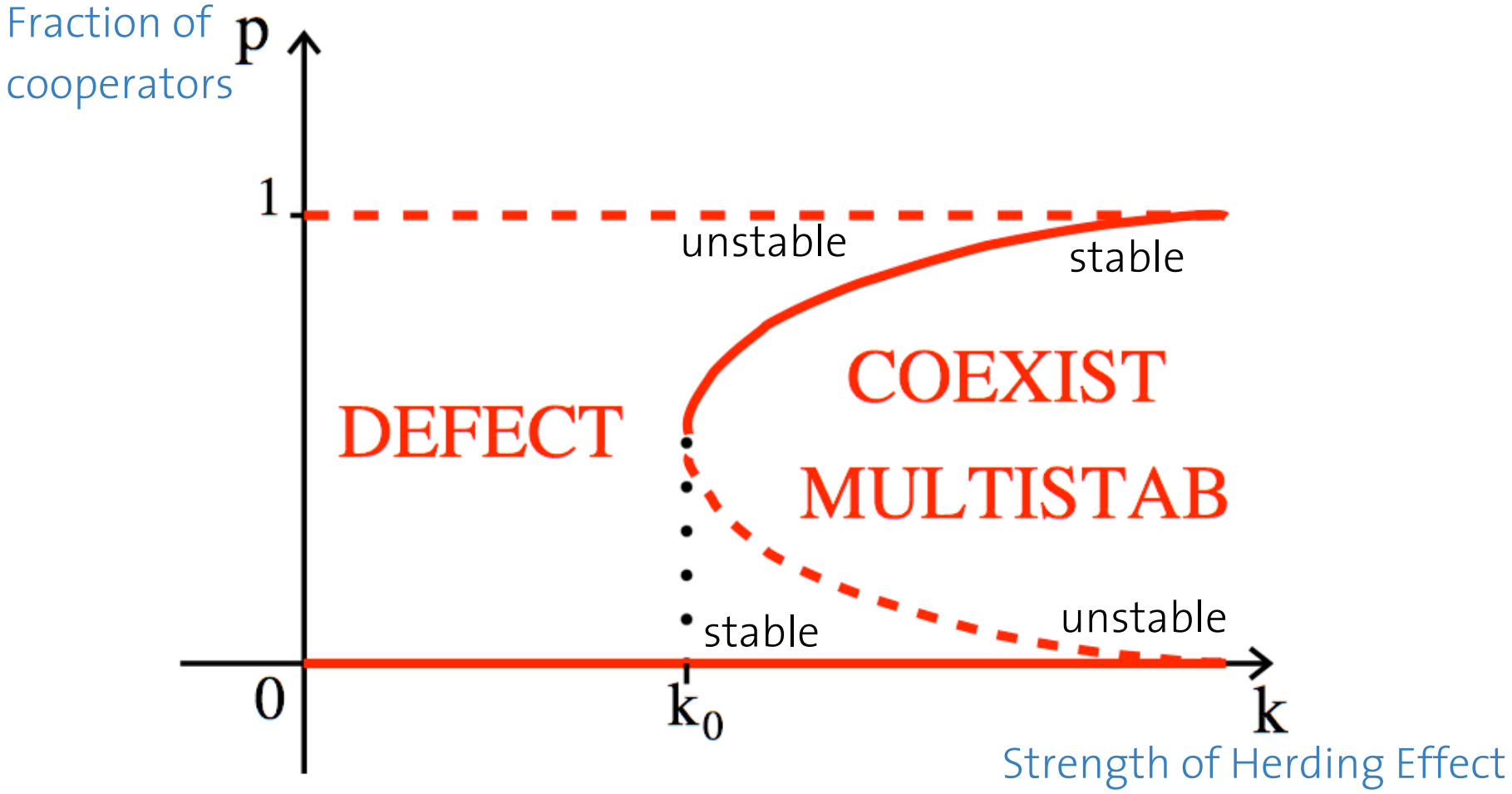


PD=Prisoner's Dilemma, HG=Harmony Game, SH=Stag Hunt, SD=Snowdrift Game

Herding Effect in the Prisoner's Dilemma "Inverts" the Outcome!

