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# Research at the Chair of Sociology, in particular of Modeling and Simulation

Dirk Helbing
with Michael Mäs, Karsten Donnay, Stefano Balietti,
and many others

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# Understanding the Complexity of Traffic Dynamics on Freeways

Dirk Helbing

with Martin Treiber, Arne Kesting,
Stefan Lämmer, Martin Schönhof, and others

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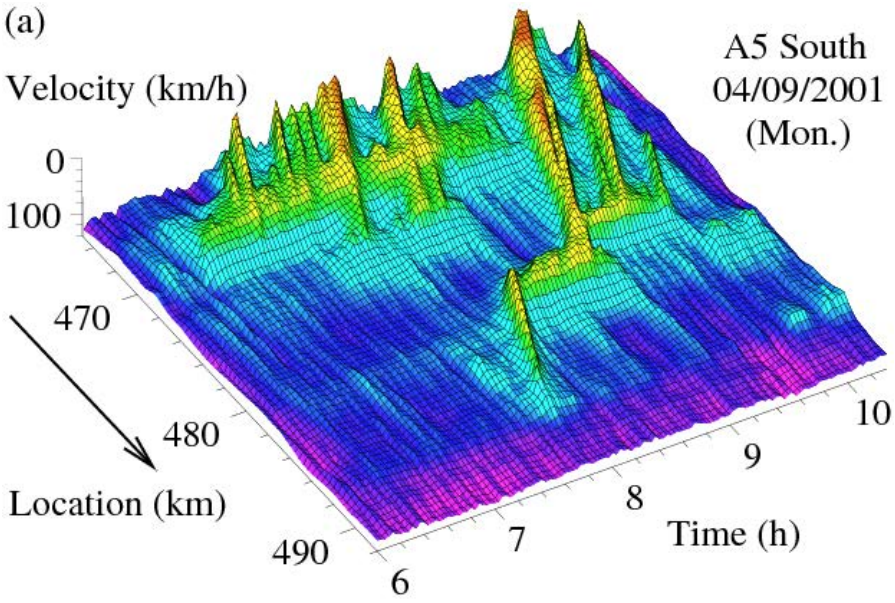
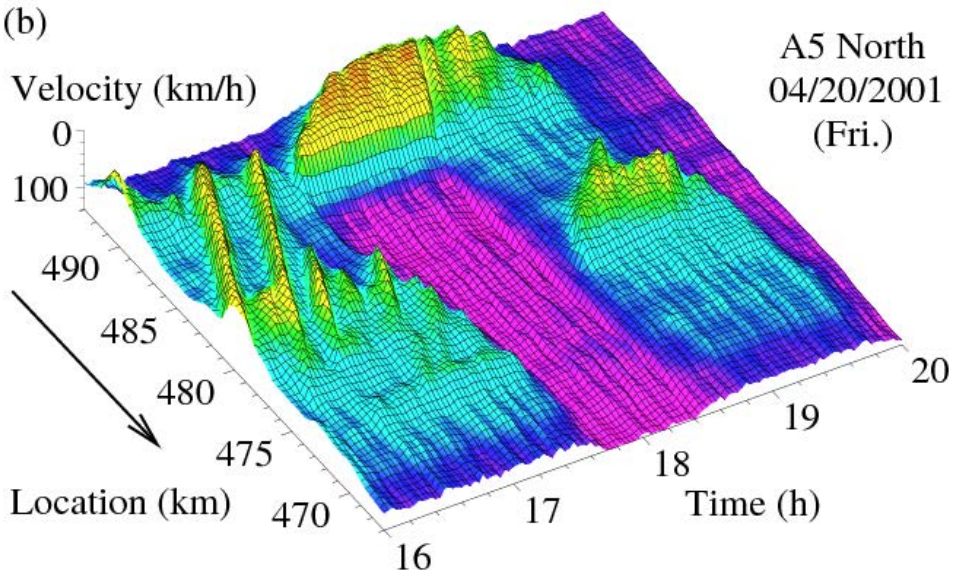
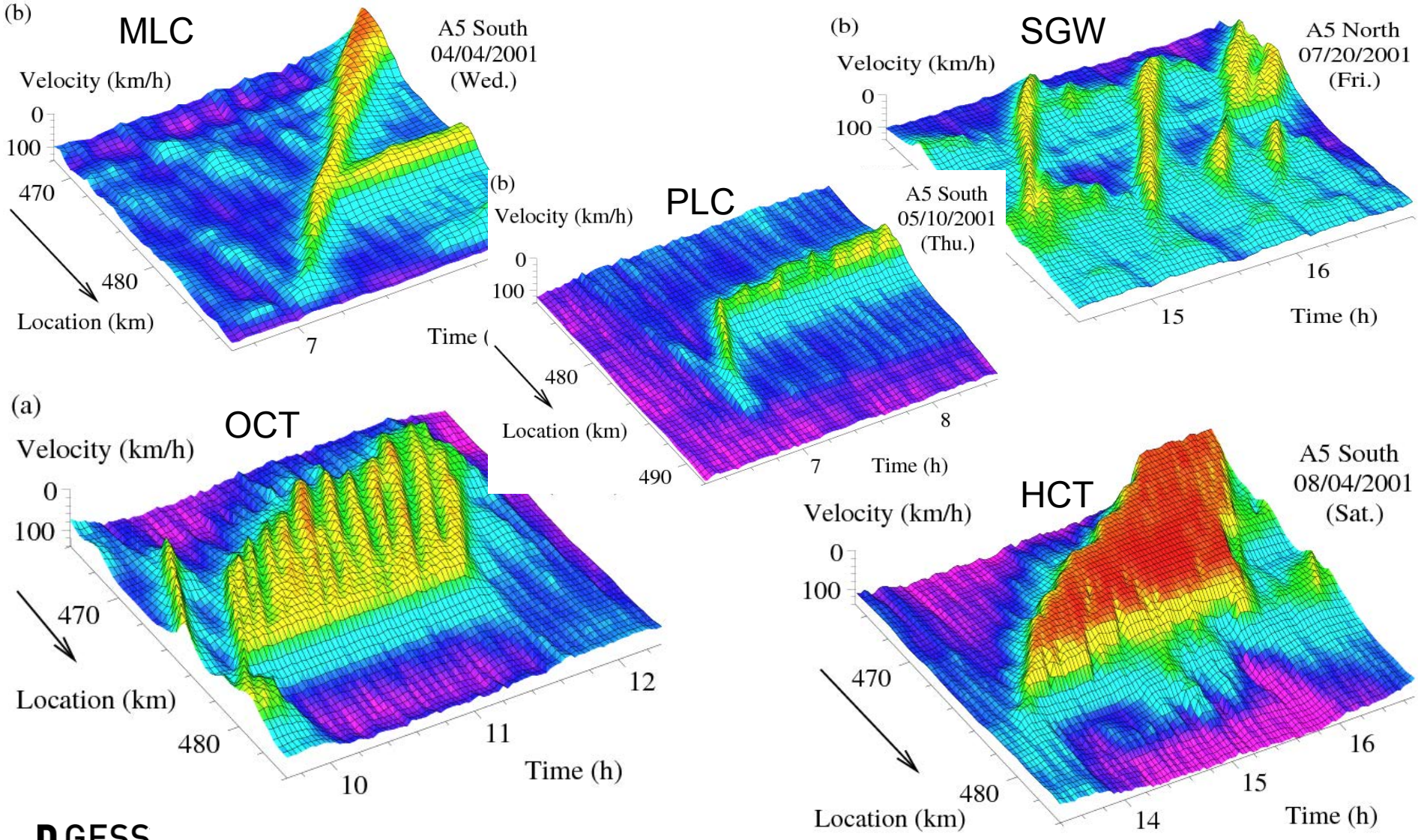
# Complexity of Congestion Patterns

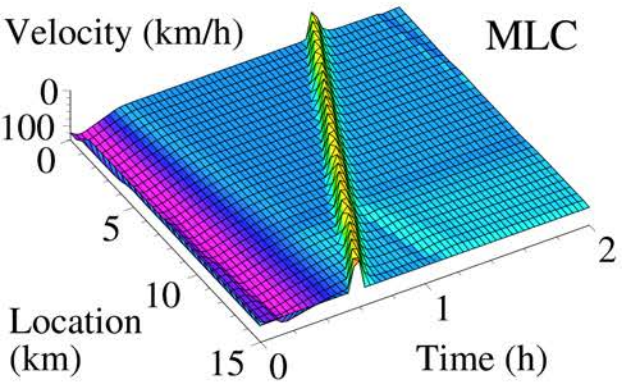


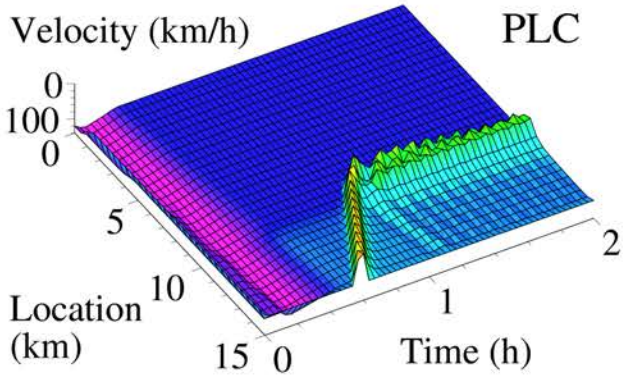



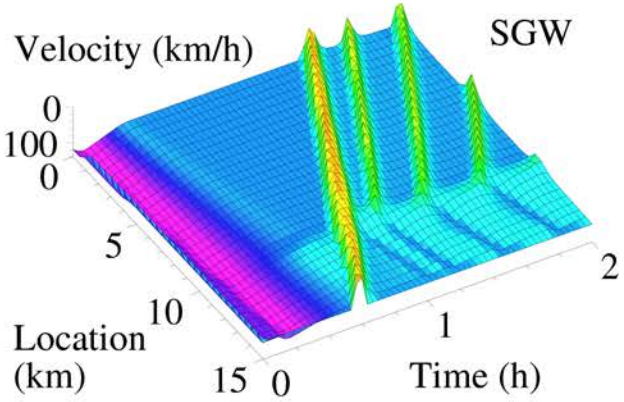
# Surprising Variety of Congestion Patterns

