ETH
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Cooperation and Conflict in the Prisoner's Dilemma and the Emergence of Norms

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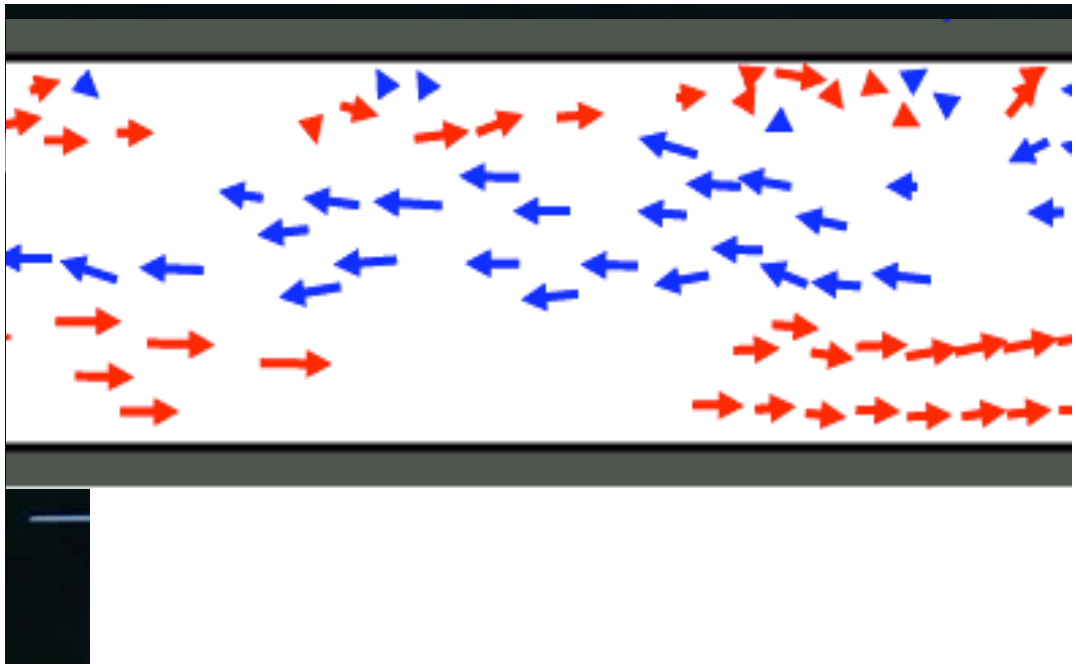
with Wenjian Yu, Carlos Roca, Sergi Lozano,

Anders Johansson, Heiko Rauhut and others

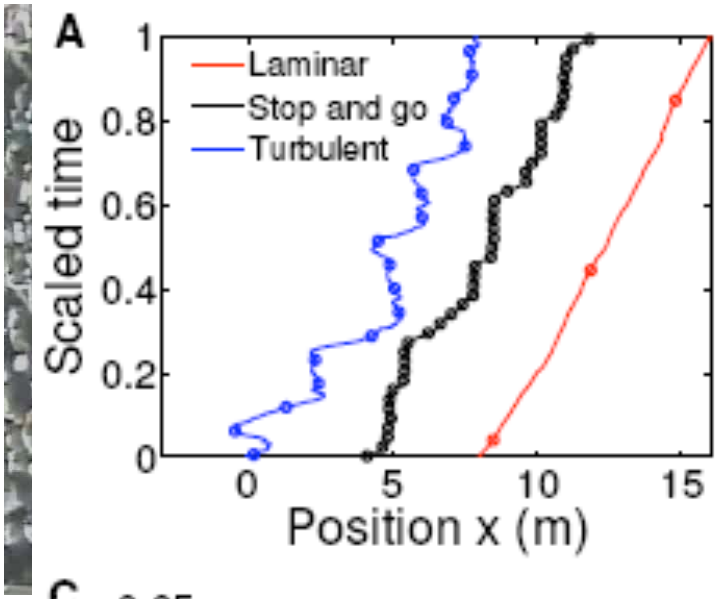
Emergence of Coordination in Pedestrian Counterflows

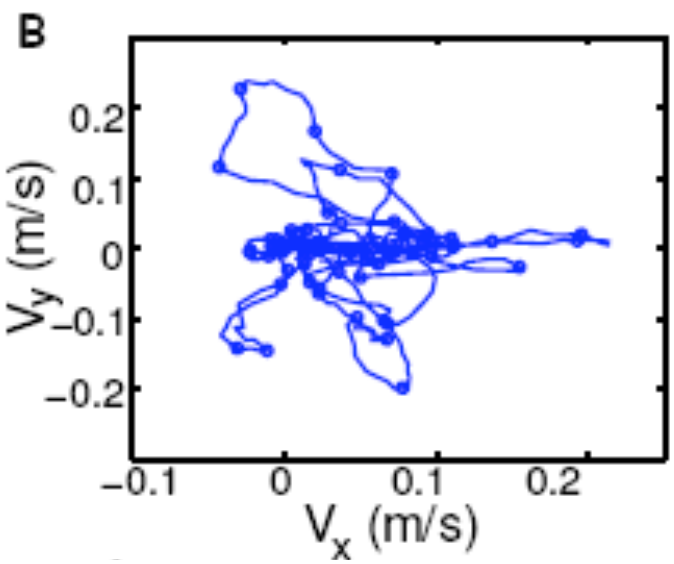
Acts like Adam Smith's "invisible hand"



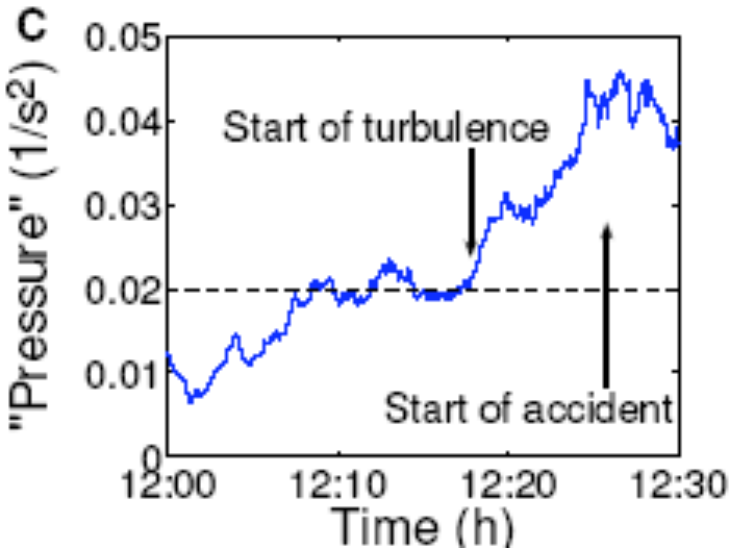
Based on individual interactions, lanes of uniform walking directions emerge in pedestrian crowds by self-organization. This constitutes a „macroscopic" social structure. Nobody orchestrates this collective behavior, and most people are not even aware of it. A behavioral convention „institutionalizes"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

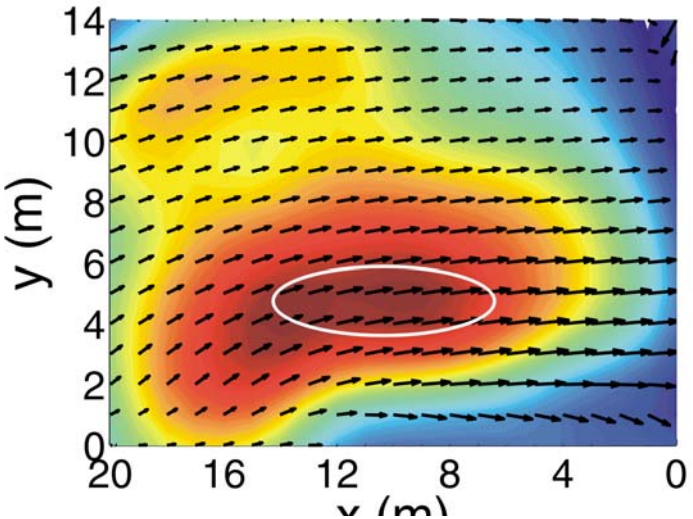
Breakdown of Coordination: Stop-and-Go and Turbulence Flow





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





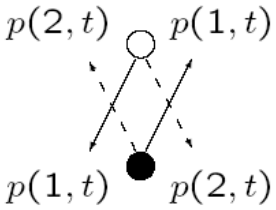
Increased driving forces occur in crowded areas when trying to gain space, particularly during “crowd panic”

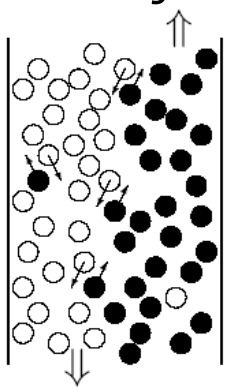
The Miracle of Cooperation and Social Norms

- Without cooperation, our social benefit systems would not work, our environment would be overly exploited and polluted, and we would be victims of the "tragedy of the commons", the public goods dilemma, i.e. society would be on a primitive level.
- Social dilemmas are mathematically described by the public goods game, the prisoner's dilemma, the snowdrift, stag hunt, and other games.
- Norms represent shared behavioral rules and constitute a major part of our culture. They have been called the cement (J. Elster) or grammar of society (C. Bicchieri). In fact, they guide our behavior like an invisible hand (A. Smith), thereby giving social interactions a certain structure ("scaffolding"), and they support efficient interactions, thereby acting like a "lubricant".
- While the evolution of conventions is described by coordination games, the evolution of norms seems to require a sanctioning ("punishment") of non-conforming behavior.
- Still, the evolution of cooperation and norms is not fully understood. For example, how are the two related? Is it the same problem or not?

Evolutionary Games: 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	Pedestrian 2: 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: $dp(i,t)/dt = r\,[S(i,t) - A(t)]p(i,t)$

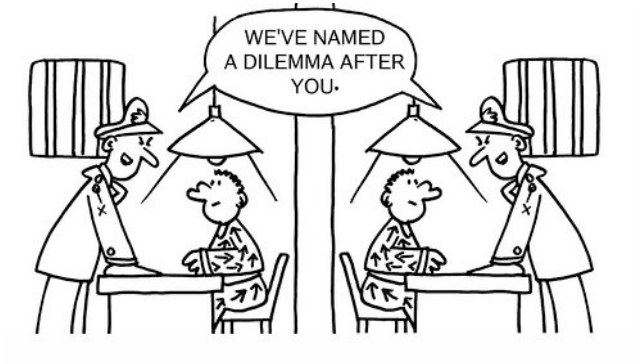
$$dp(i,t)/dt = -2rB[p(i,t)-1/2]\,p(i,t)\,[1-p(i,t)]$$ i=1: right, i=2: left

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)

The Prisoner's Dilemma (PD)

In the prisoner's dilemma, the same analysis leads to defection only.

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:

$S_1 = S_2 = S = -5$

$P_1 = P_2 = P = -2$

$R_1 = R_2 = R = -1$

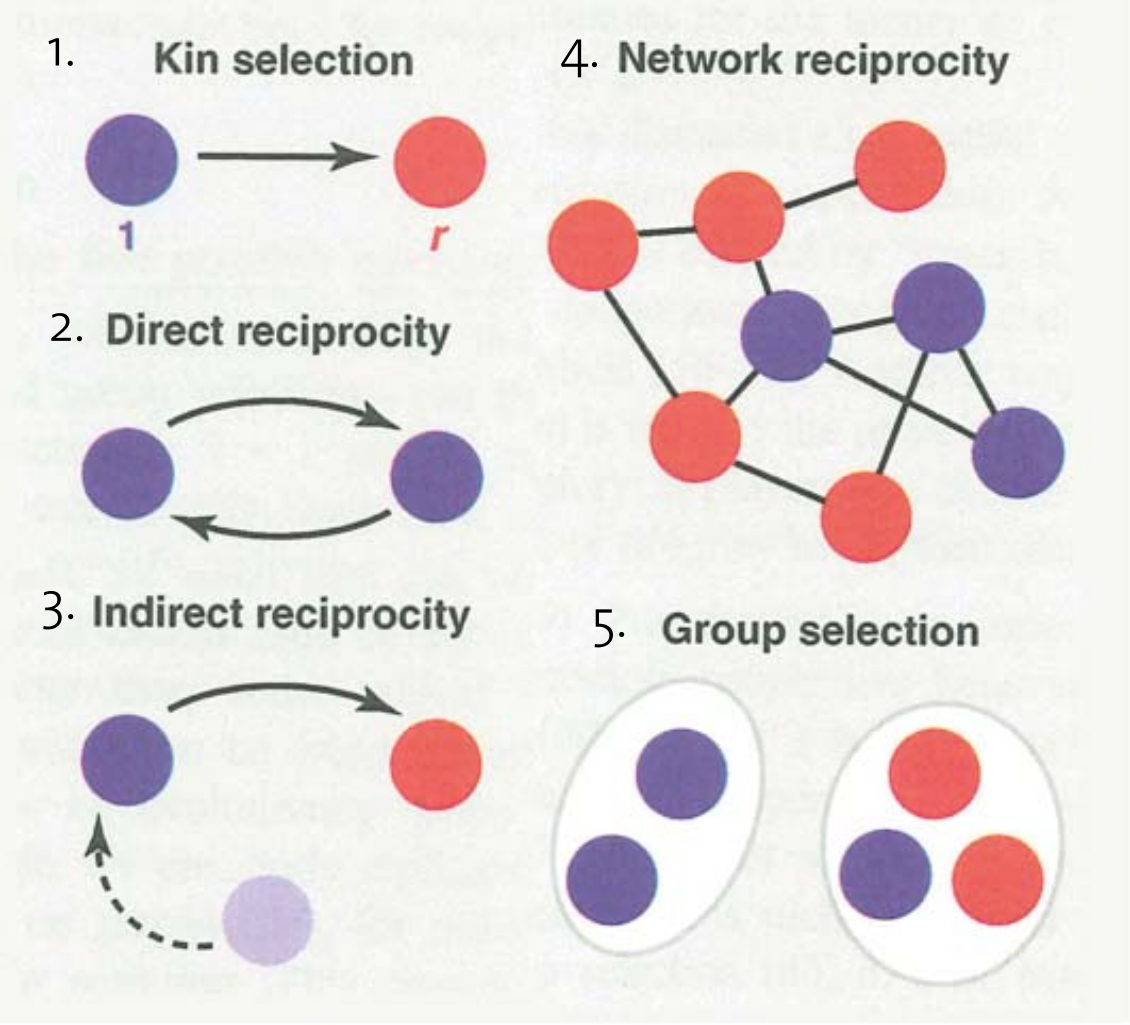
$T_1 = T_2 = T = 0$

Many "social dilemmas" are of a similar kind (e.g. the public goods game)