Assume that payoffs depend on the strategy distribution

Even a simple linear dependence changes system behavior dramatically!



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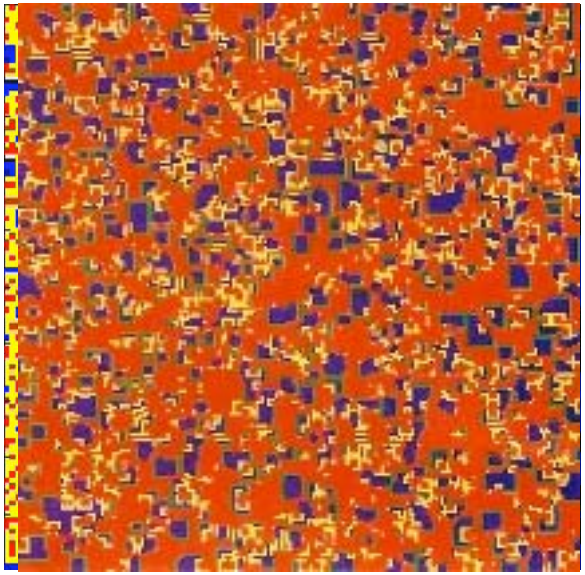
Combining Game Theoretical Interactions with Success-Driven Motion (Migration)

Start with the Spatial Prisoner's Dilemma...

Nowak and May (1992) have extended the prisoner's dilemma to simultaneous spatial interactions in an LxL 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

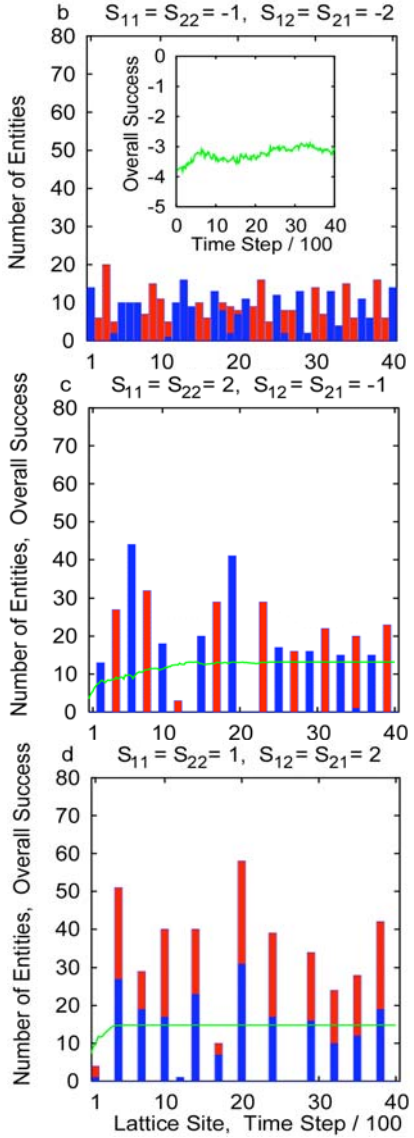
Marrying Models of Motion with Game Theory

- What will happen when integrating game-theoretical models and models of mobility?
- Will the resulting individual-based models produce new kinds of self-organization?
- Why are group, class, and niche formation, agglomeration, segregation etc. so widespread in social, economic, and biological systems, although one often tries do counteract these phenomena?
- What is the role of mobility for social cooperation?
- Is migration a “bad thing”?
- Does leaving the birth place necessarily reduce cooperation by cutting social ties, as one may think?

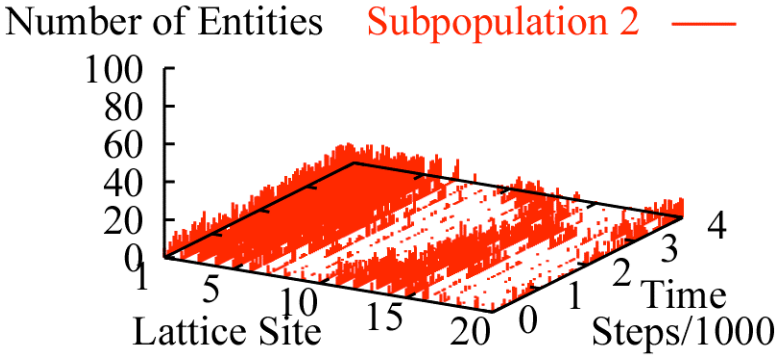
… and Extend It, Considering Success-Driven Migration