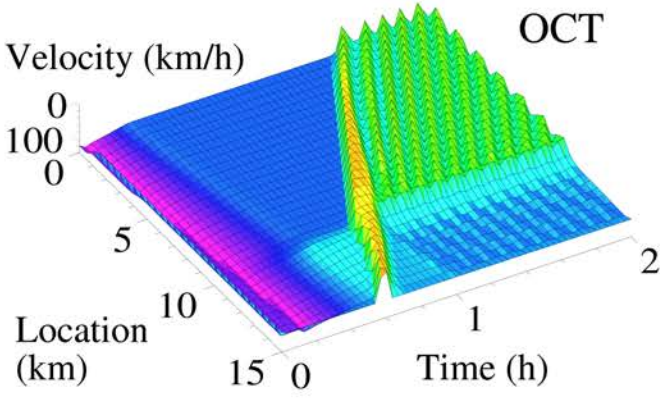


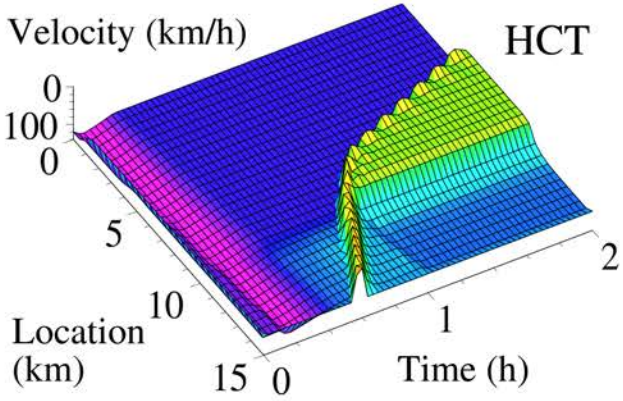
# Computer Simulated Congestion Patterns



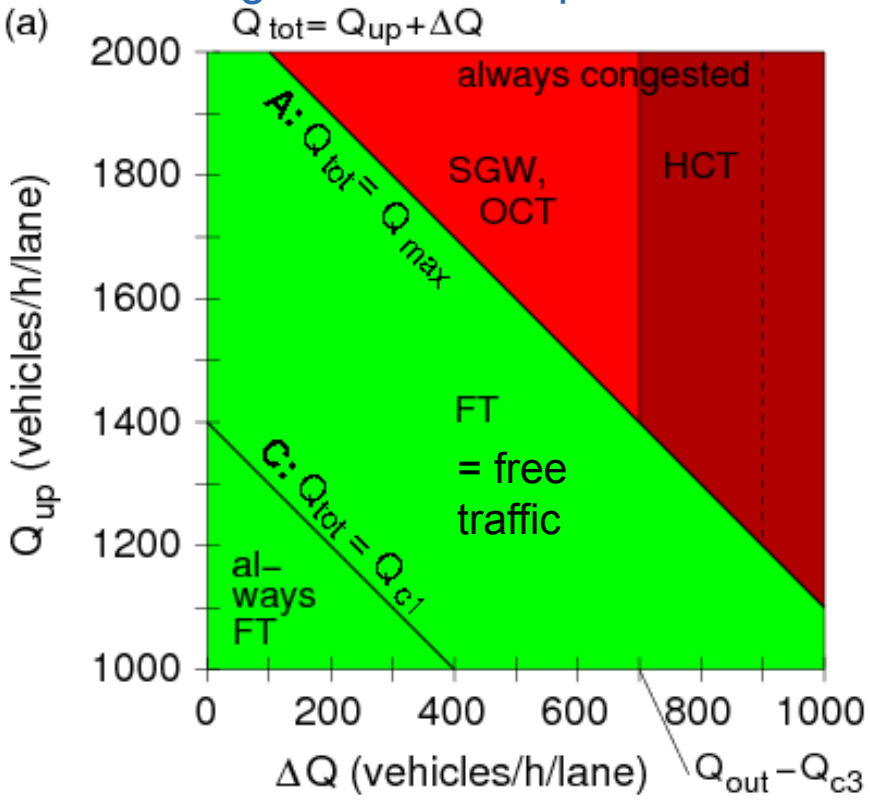



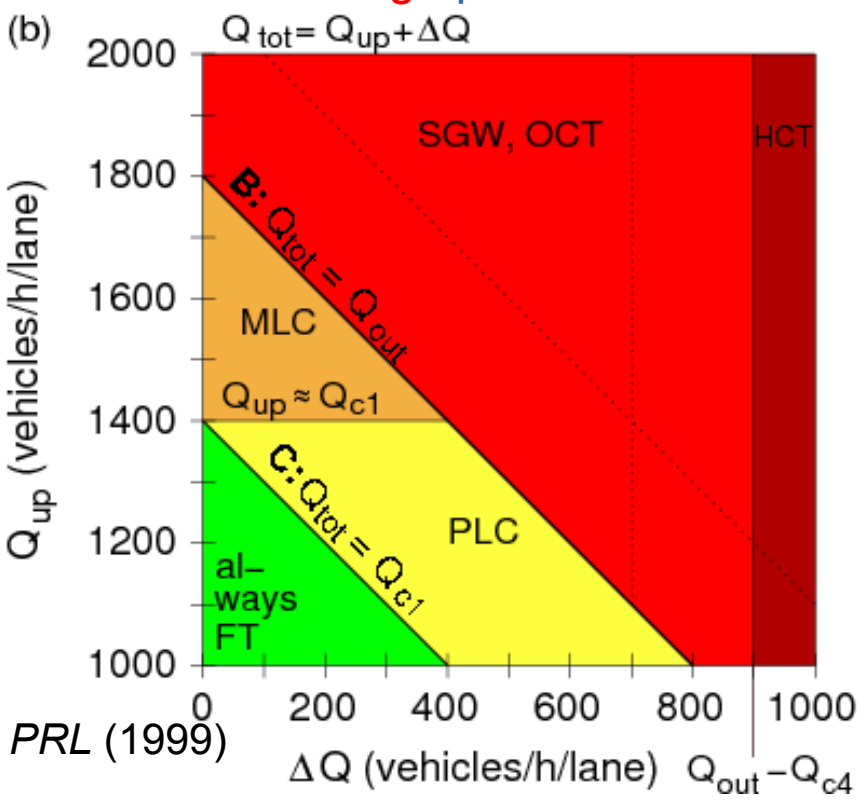

*Phys. Rev. Lett.* **82**, 4360 (1999).

# Phase Diagram of Traffic States and Universality Classes

Phase diagram for small perturbations

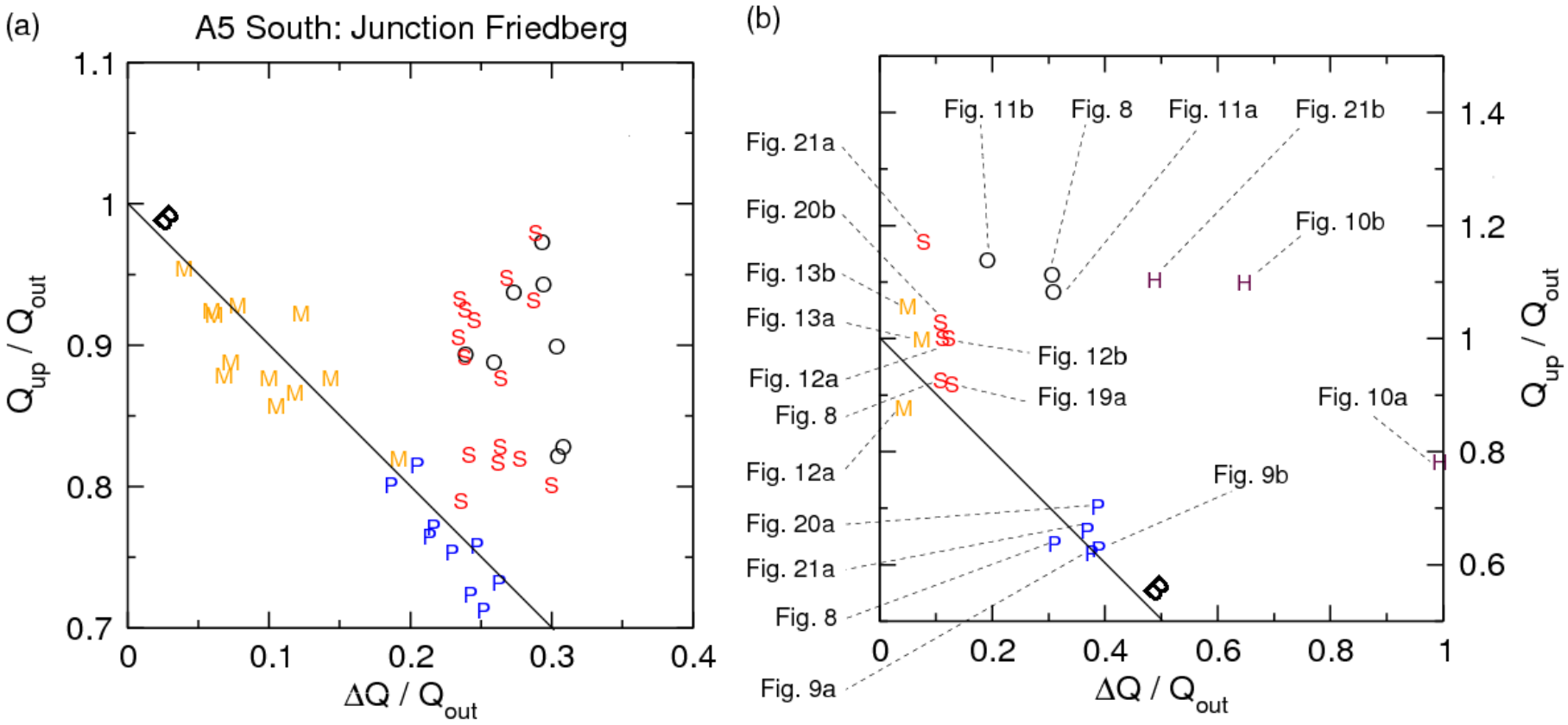



for large perturbations



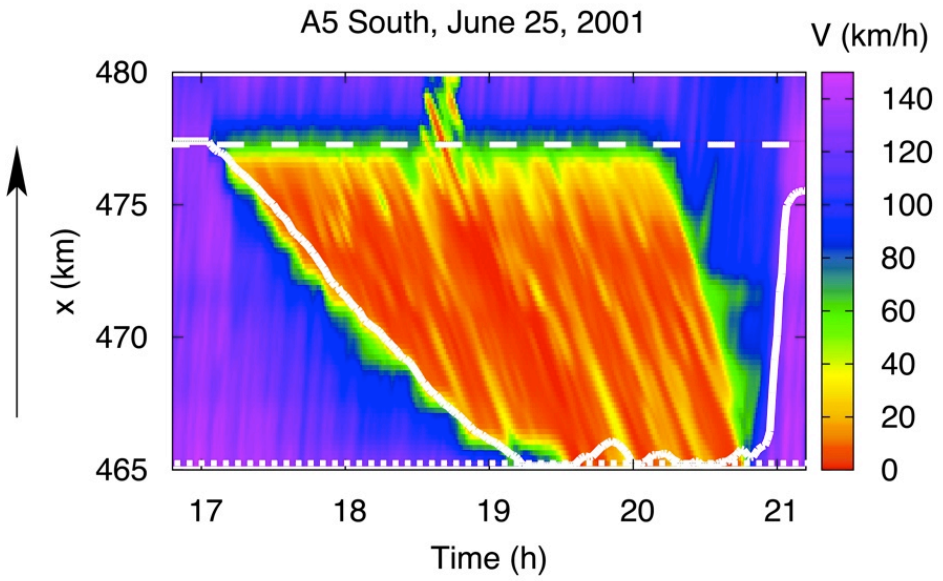

After: *PRL* (1999)