Overview of Mechanisms Supporting Cooperation

Mechanisms:

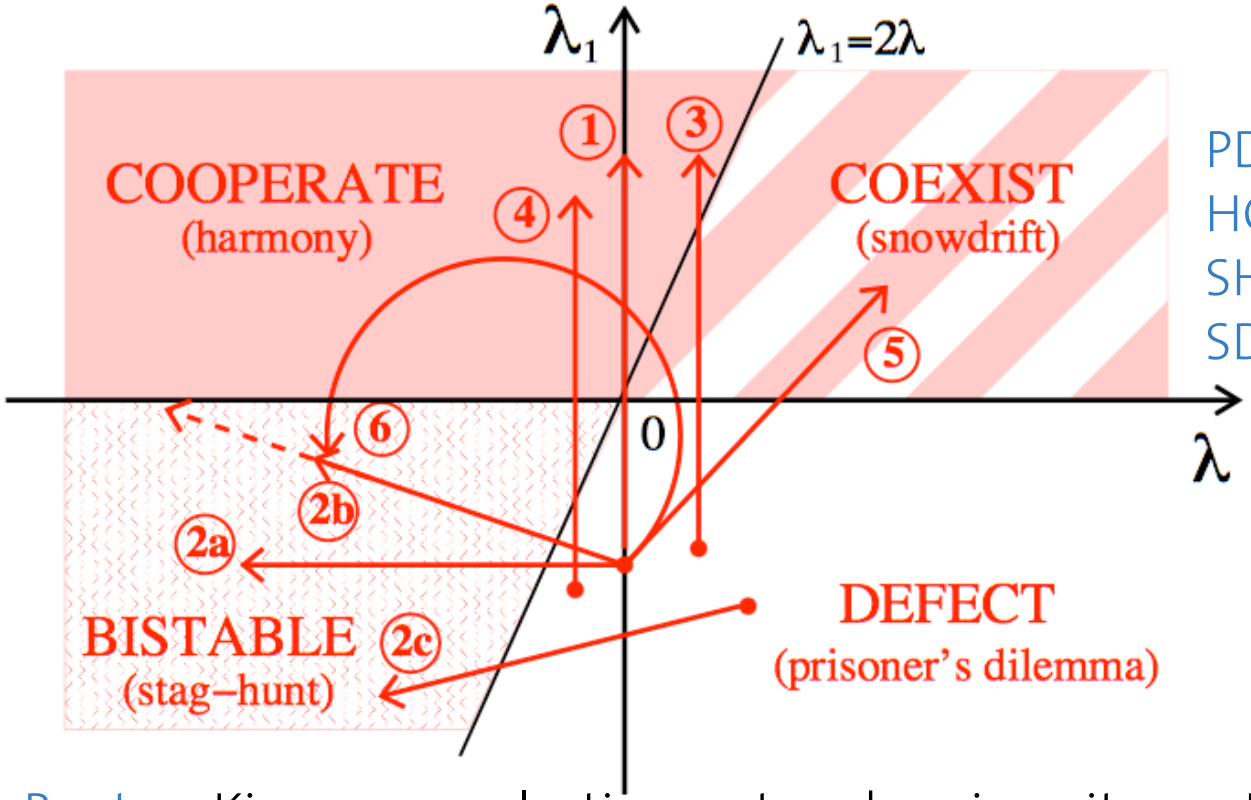
1. Genetic relatedness
2. Repeated interaction
3. Reputation
4. Clustering
5. Competition also *between* groups



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

Routes to Cooperation

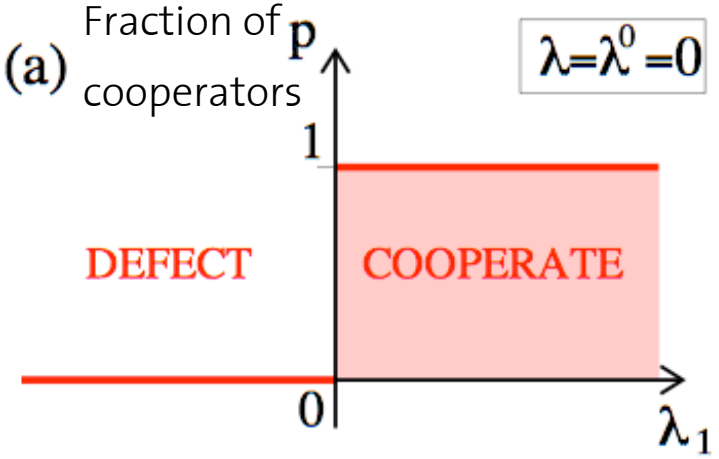
Routes to cooperation require to destabilize defection (PD --> SD)
or to stabilize cooperation (PD -->SH) or both (PD -->HG)



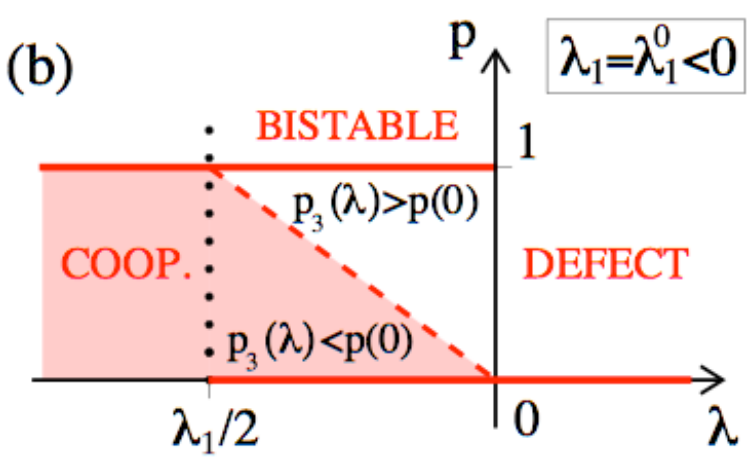
PD = Prisoner's Dilemma
HG= Harmony Game
SH = Stag Hunt Game
SD = Snowdrift Game

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

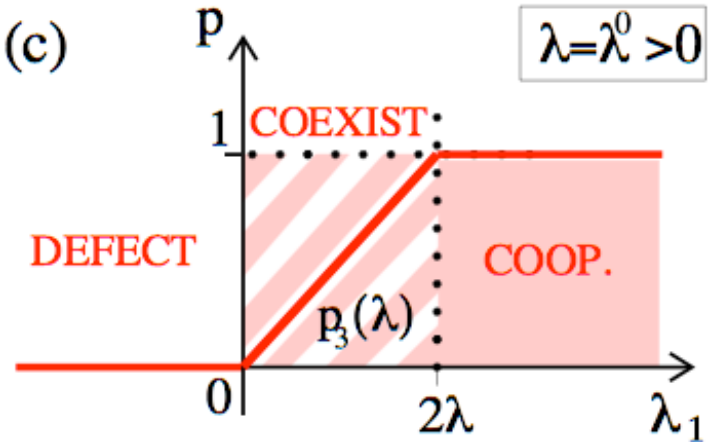
Routes to Cooperation when Manipulating Payoffs