- We will now combine strategic interaction, as described by game theory, with a special, success-driven kind of motion. Individuals are assumed to have a preference for a favorable neighborhood. A higher expected payoff, i.e. a higher level of cooperation, makes a neighborhood more attractive.
- We generalize the spatial prisoner's dilemma by adding a success-driven motion step before the interaction and imitation steps. We assume that $N < L^2$ grid locations are occupied, and individuals can move to empty sites.
- To keep things simple, for each empty site within a certain mobility radius M, each individual is assumed perform a "test interaction" to determine the fictious total payoff that would result when moving to this location ("neighborhood exploration"). The individual would then move to the location with the highest payoff, and in case of several equivalent locations, to the closest of them. We assume a random sequential update and periodic boundary conditions.
- Restricting migration to empty sites resembles relocations (e.g. between apartments) and reflects that individuals tend to occupy a certain territory.

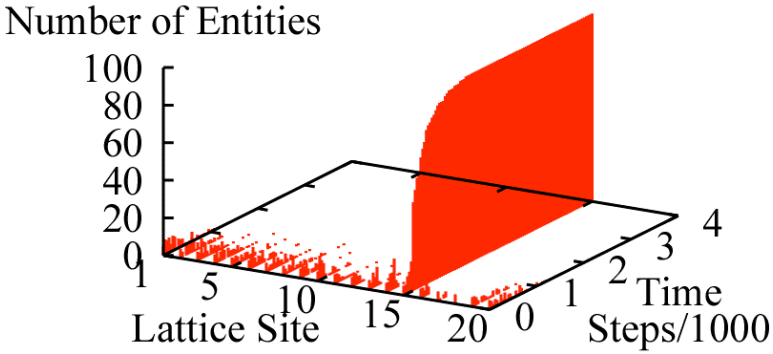
Spatio-Temporal Pattern Formation Due to Success-Driven Migration



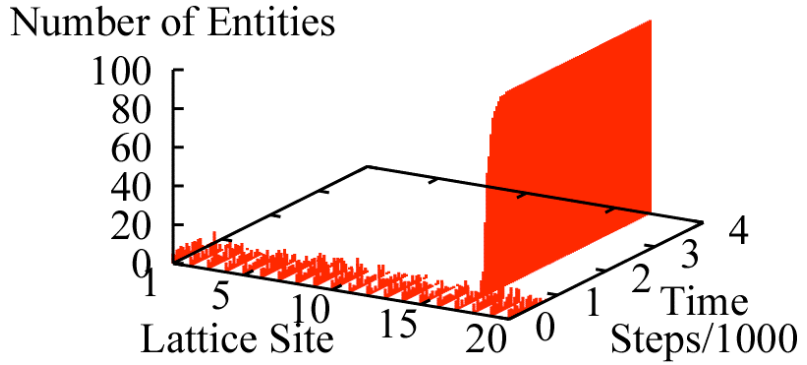
Segregation
("Lane Formation")