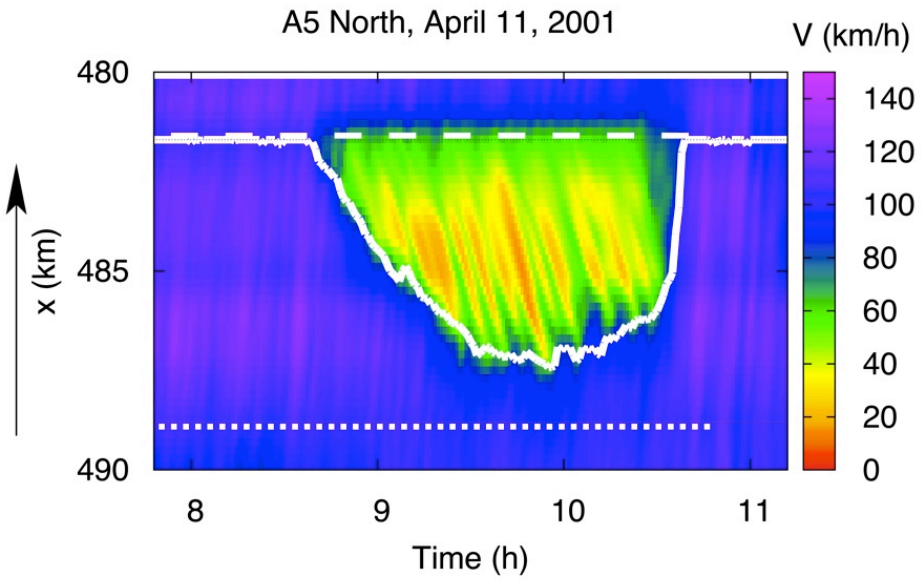
# Empirical Phase Diagram




M = MLC = moving localized cluster, P = PLC = pinned localized cluster
O = OCT = oscillating congested traffic, S = SWG = stop-and-go waves
H = HCT = homogeneous congested traffic

# Traffic Congestion and Travel Times Are Predictable



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# Pedestrian, Crowd, and Evacuation Dynamics

Dirk Helbing

with Anders Johansson, Wenjian Yu, Mehdi Moussaid,

Illes Farkas, Peter Molnar, Tamas Vicsek and others

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# Lane Formation in Pedestrian Counterflows

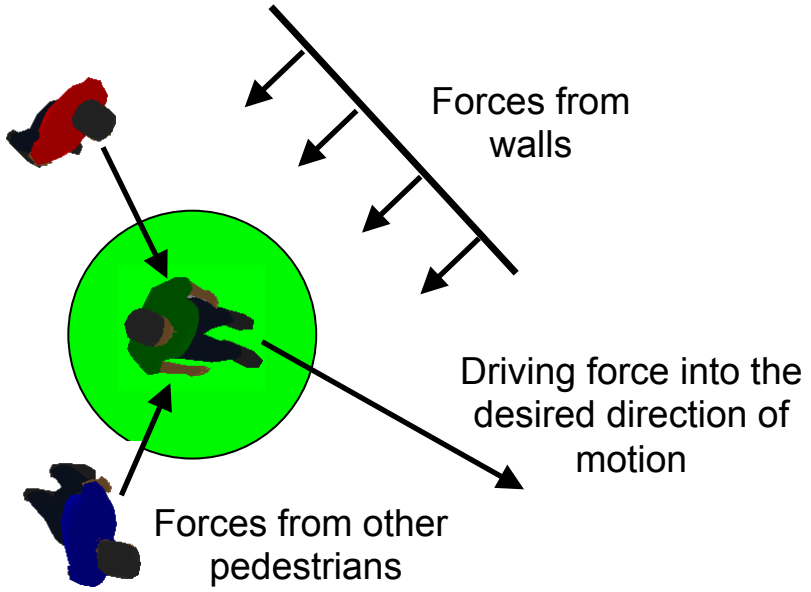

# The Social Force Model

The social force model assumes individual goals (to reach a certain destination efficiently), social interactions (e.g. avoidance of collisions), and institutional setting (e.g. walls).

$$\frac{dx_\alpha}{dt} = v_\alpha(t) \quad \text{(equation of motion)}$$

$$\underbrace{\frac{dv_\alpha}{dt}}_{\text{acceleration}} = \underbrace{\frac{1}{\tau_\alpha}(v_\alpha^0 e_\alpha^0 - v_\alpha)}_{\text{driving force}} + \underbrace{\sum_{\beta(\neq\alpha)} F_{\alpha\beta}^{\text{int}}}_{\text{interactions}} + \underbrace{F_\alpha^{\text{walls}}}_{\text{boundaries}}$$

(acceleration equation)



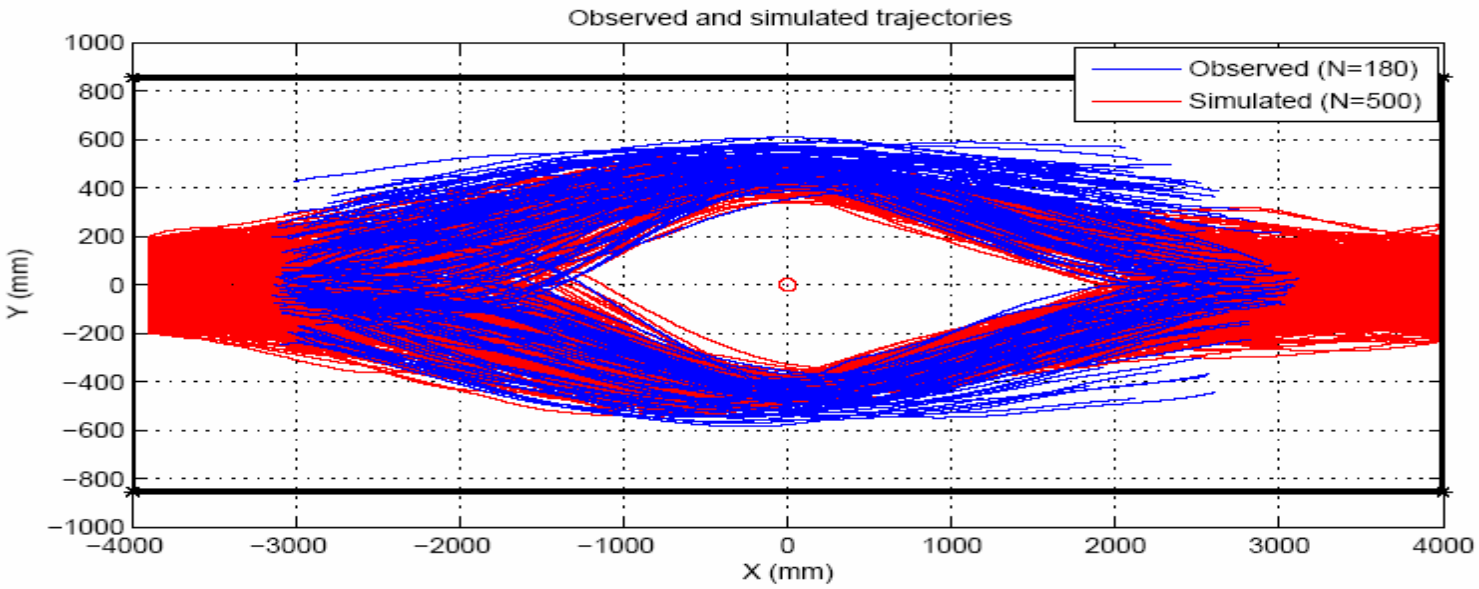
# Experimental Study of Individual Avoidance Behavior

Avoidance of a static pedestrian

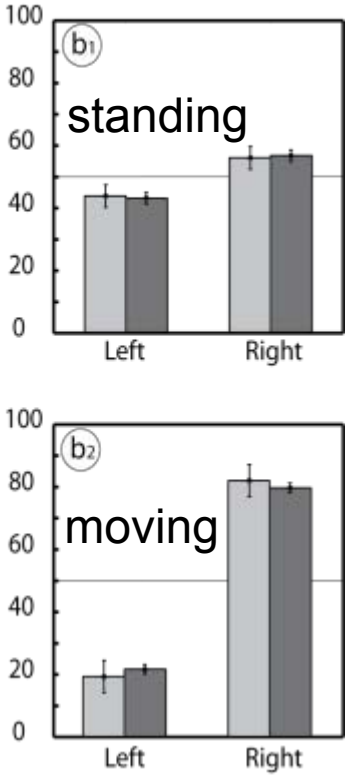
Avoidance of a moving pedestrian

# Validation 1: Corridor Experiment

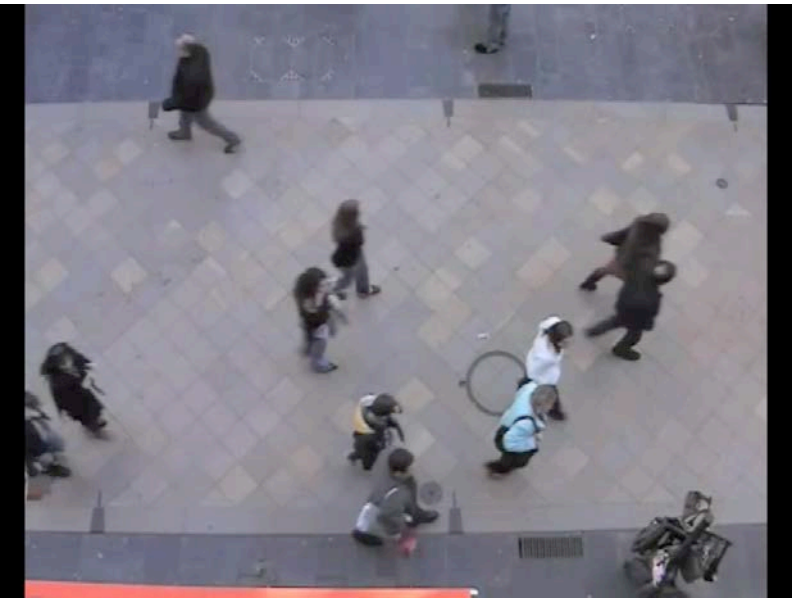
Observed and simulated pedestrian trajectories