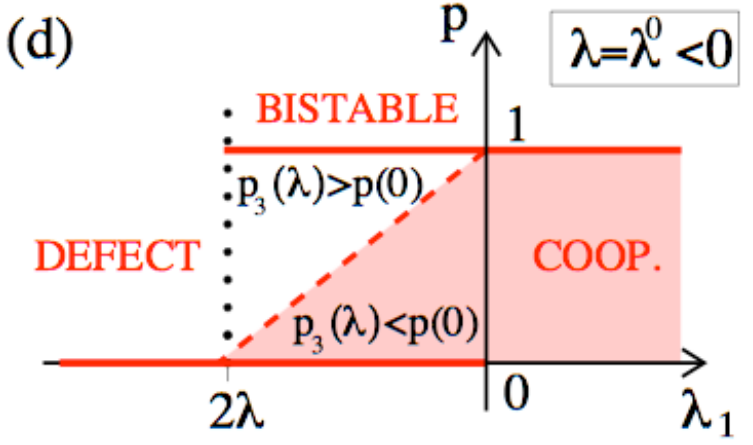
Route 1: From PD to HG



Route 2: From PD to SH



Route 3: From PD to HG via SD



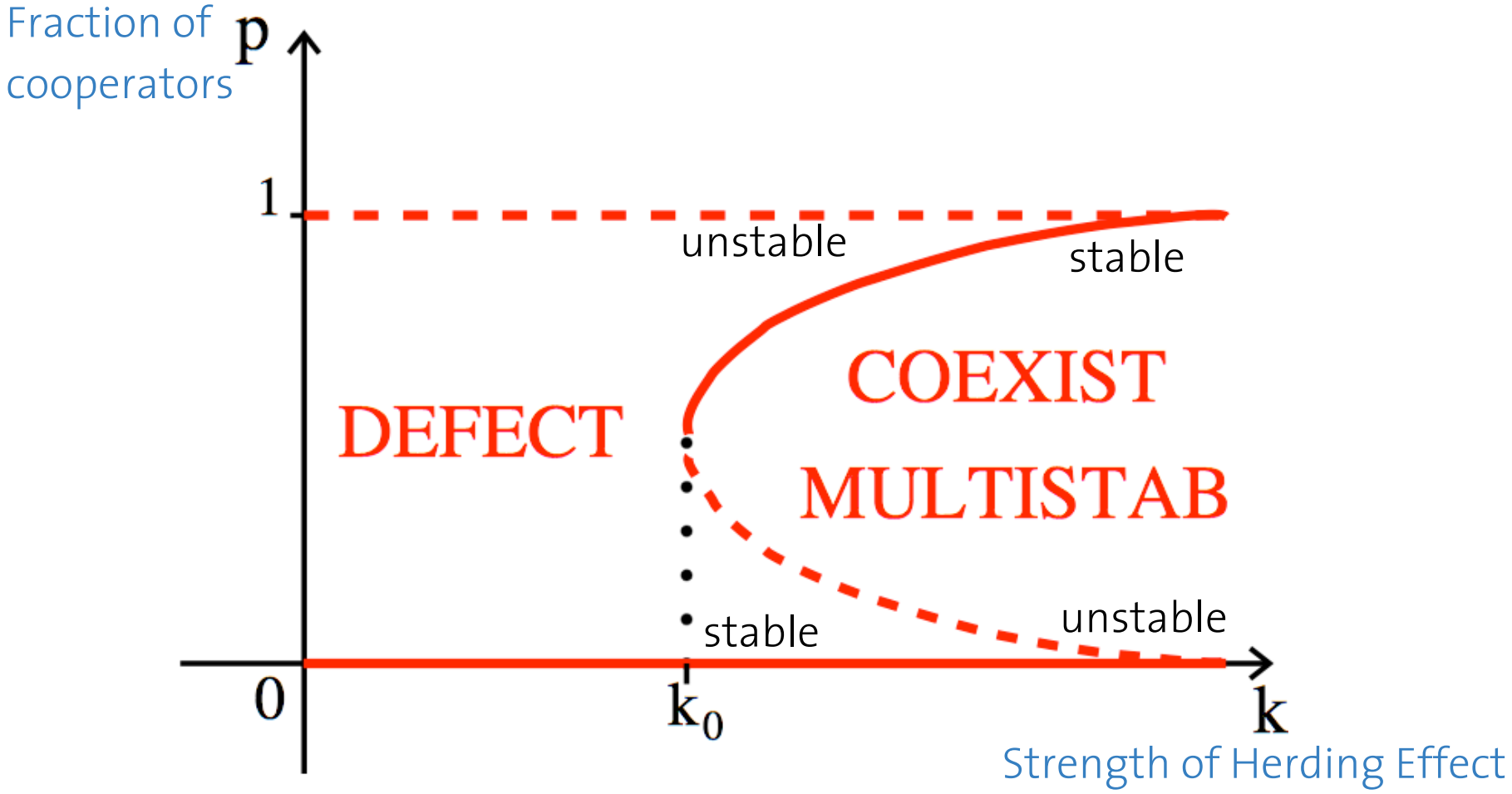
Route 4: From PD to HG via SH

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

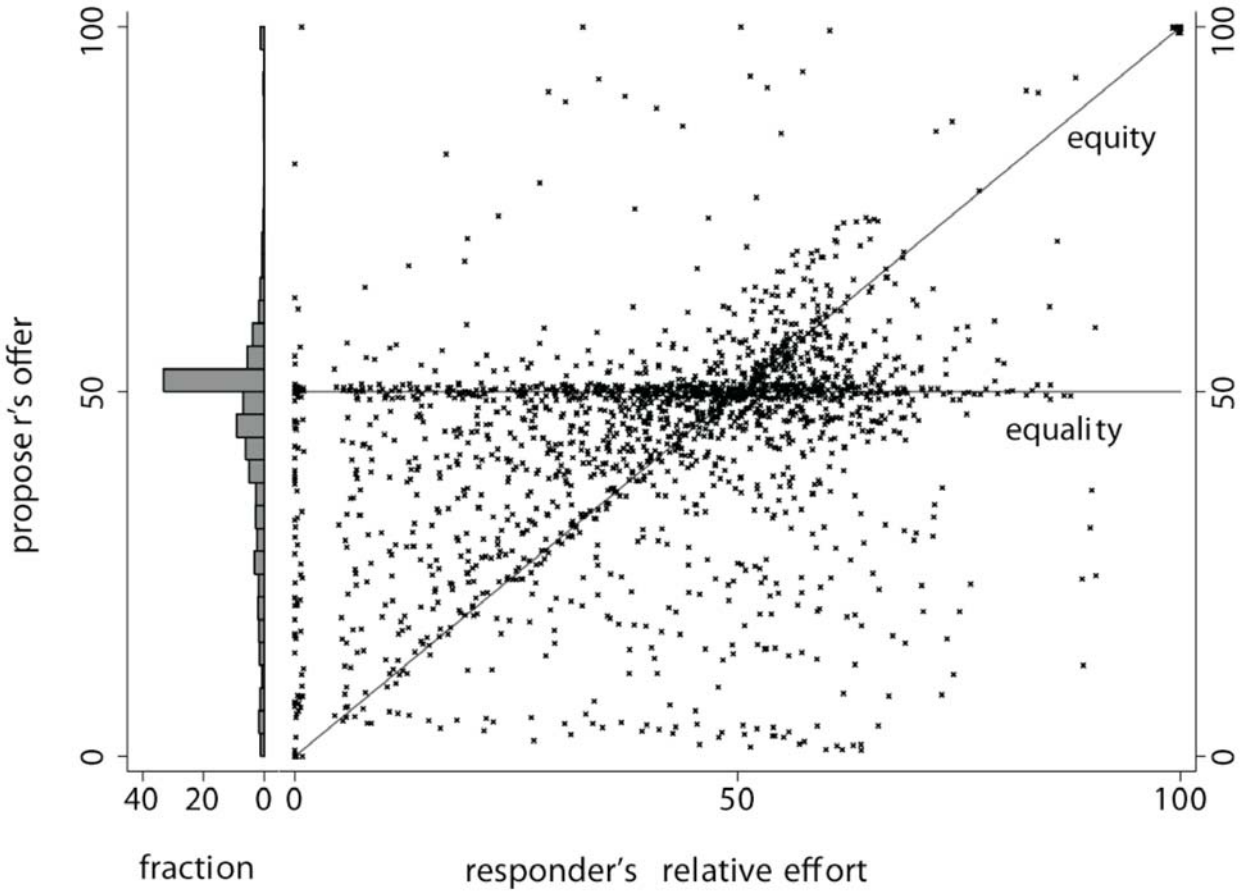
Herding Effect in the Prisoner's Dilemma "Inverts" the Outcome!

Assume that payoffs depend on the strategy distribution

Even a simple linear dependence changes system behavior dramatically!



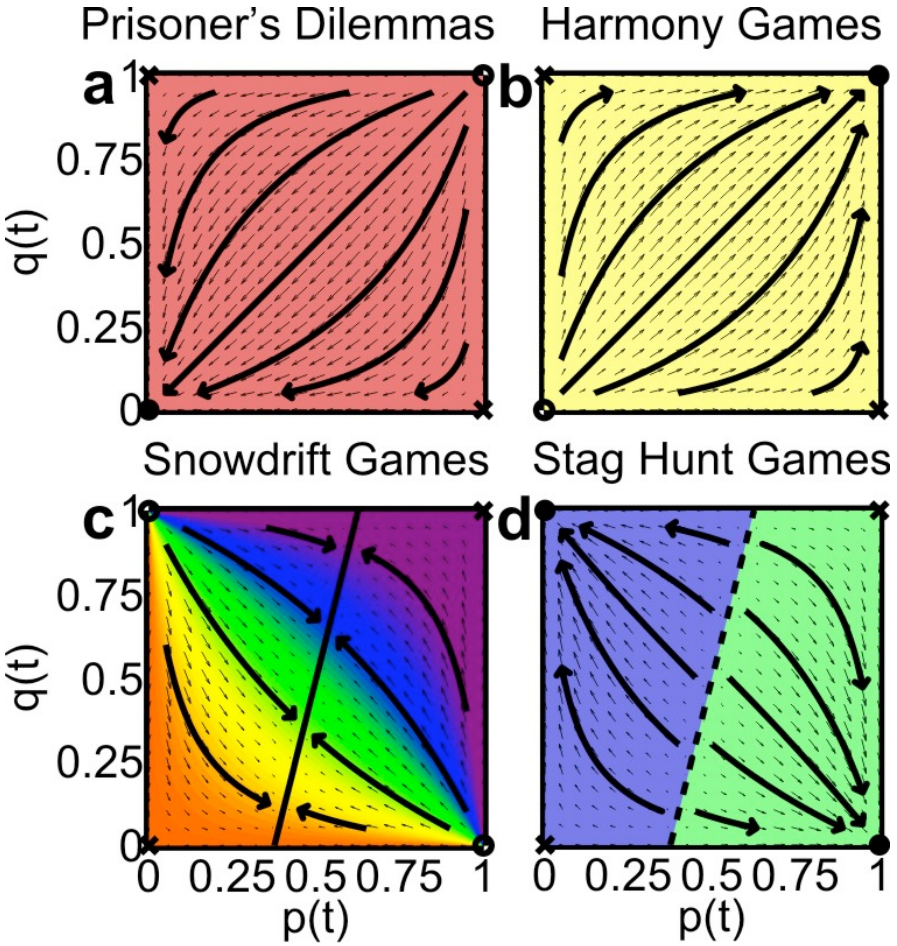
Conflict between Individuals Preferring Equity and Equality Norms



Results of an Ultimatum Game Experiment

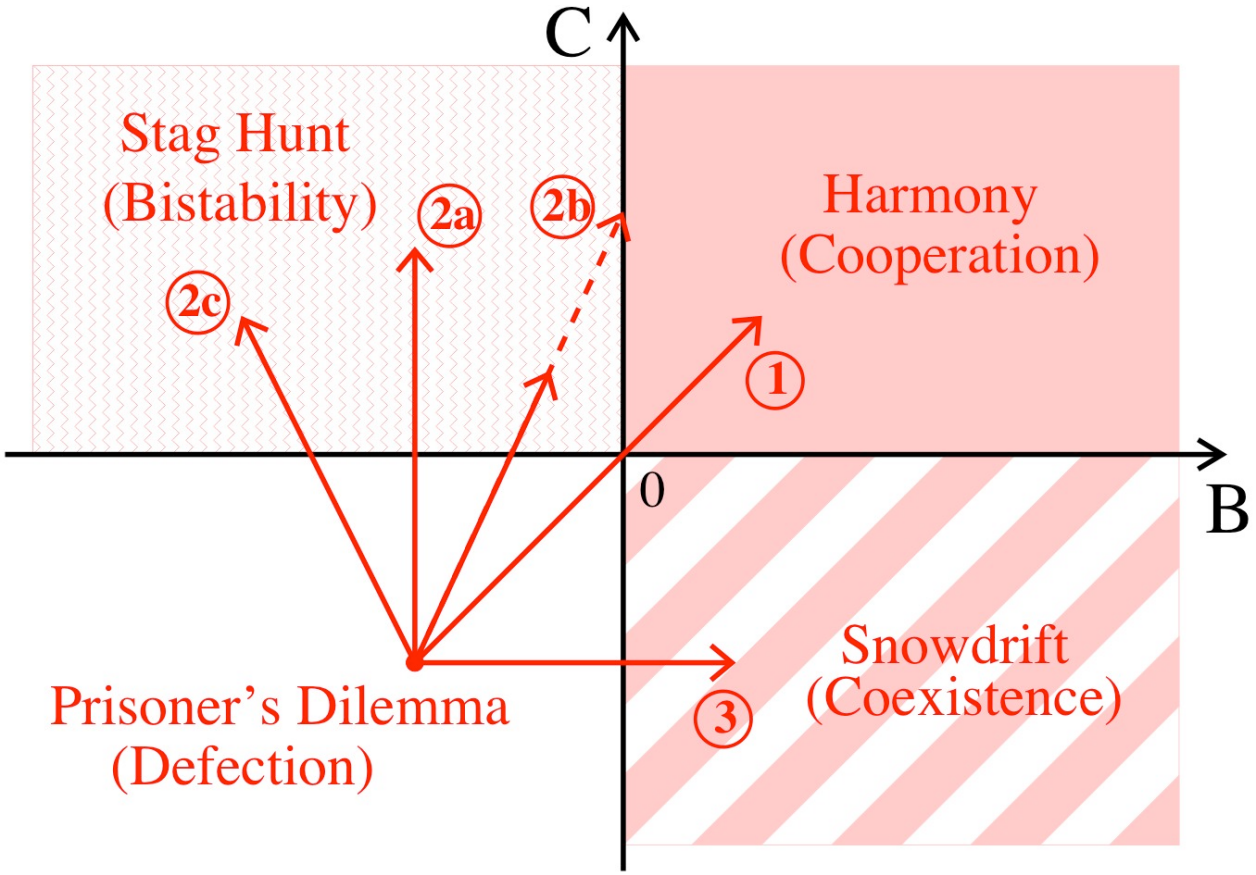
Work with Fabian Winter and **Heiko Rauhut** (see separate talk)

Situation in Two Populations with Conflicting Interests



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.

How to Transform the Prisoner's Dilemma into Other Games



Route 1: Kin selection, 3: Network interactions (don't support norms)

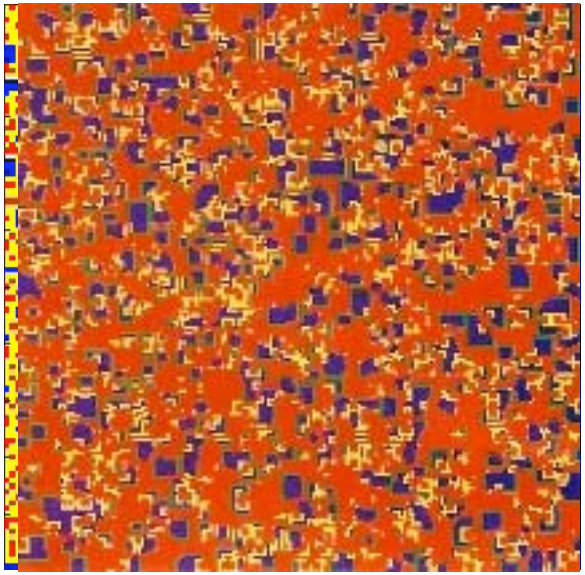
2a: Direct reciprocity, 2b: Indirect reciprocity, 2c: Punishment (support norms)

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?

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.