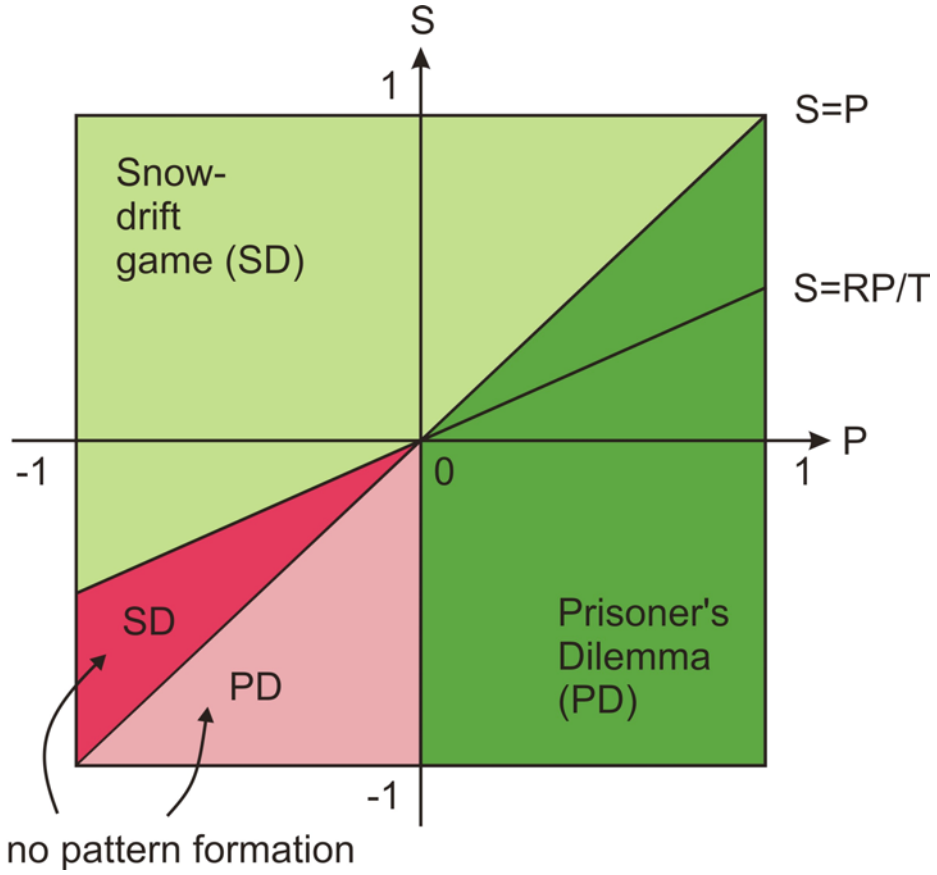
Repulsive Agglomeration
("Ghetto Formation")

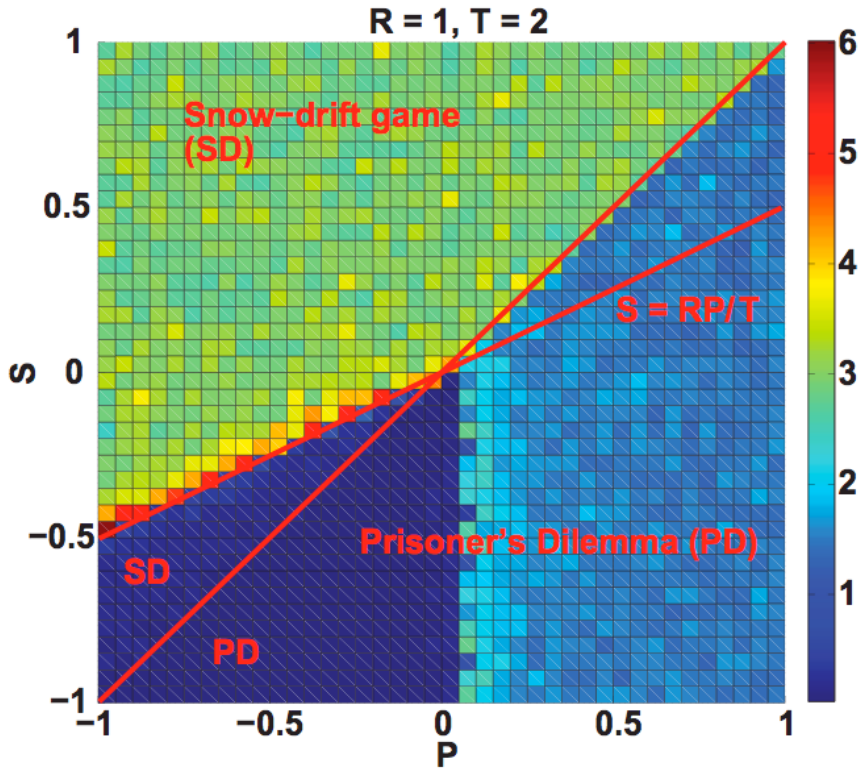


Attractive Agglomeration
("Clustering")



Agglomeration in the Prisoner's Dilemma and Snow Drift Game





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... to be continued with the Lecture on Cooperation, Norms, and Conflict