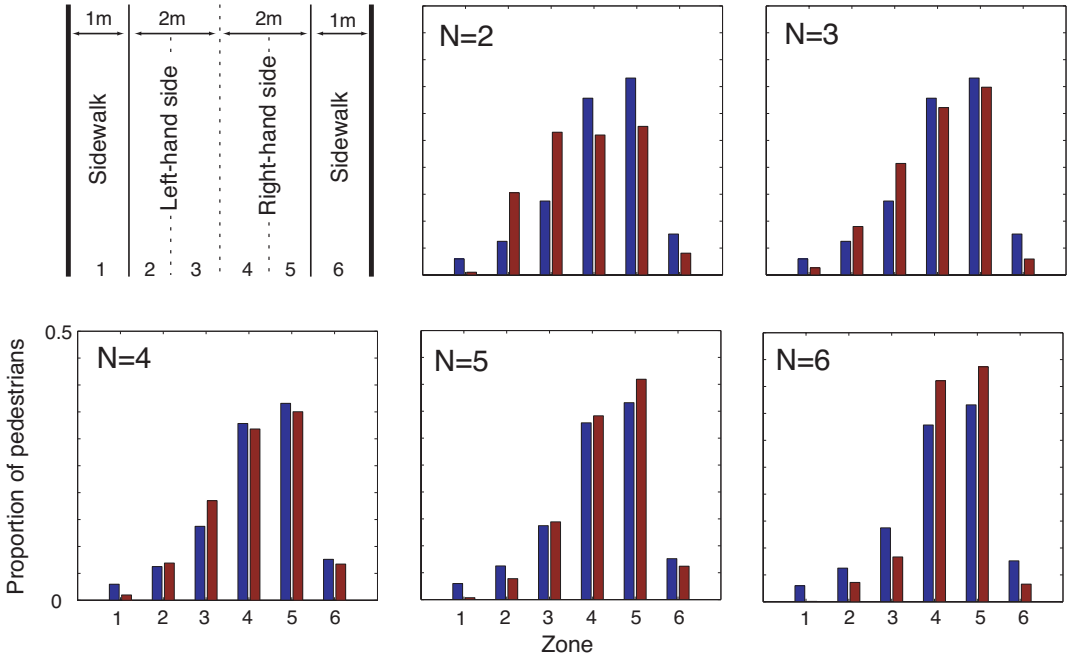

preferred avoidance side



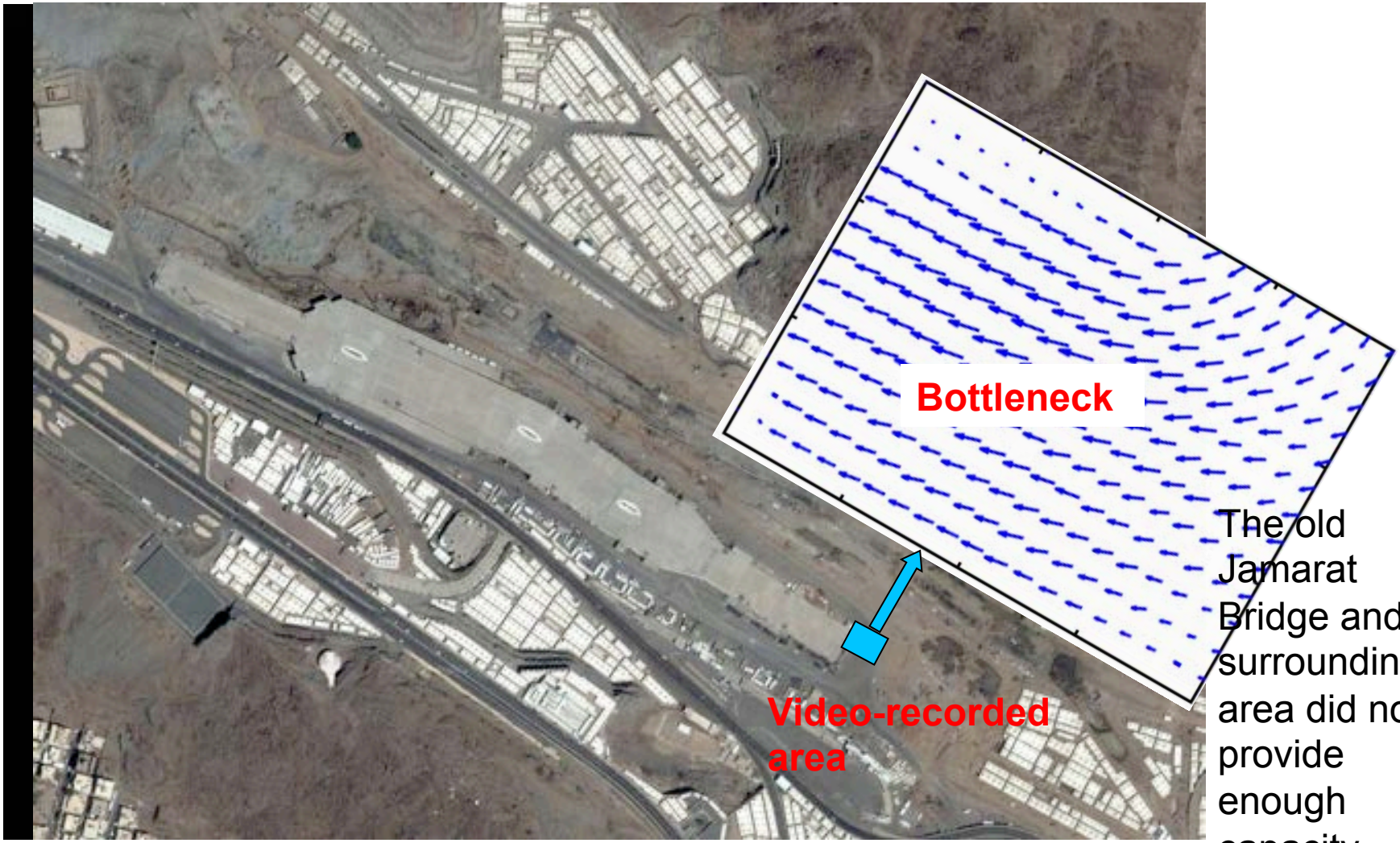
# Validation 2: Collective Dynamics



Observations in a crowded street

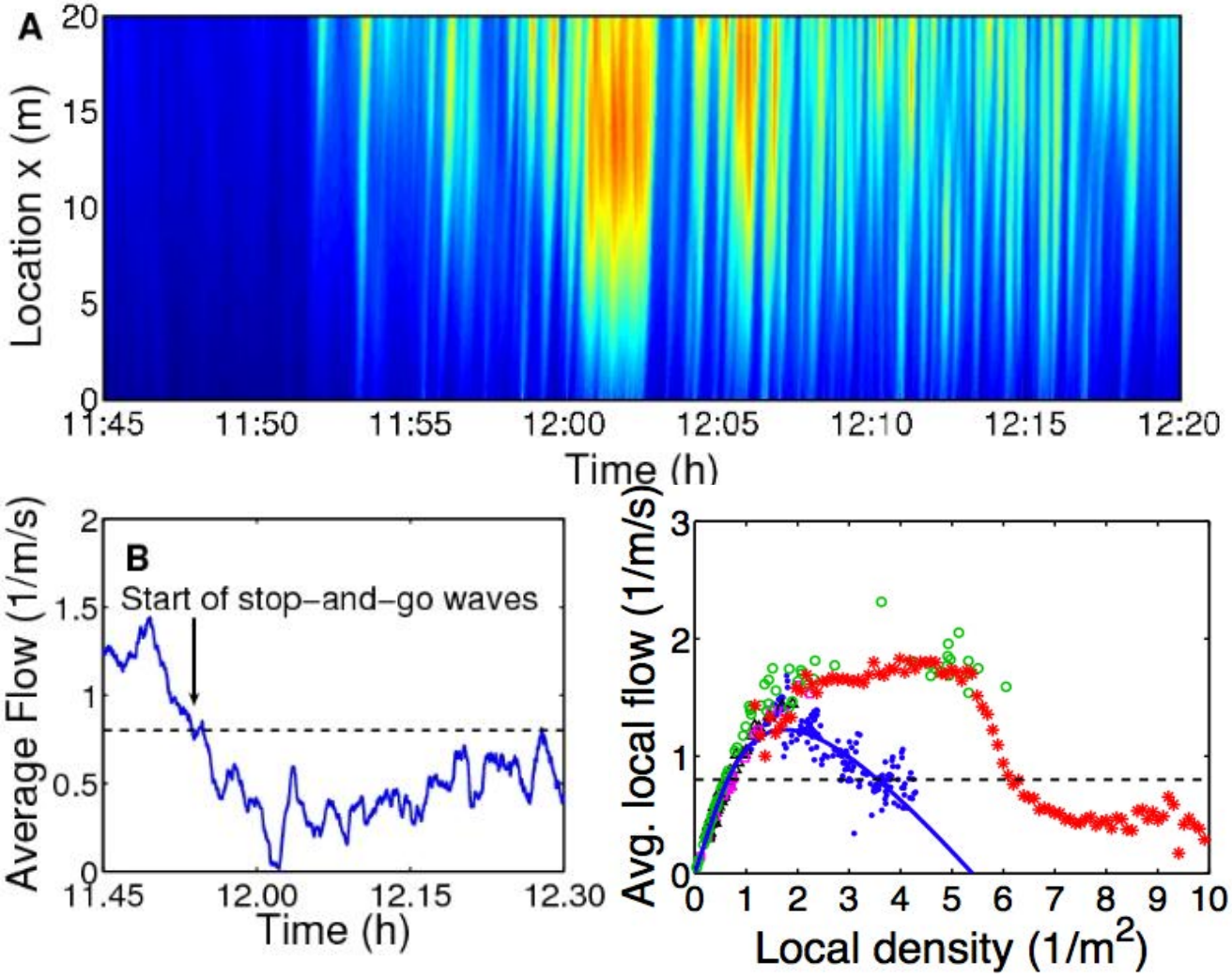


# The Jamarat Bridge (as of January 2006)



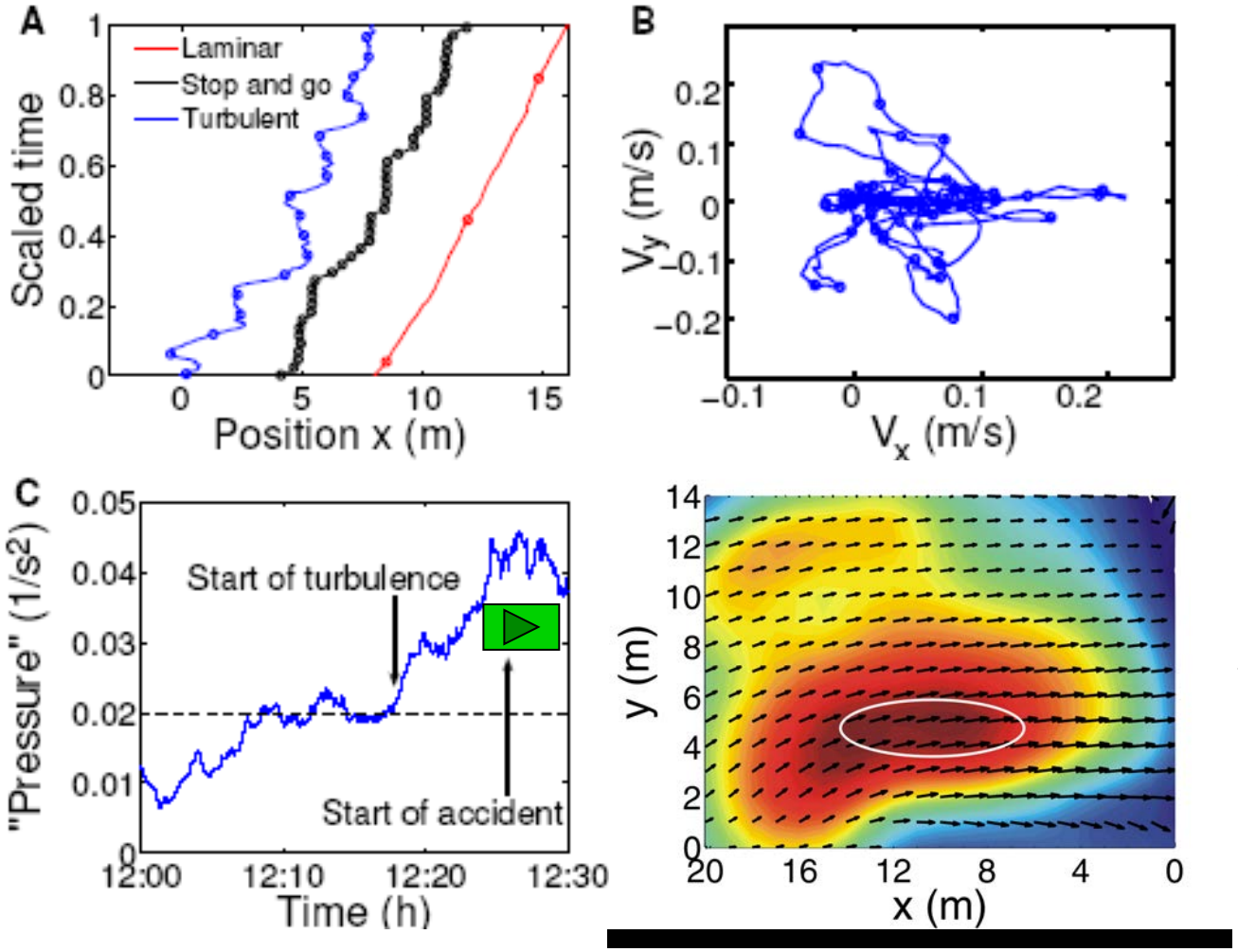

The old Jamarat Bridge and surrounding area did not provide enough capacity anymore

# Transition from Smooth to Stop-and-Go Flow




Mechanism is very different from stop-and-go waves in vehicle traffic!

# Transition from Stop-and-Go Flow to "Crowd Turbulence"




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"

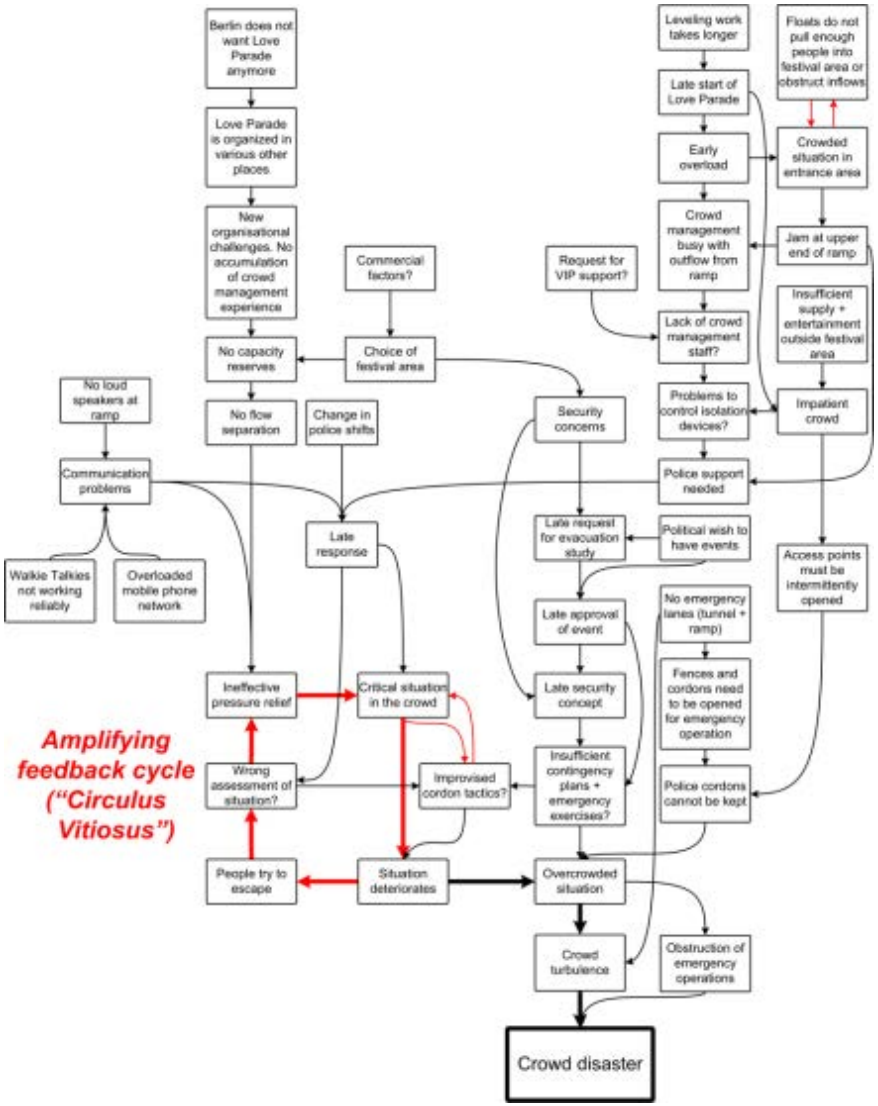
# The Change in Organization from 2006 to 2007

2006: Large accumulations, dense crowds, and long exposure times to intensive sun.

2007: Unidirectional and smooth flows.