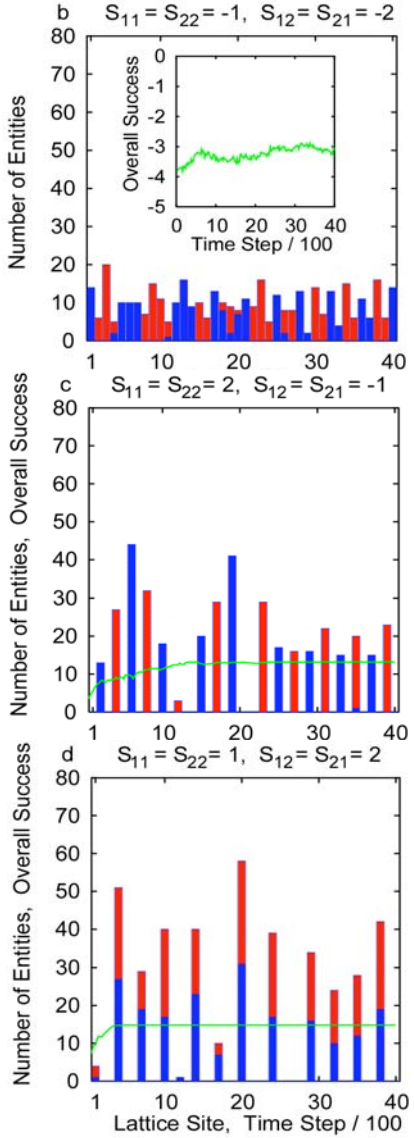
Source: M. A. Nowak and R. M. May, Nature 359, 826 (1992).

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

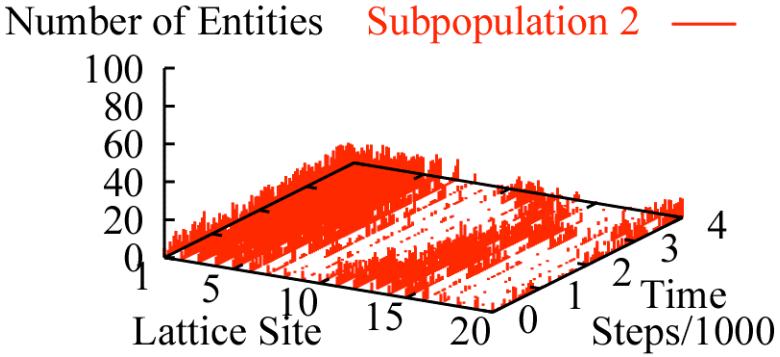
… and Extend It, Considering Success-Driven Migration

- 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.

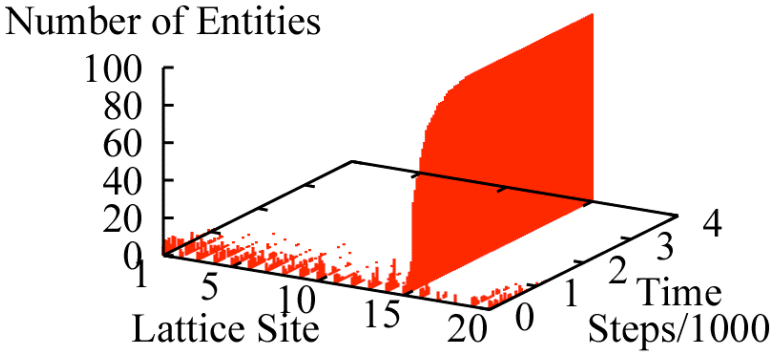
Spatio-Temporal Pattern Formation Due to Success-Driven Migration



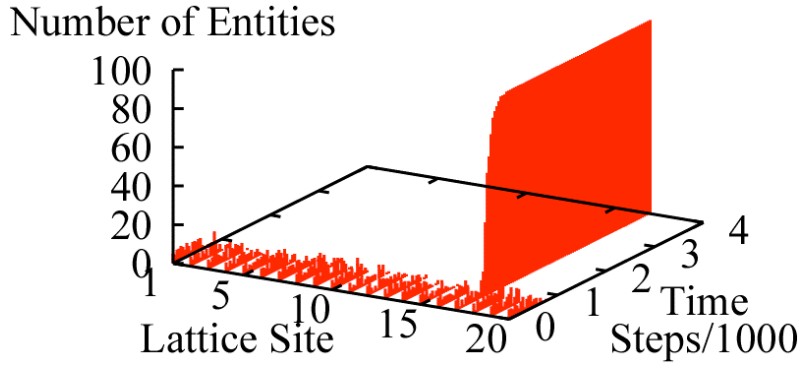
Segregation
("Lane Formation")



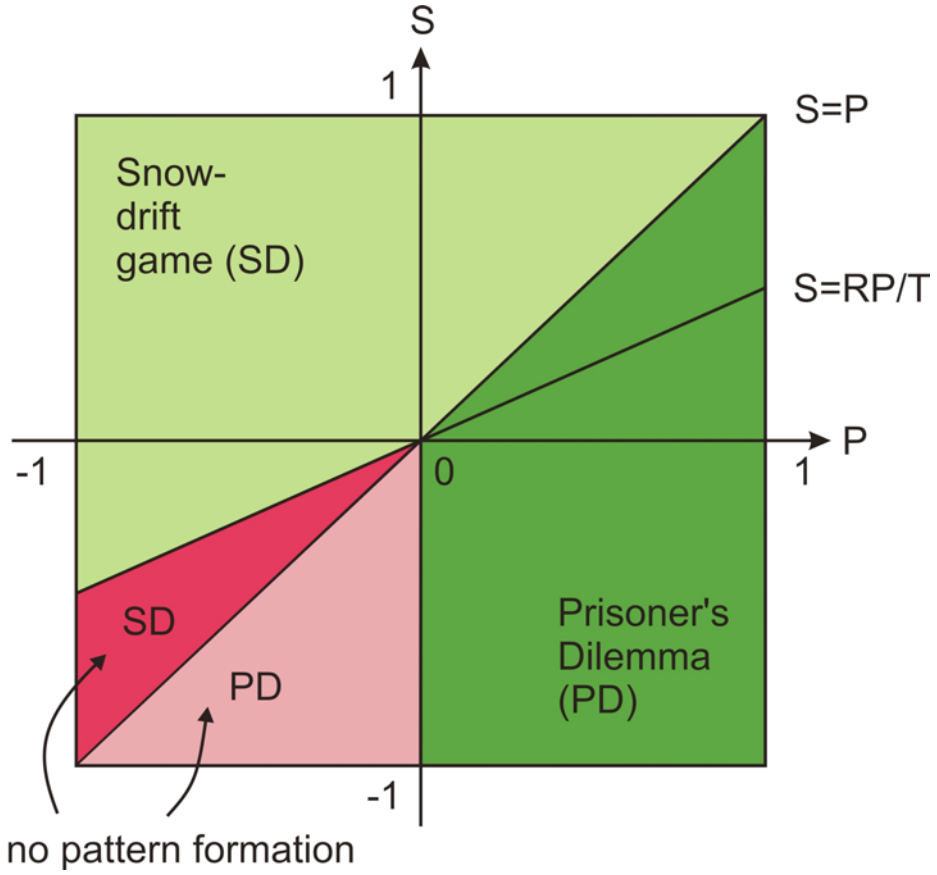
Repulsive Agglomeration
("Ghetto Formation")

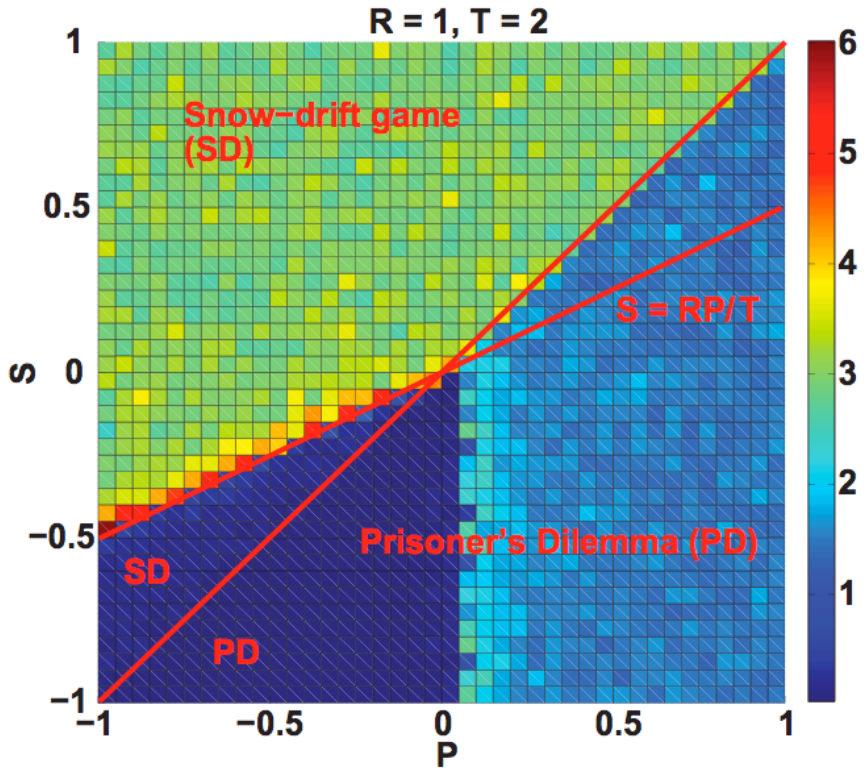


Attractive Agglomeration
("Clustering")



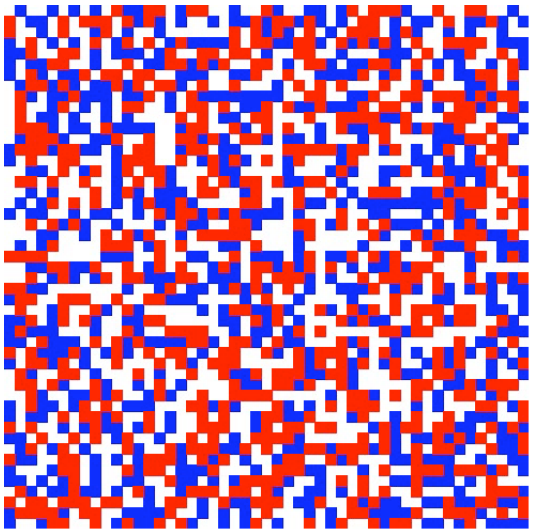
Agglomeration in the Prisoner's Dilemma and Snow Drift Game