Pilgrims liked and supported the new organization.

# Everyone Was Happy with the Result

# Crowd Disasters as Systemic Failures



# Crowd Turbulence as Final Cause of the Love Parade Disaster

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# The Micro-Macro Problem

Dirk Helbing

and Michael Mäs

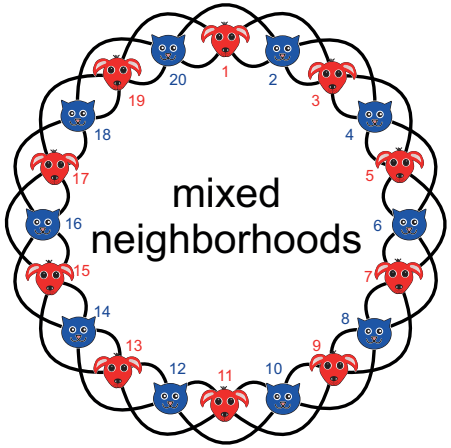
D GESS

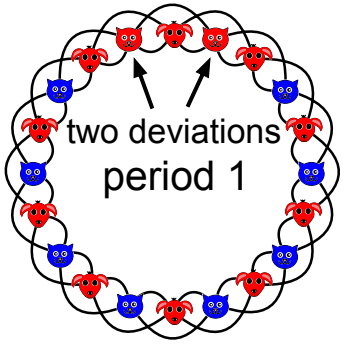
# “The whole is more than the sum of its parts”

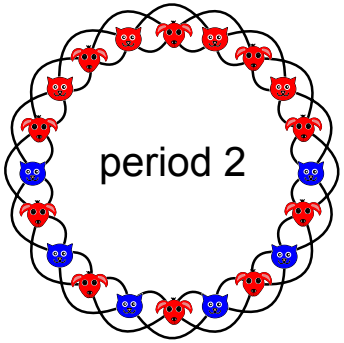
The “whole does not equal the sum of its parts; it is something different, whose properties differ from those displayed by the parts from which it is formed.” (Durkheim 1982:128)

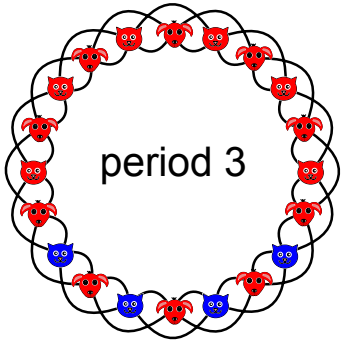
“The determining cause of a social fact must be sought among antecedent social facts and not among the states of the individual consciousness.” (Durkheim 1982:134)