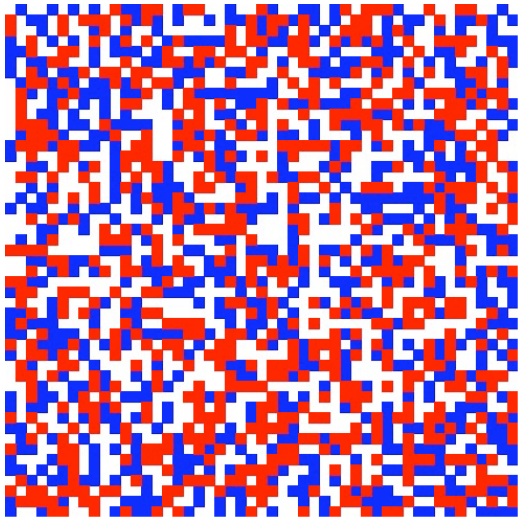


Imitation and Success-Driven Motion, Separately and Together

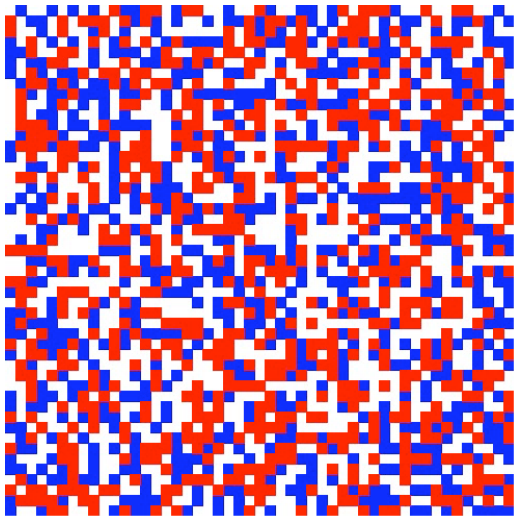
P = 0
R = 1
S = 0
T = 1.4



imitation only

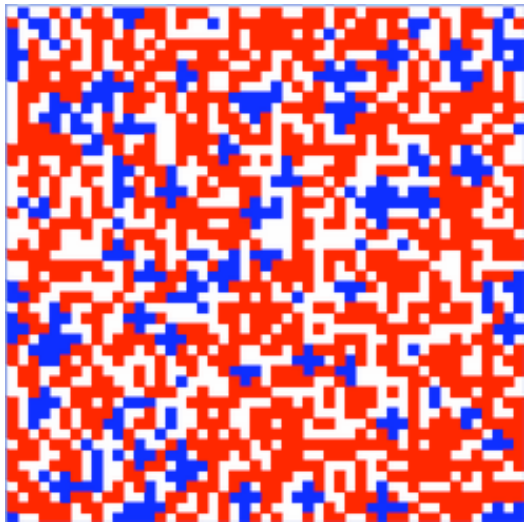


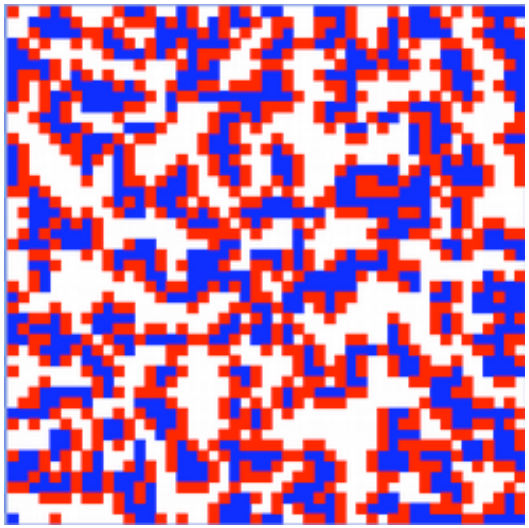
migration only

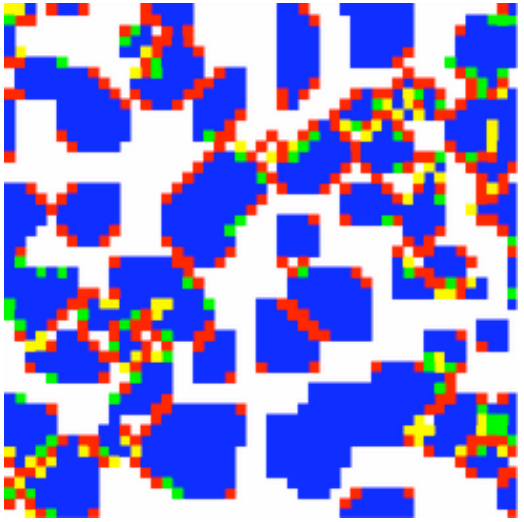


imitation & migration

blue = C
red = D

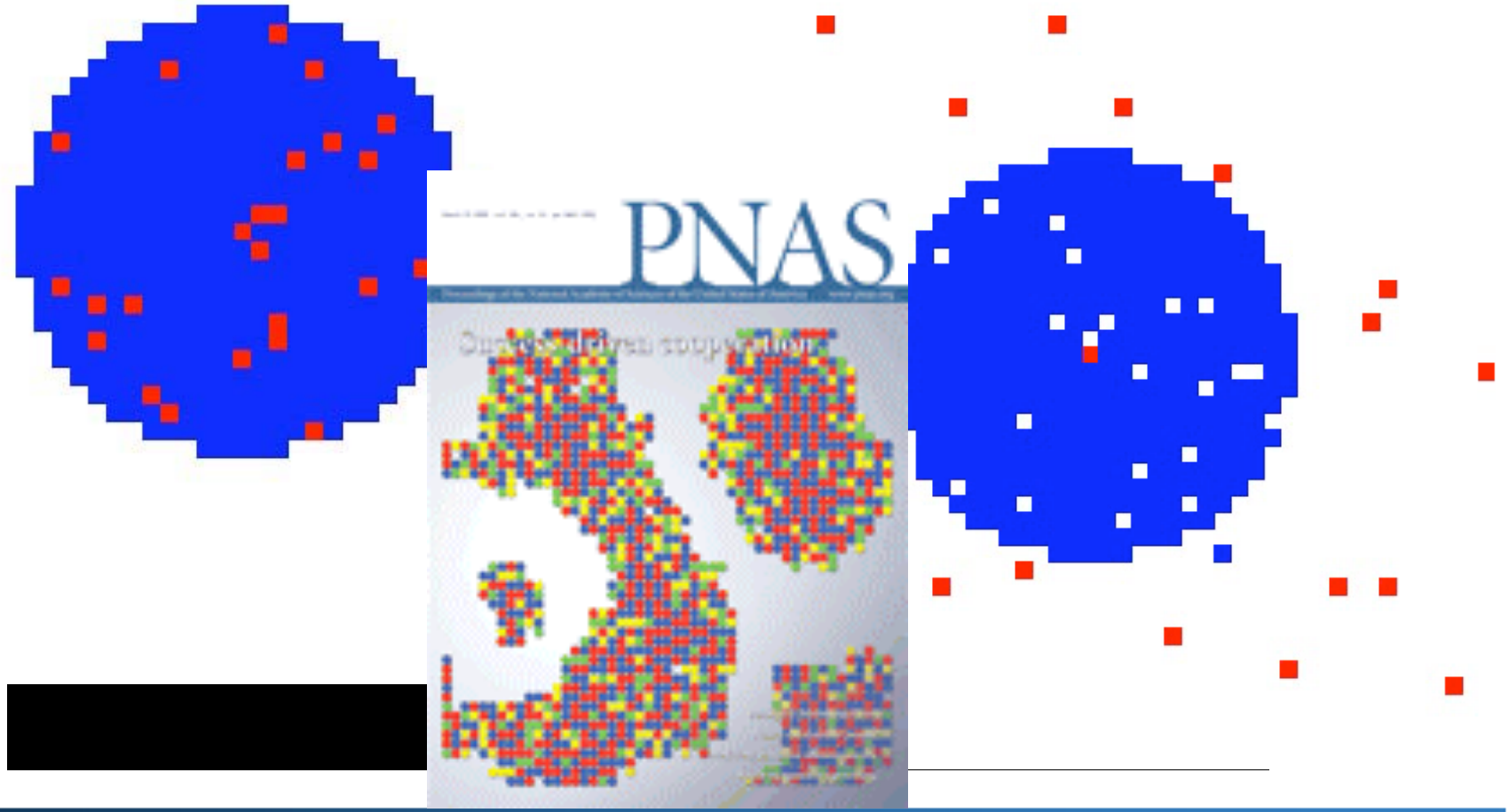




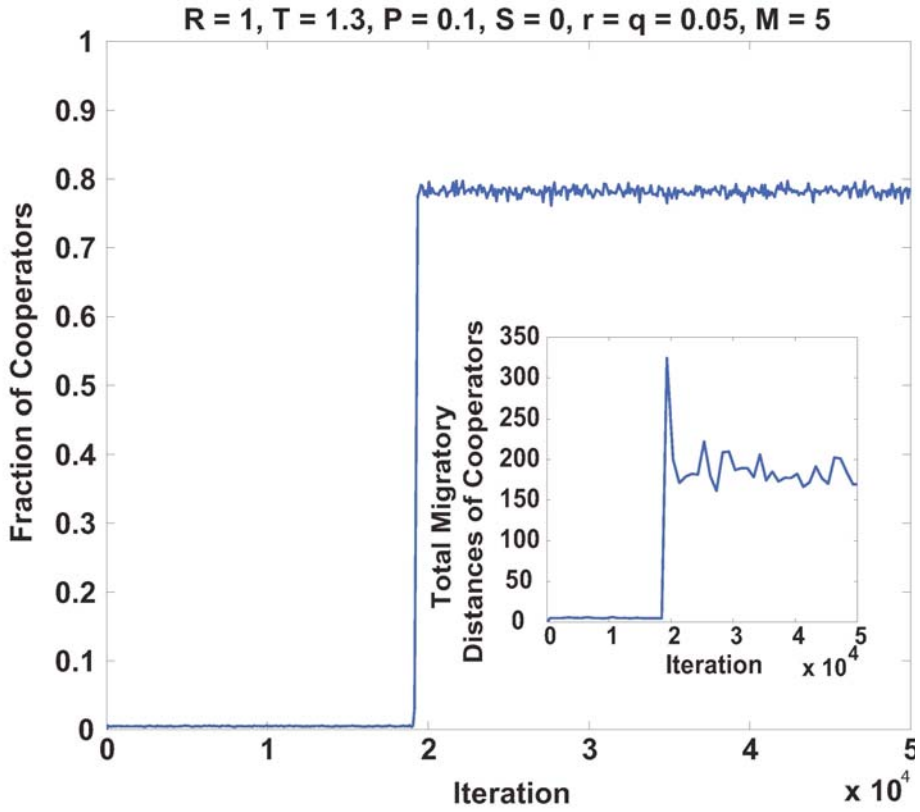


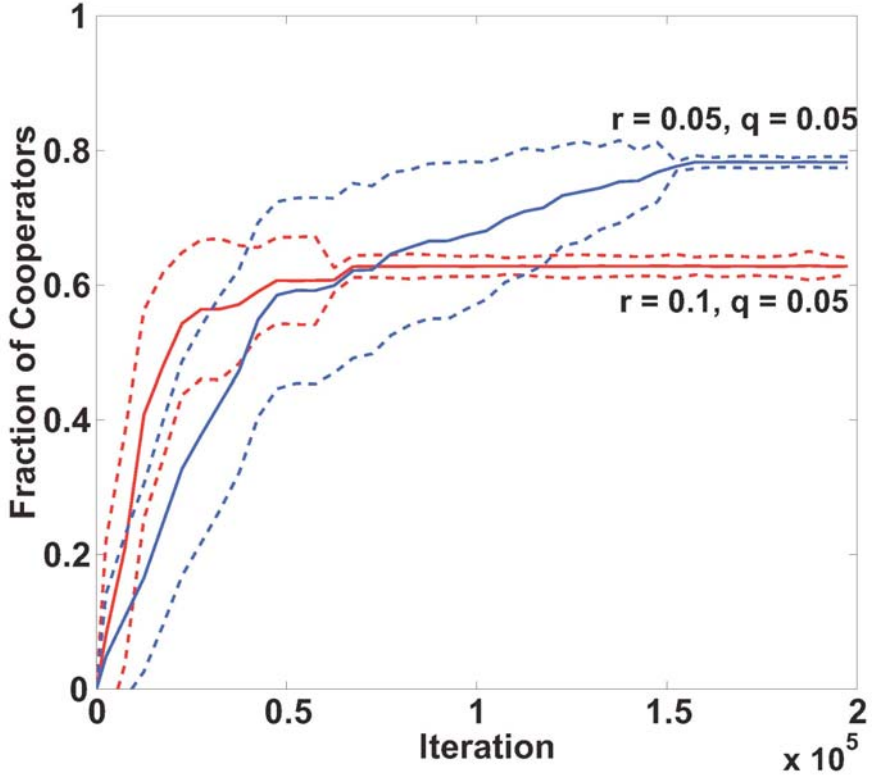
The Breakdown and Outbreak of Cooperation

Red, yellow: defectors (cheaters)
Blue, green: cooperators

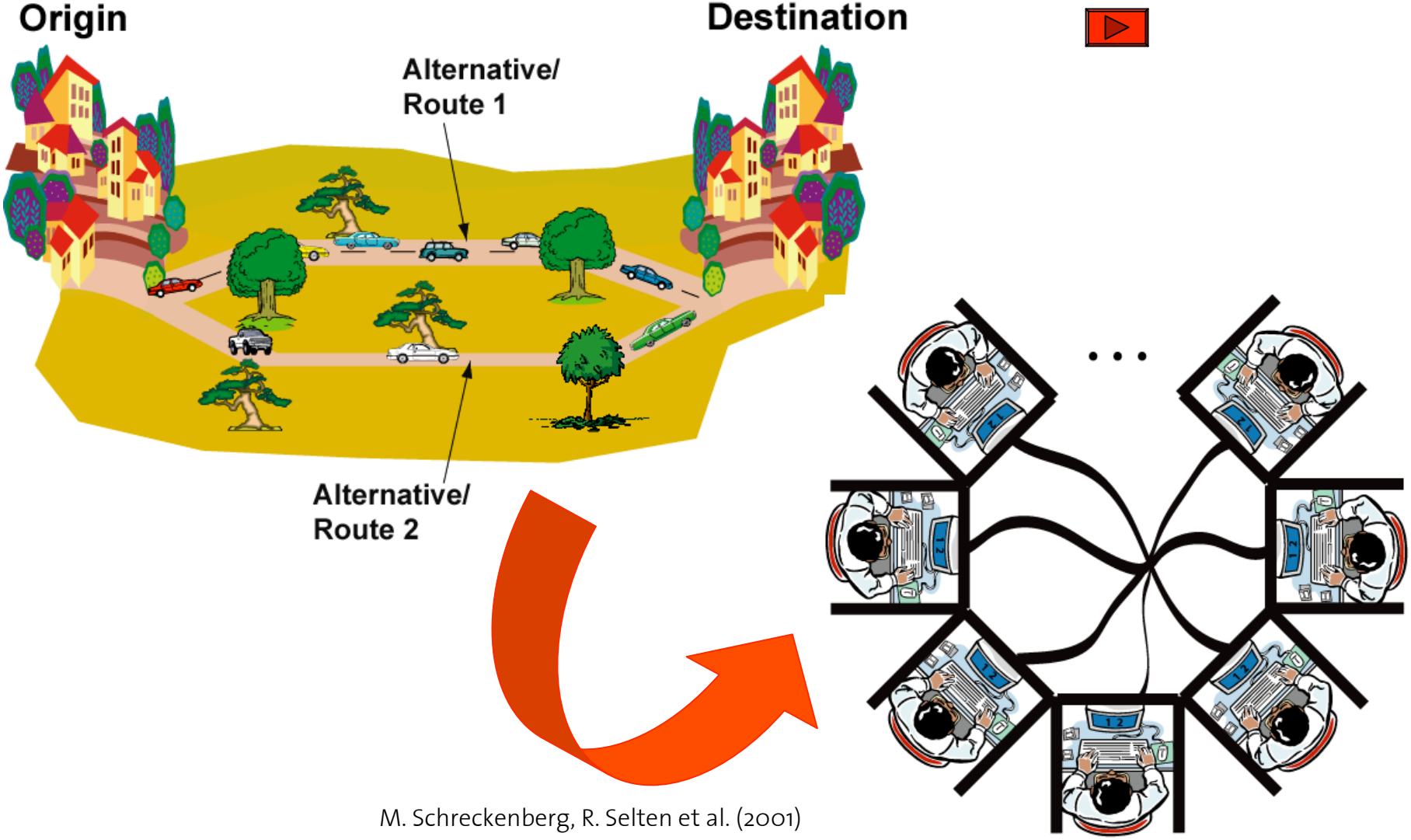


Time-Dependence of Transition of Predominant Cooperation





Route Choice Dilemma



M. Schreckenberg, R. Selten et al. (2001)

The 2-Person Route Choice Dilemma

a

	coop.	def.
cooperation	0	–300
defection	100	–200

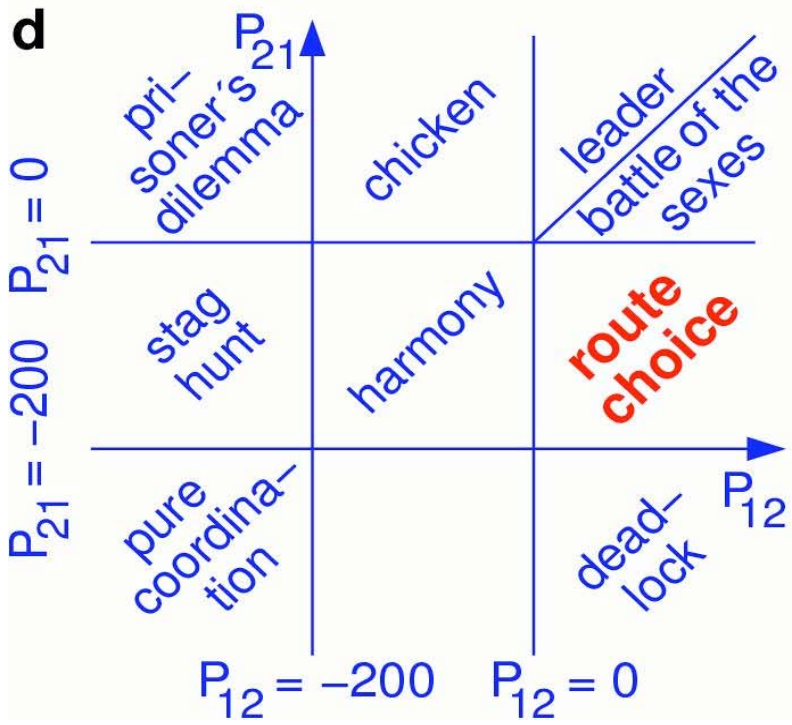
b

	1	2
strategy 1	0	P_{12}
strategy 2	P_{21}	–200

c

	1	2
route 1	0	300
route 2	–100	–200

d



e

	11	12	21	22
11	0 ③ ③	300 ②	300 ①	600
12	–100 ②	–200 ④ ④	200	100
21	–100 ①	200	–200	100
22	–200	–300	–300	–400

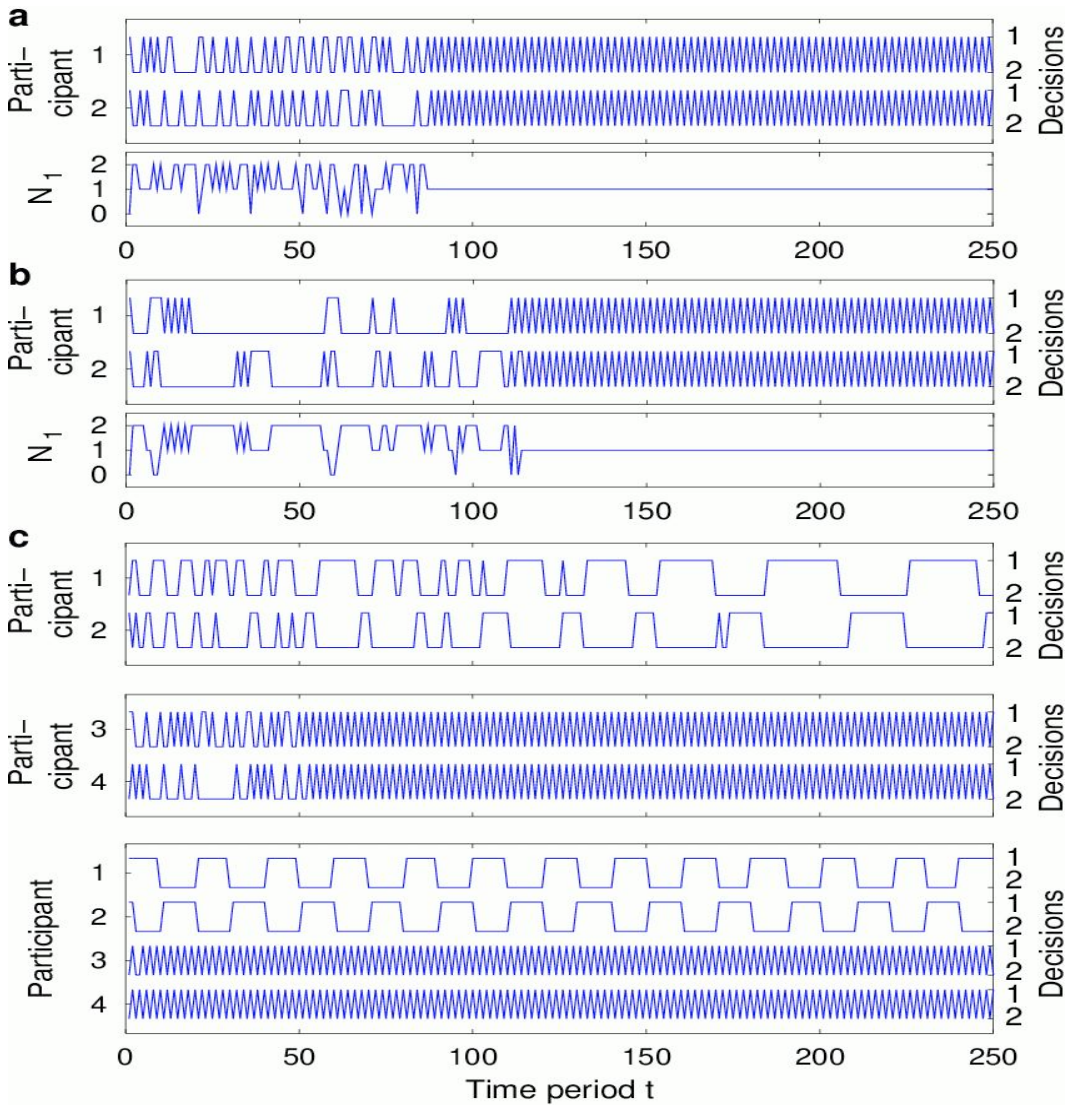
Outbreak of Turn-Taking: Experiments and Simulations

2 Persons: Experiment

2 Persons: Simulation

Subsequent 4-Person Experiment

Multi-Period Decisions

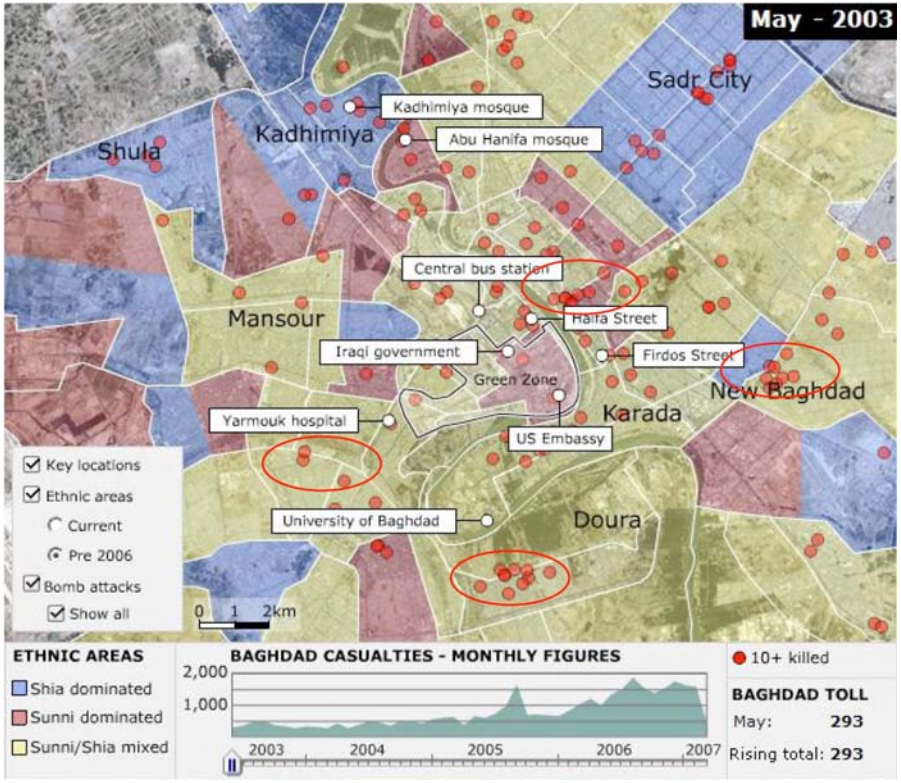


Intermediate Summary

- Extending spatial games by success-driven migration allows to describe
  - survival and spreading of cooperation in large parameter area of the PD

  by spatio-temporal pattern formation
  - noise-resistance
  - outbreak of predominant cooperation
- Success-driven migration can destabilize a homogeneous strategy distribution, but produces adaptive, self-stabilizing patterns (rather than frozen ones), allowing cooperators to evade invasion attempts of defectors
- This "inverts" the result of the replicator equation predicting 100% defectors
- The mechanism is local, and it does not change the payoffs (in contrast to taxes or punishment, for example)
- Mobility is an important factor supporting human sociality

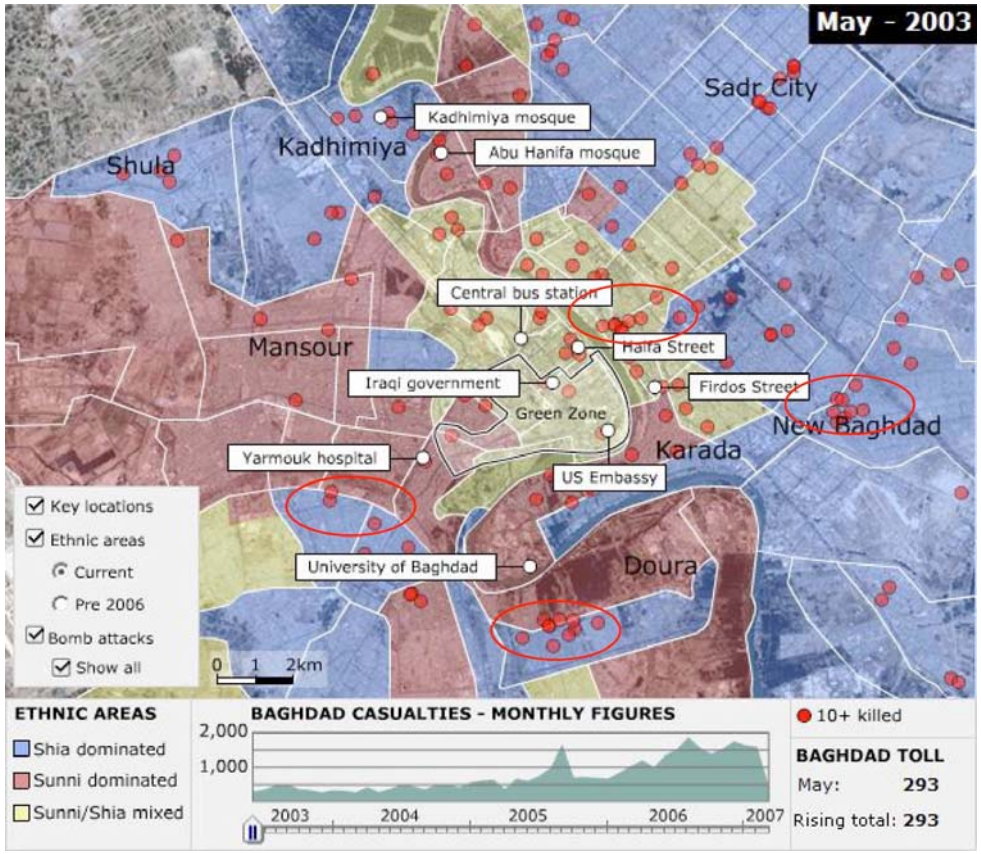
Interrelation of Spatial Interaction, Conflict, and Migration