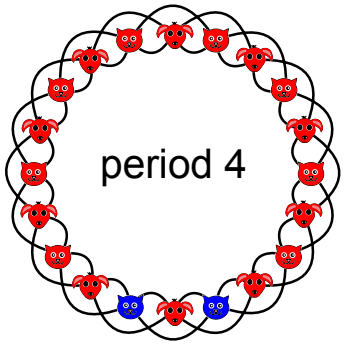
# Noise on the Micro-Level Can Affect Macro-Level

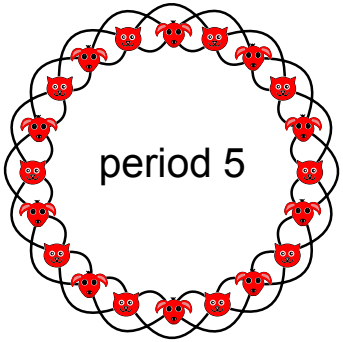


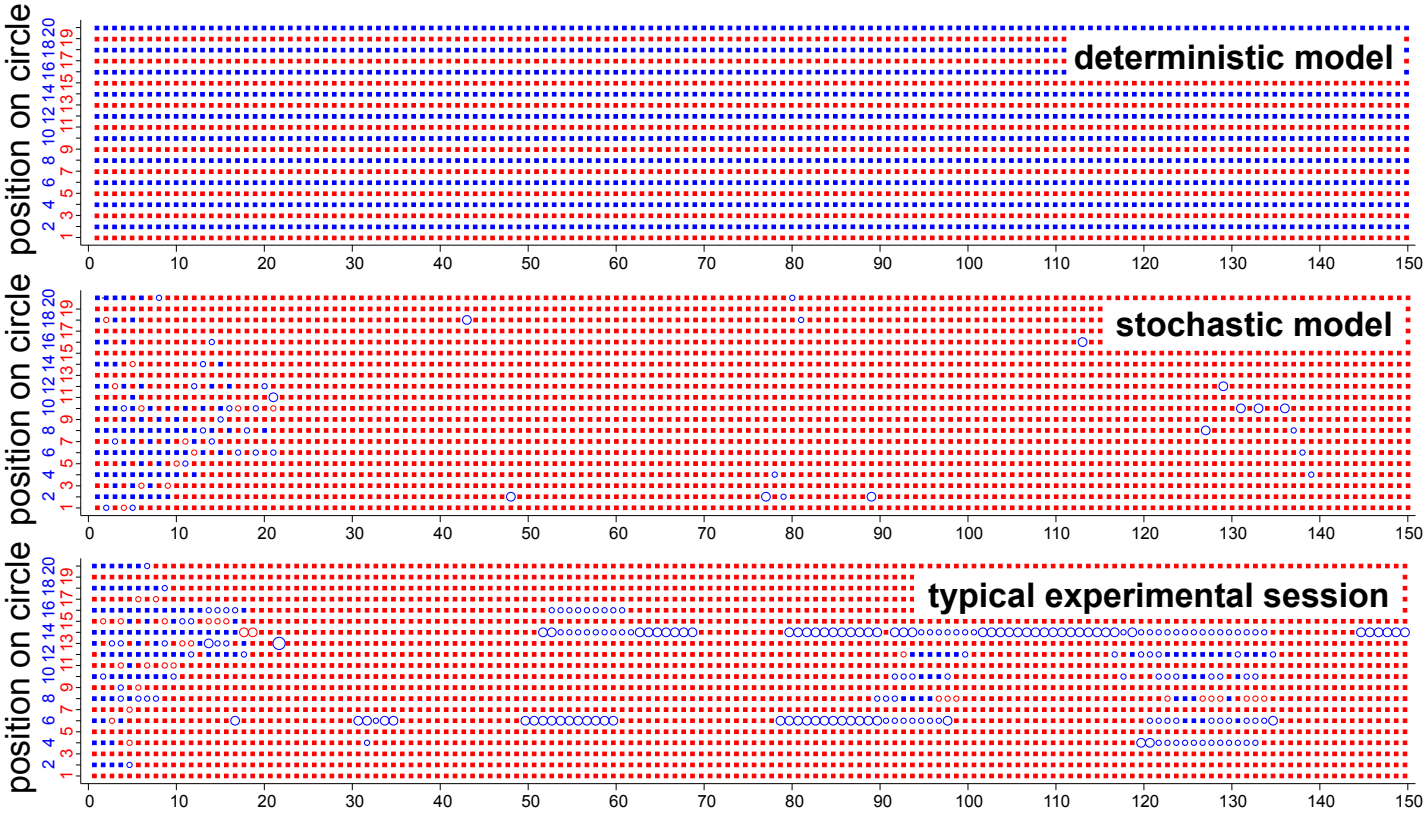



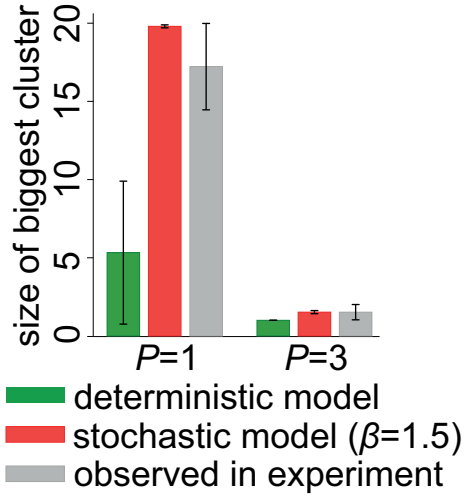



# To Understand Macro-Level Outcomes of Decision-Making, Noise Must Be Considered



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# Opinion Formation: Differentiation and Cultural Diversity

Dirk Helbing

with Michael Mäs, Andreas Flache, Heiko Rauhut,

Jan Lorenz, Frank Schweitzer

and others

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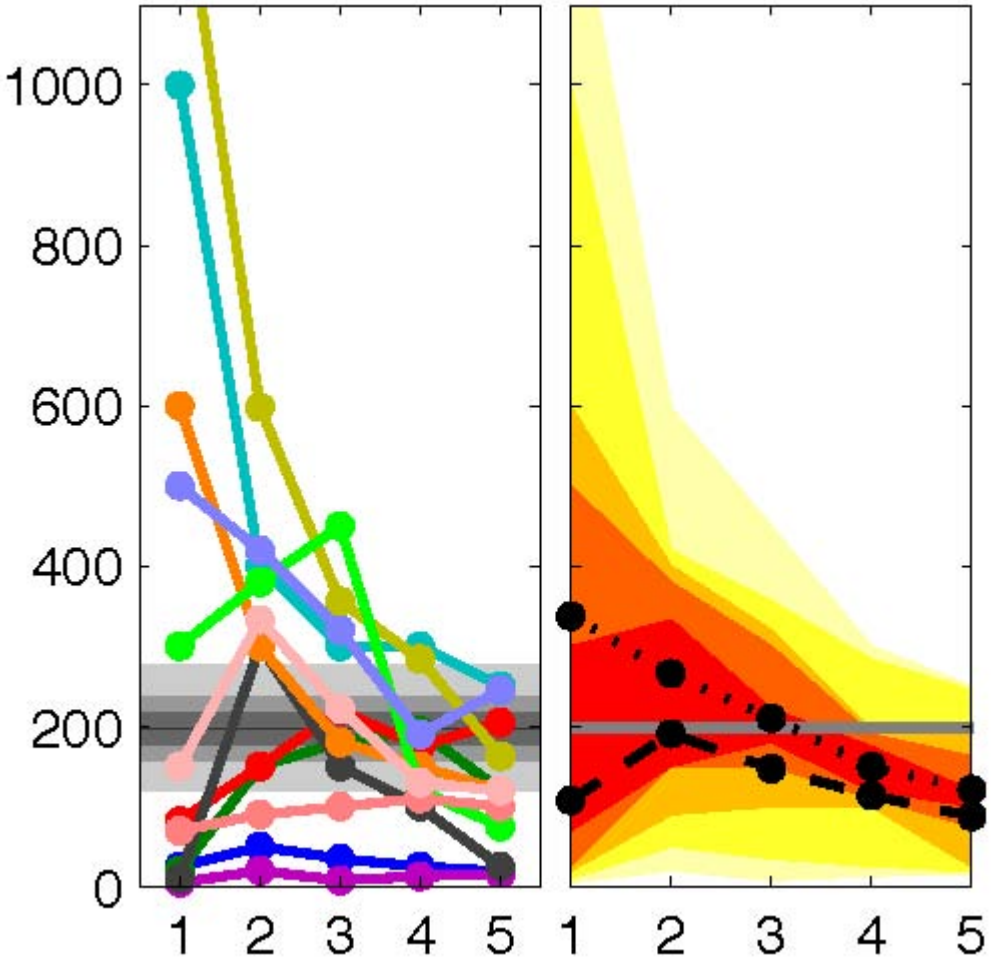
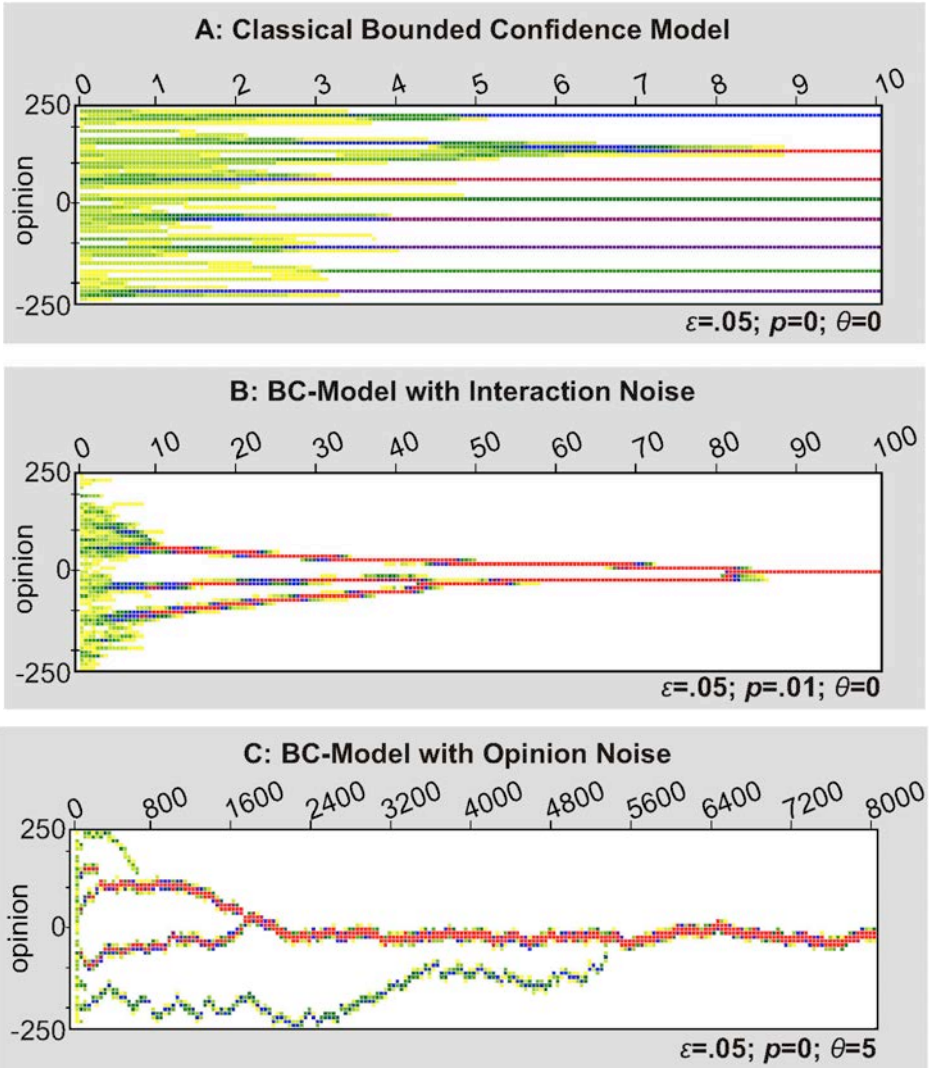
# Social Influence Causes Convergence of Beliefs