Ethnic areas and bomb attacks before 2006

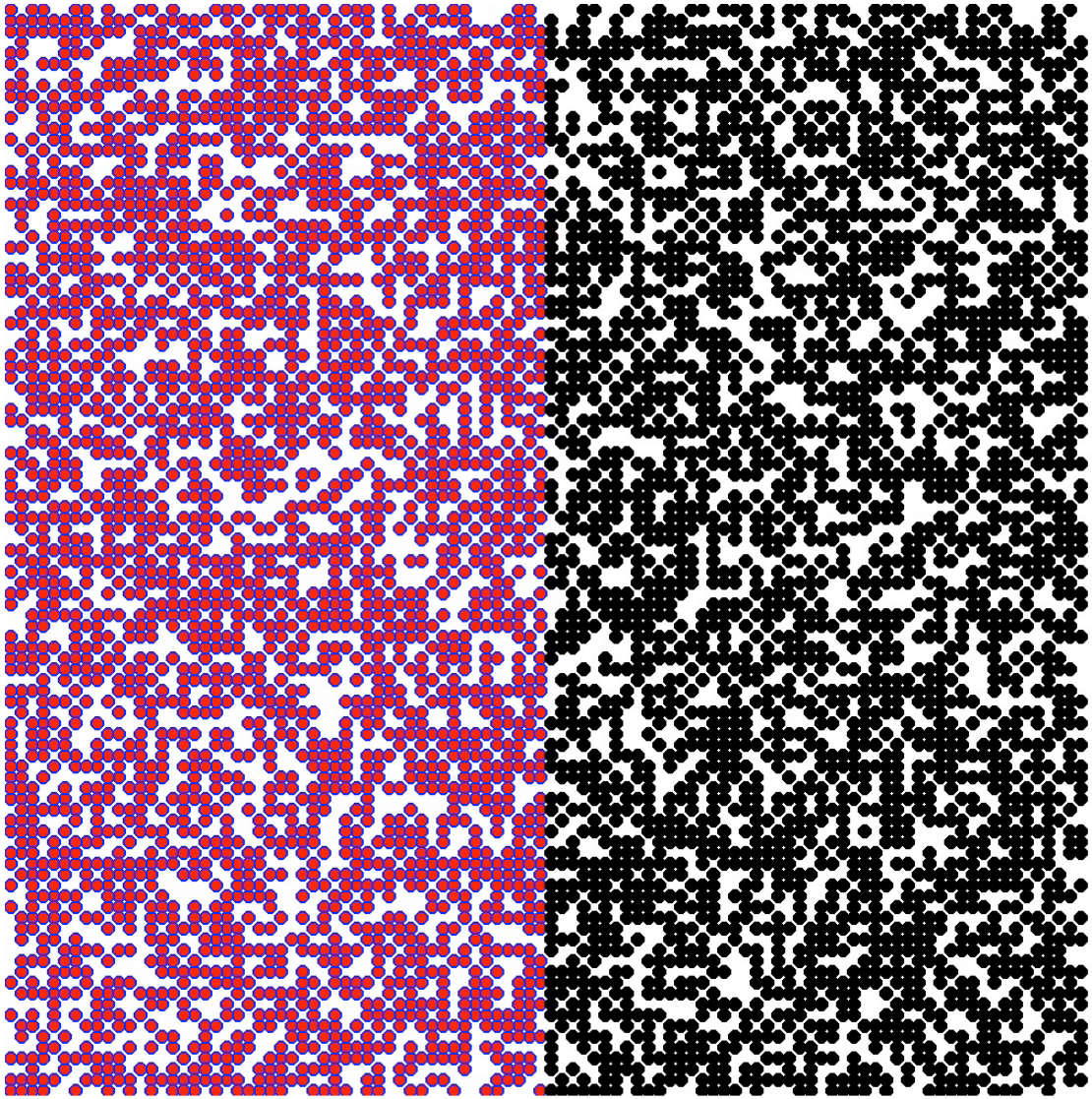
Source: BBC

Ethnic areas and bomb attacks after 2006



Conflict occurs premarily at boundaries between areas with different ethnic fractions. Mixed areas shrink.

Conflicts: Towards Simulating Conflicts

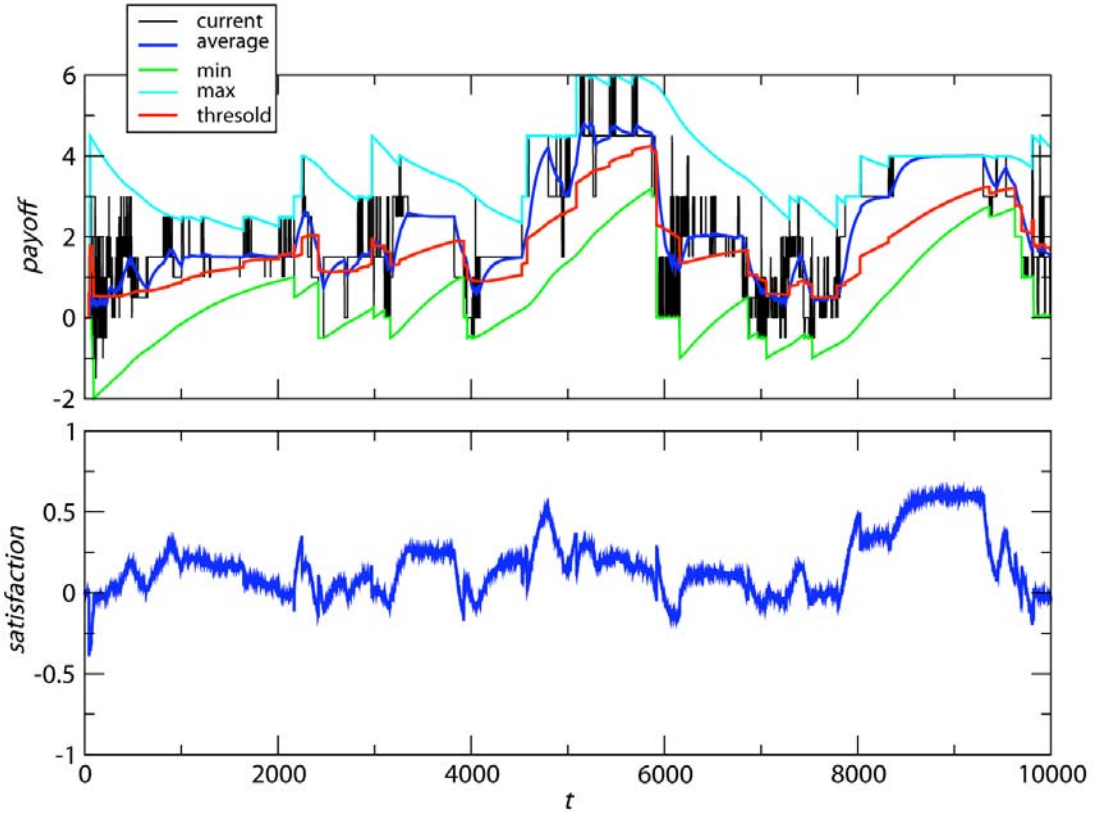


- Cultures refer to a set of symbols and meanings, including values and norms. They are regionally different.
- What may happen, if two populations with different, partially incompatible cultures start to mix (if we allow for migration)?
- Unilateral adaptation, mutual adaptation, conflict, segregation, or a combination of them?

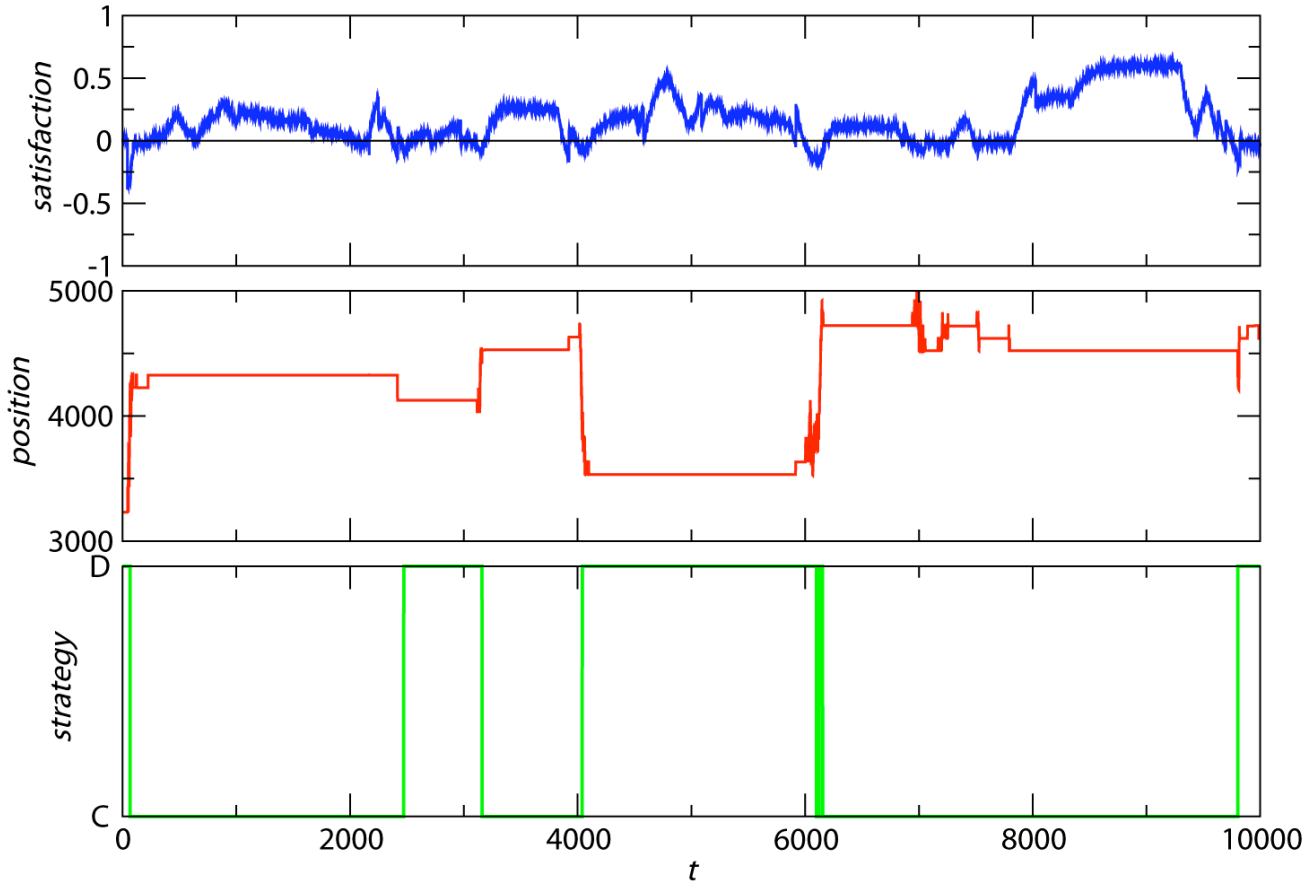
Experience-Based Strategy Choice and Satisfaction

If the player is dissatisfied (i.e. when satisfaction $s < 0$):

- migrate to a new position, in a range $-sR$, with a probability proportional to the number of available neighbors
- on a slower timescale, switch strategy with probability -s

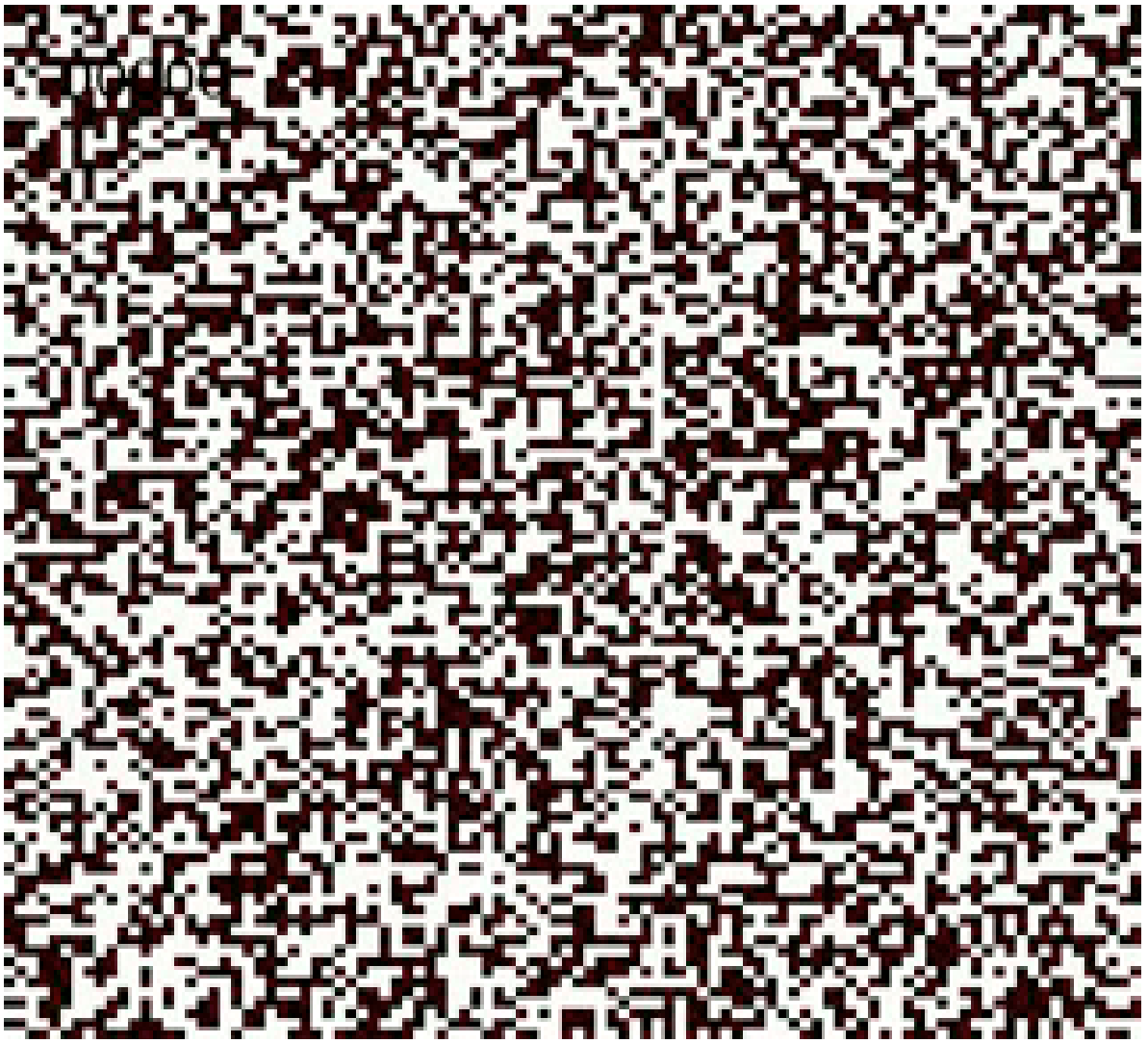


Satisfaction Drives Migration and Strategy Choice

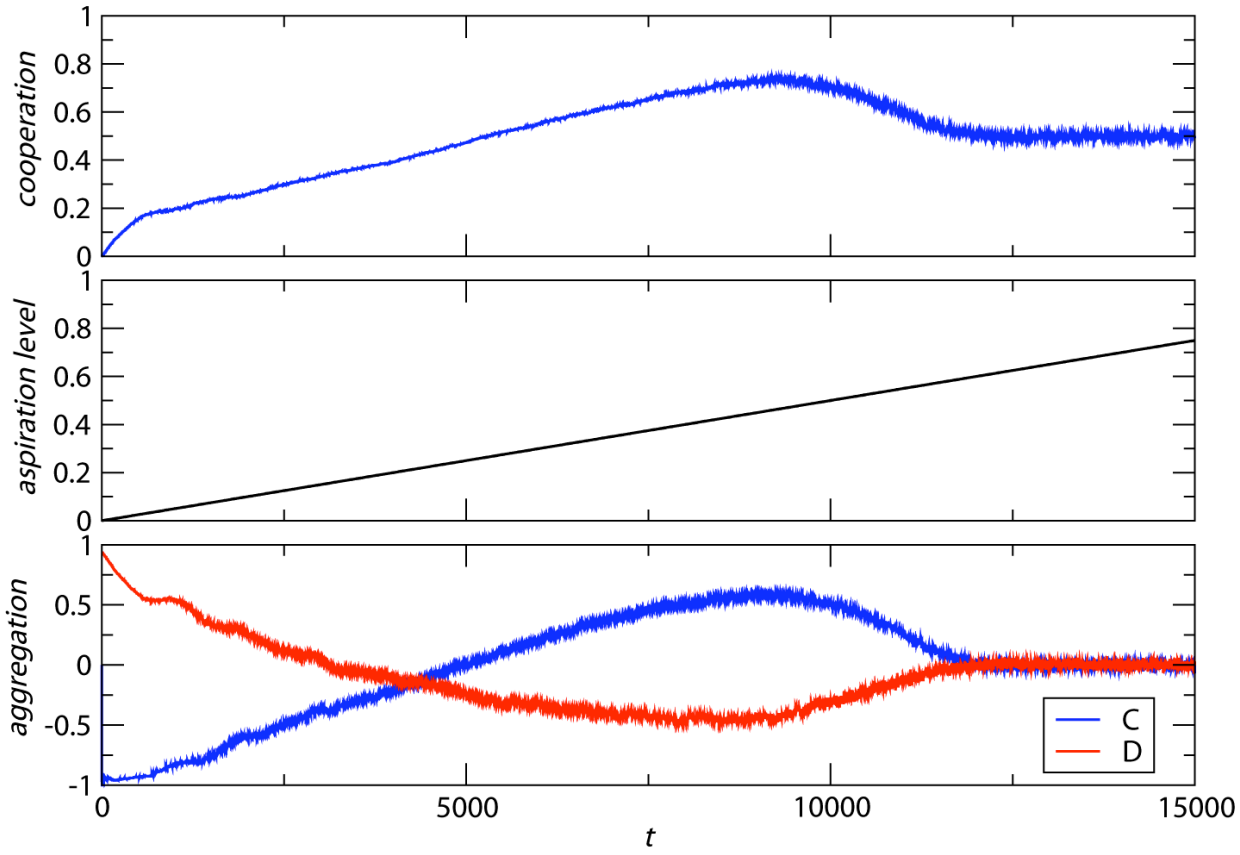


Emergence of Cooperation and Aggregation

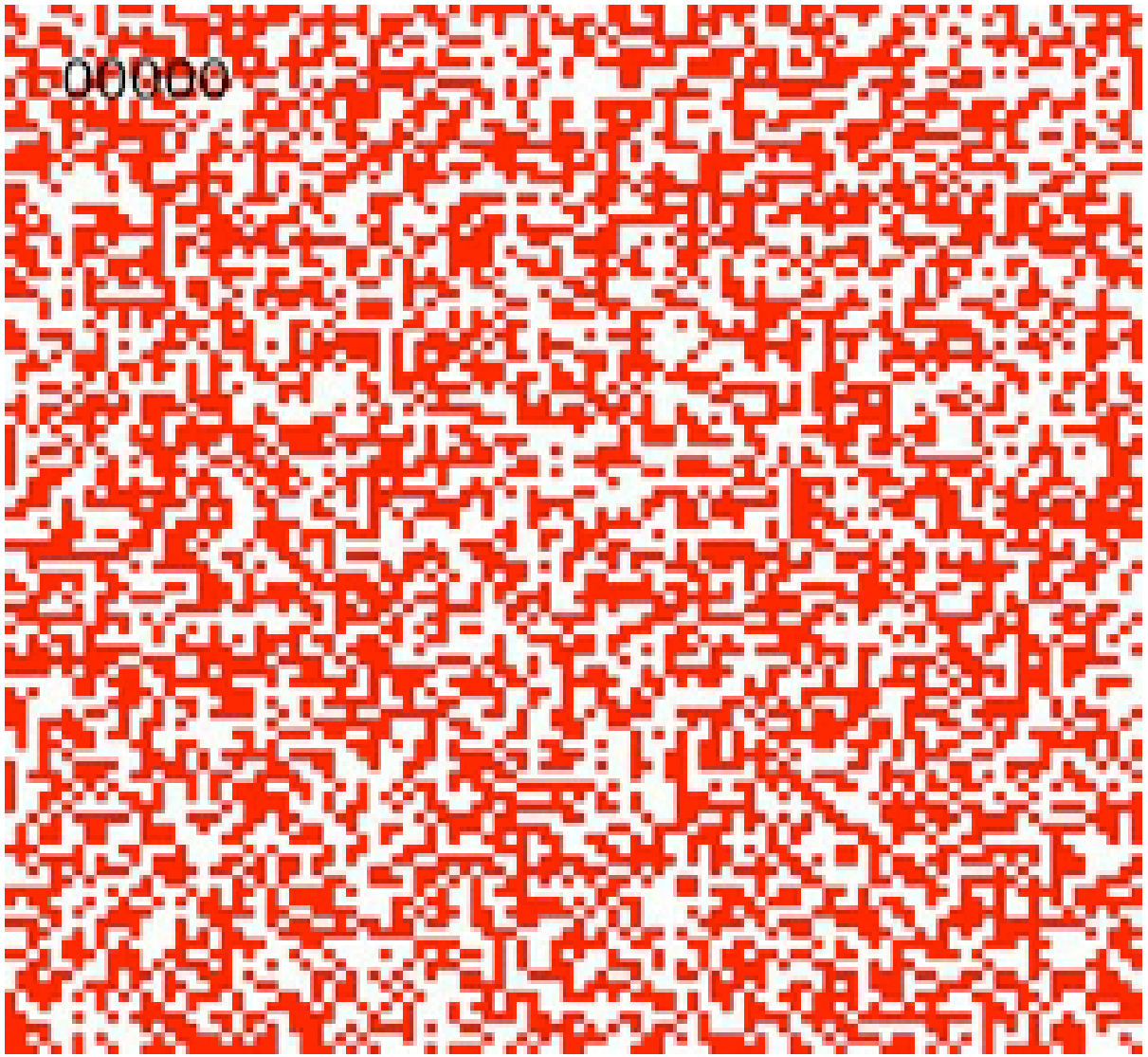
Stabilization of Cooperative Strategies



How an Increase in Greediness Can Cause a Collapse of Cooperation

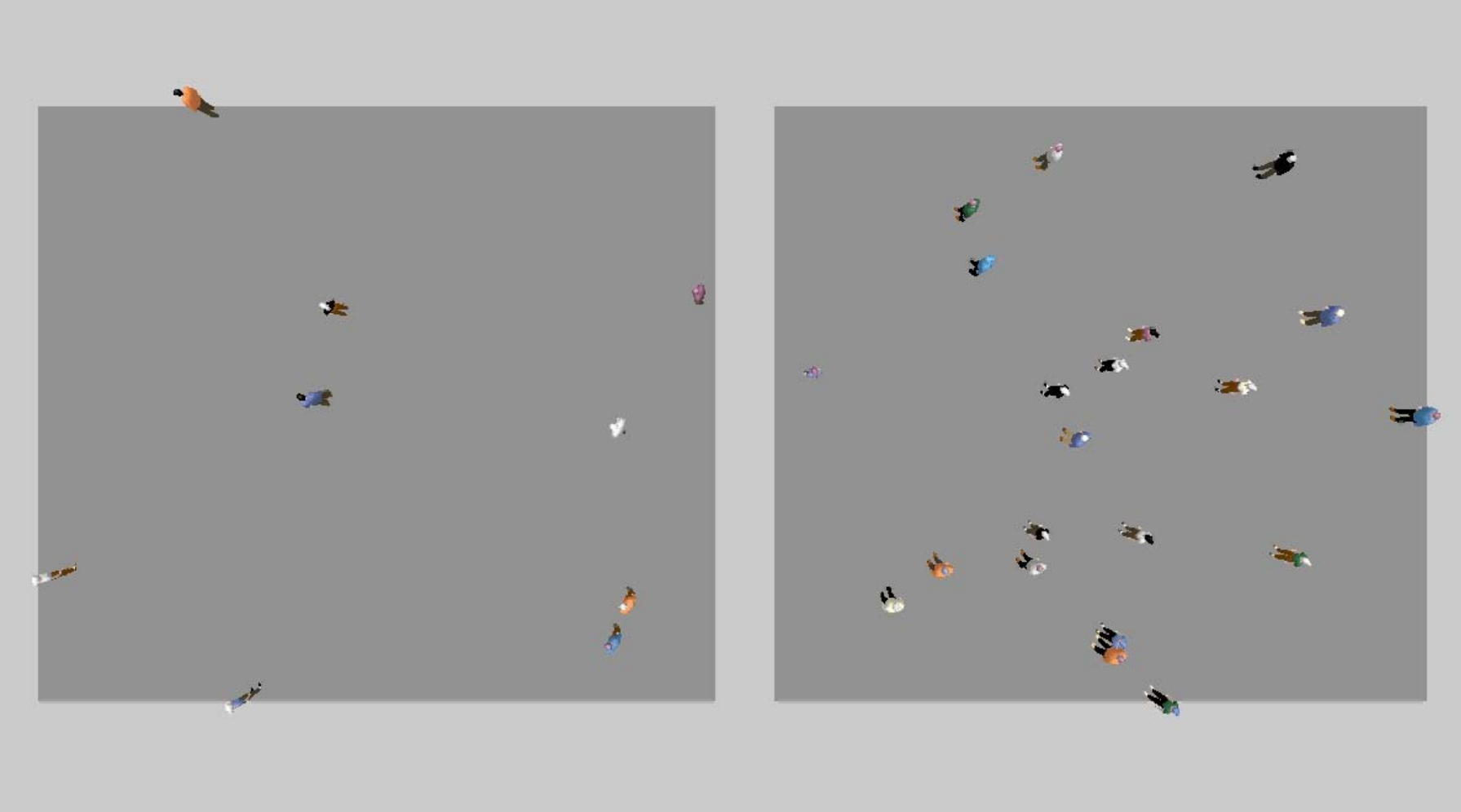


High Aspiration Level



Is the Result an Unstable and Disoriented Society?

What happens, when social bonds become weaker, but herding instinct remains?



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

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Thank you for your interest!

Any Questions?