PNAS

# Diversity despite social influence




**Research questions:**
Why doesn't diversity disappear, but often increase?

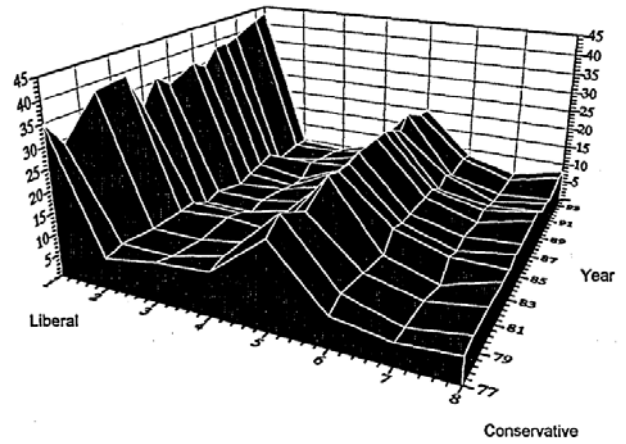
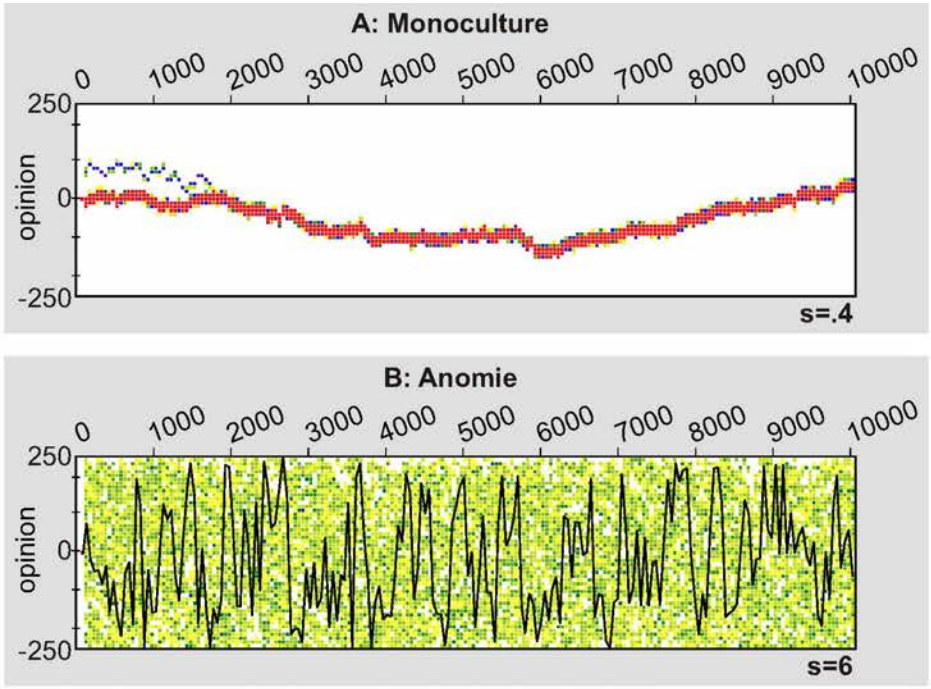
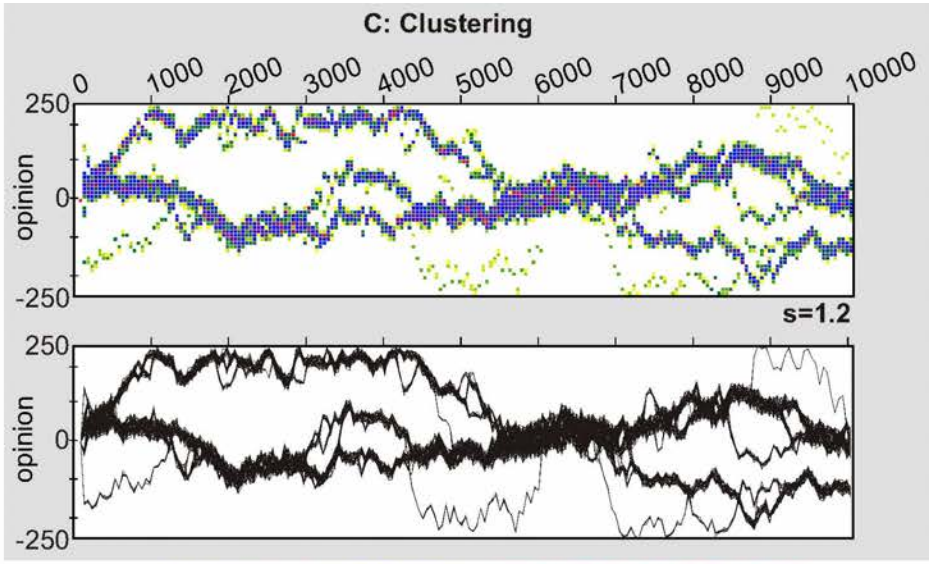



FIG. 4.—Distributions by year, attitudes toward abortion, full sample, GSS 1977–94.

# A Classical Theory Guides the Way to the Answer

"…there is in the consciousness of each one of us two consciousnesses: one that we **share in common** with our group in its entirely … the other that makes us an **individual**. Here there are two opposing forces, the one centripetal, the other centrifugal" (Durkheim 2003a: 258-259)



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# Modeling the Breakdown and Emergence of Coordination or Cooperation

Dirk Helbing

with Thomas Chadefaux, Wenjian Yu, Thomas Grund, Christian Waloszek, Carlos Roca, Sergi Lozano, Matjaz Perc, Attila Szolnoki, and others

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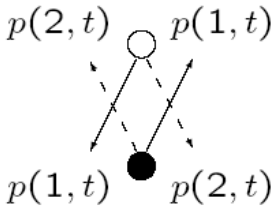
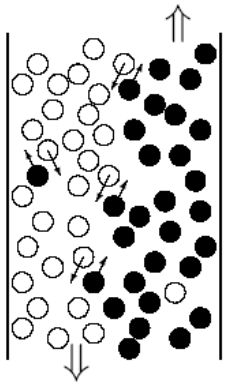
# Self-Organization of A Behavioral Convention

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 | 0, 0 |
| right | o, 0 | B, B |

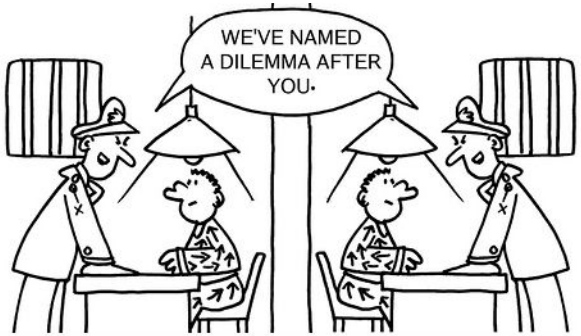
B = benefit of evading on the same side = time saved compared to one pedestrian evading to the right and the other one to the left

$$dp(i,t)/dt = -2rB[p(i,t)-1/2]\, p(i,t)\, [1-p(i,t)]$$ 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 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 2: Cooperate | Player 2: Defect |
|---|---|---|
| Cooperate | $R_1$ $R_2$ | $S_1$ $T_2$ |
| Defect | $T_1$ $S_2$ | $P_1$ $P_2$ |

For example:

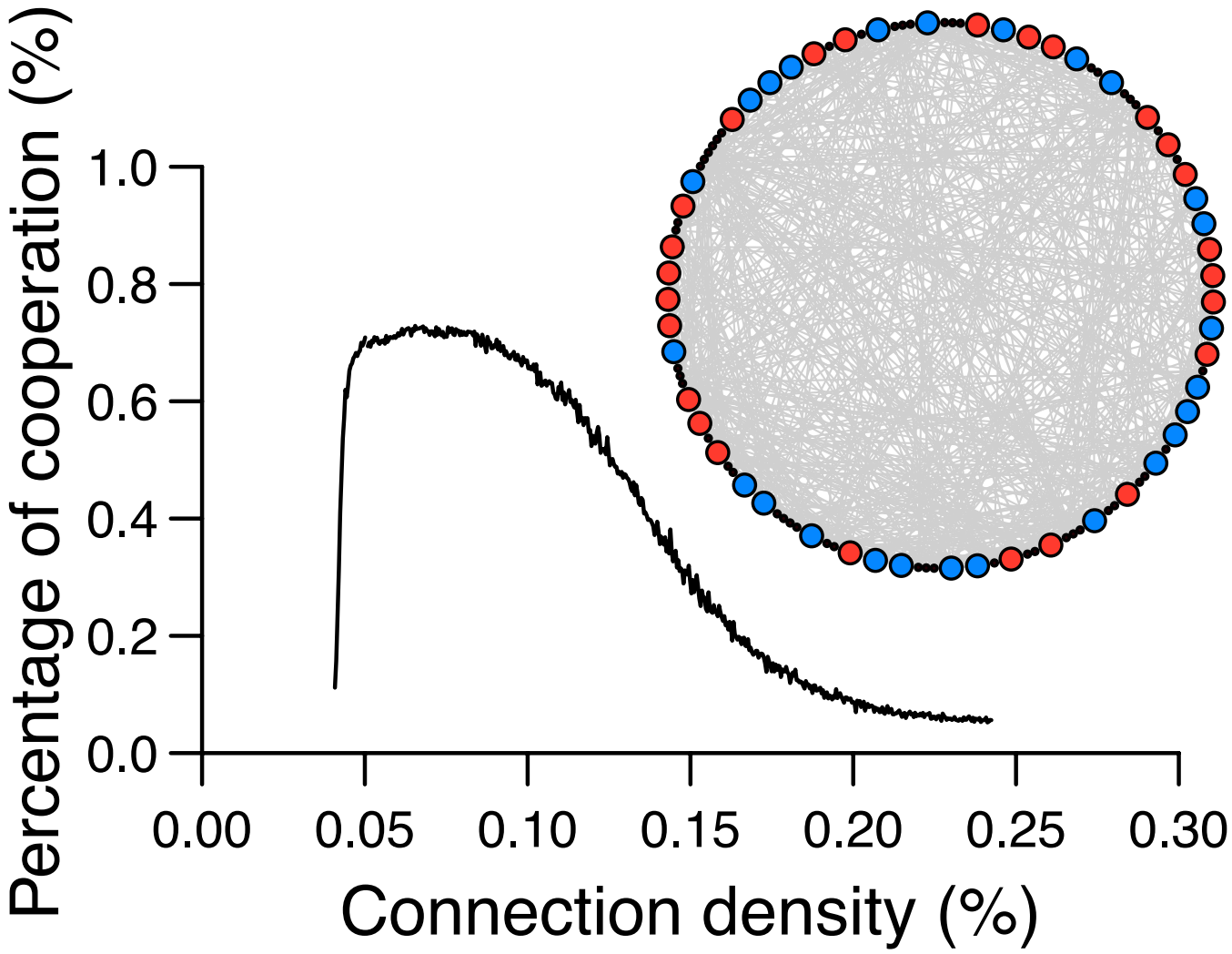
$S_1 = S_2 = S = -5$

$P_1 = P_2 = P = -2$

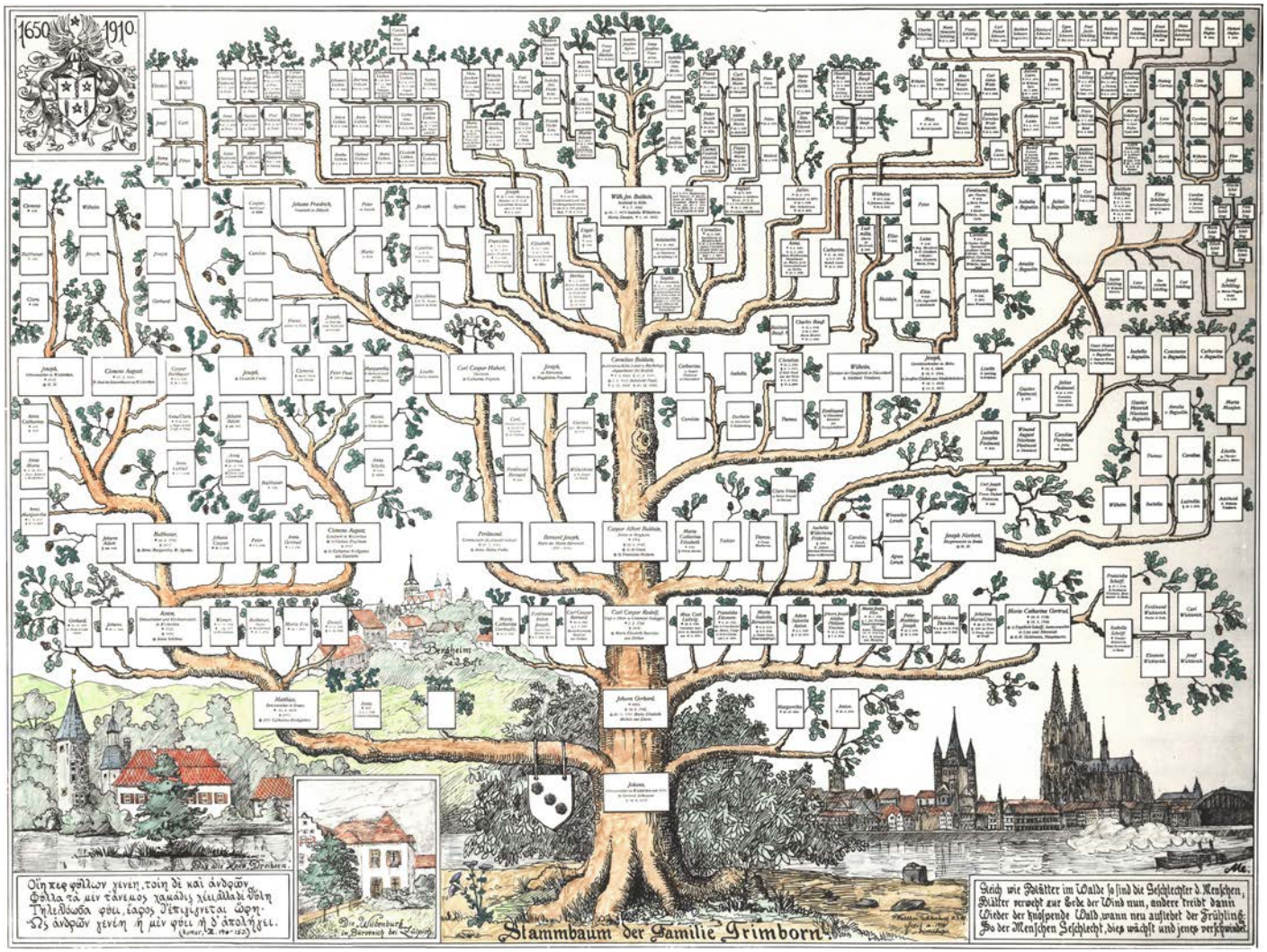
$R_1 = R_2 = R = -1$

$T_1 = T_2 = T = 0$

# Prisoner‘s Dilemmas in an Increasingly Connected World

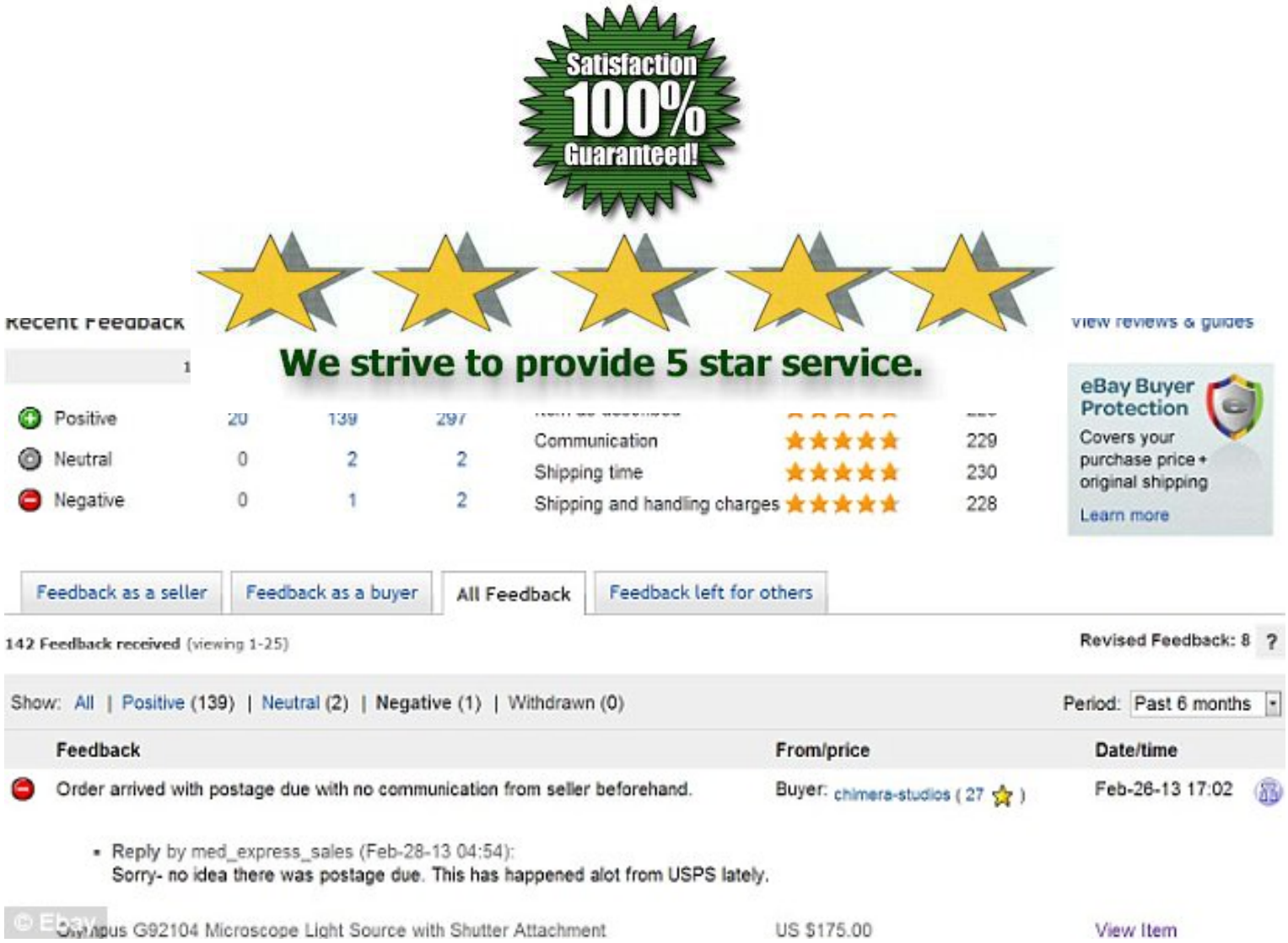


# Kin Selection, Genetic Favoritism



# Direct Reciprocity

# Reputation, Indirect Reciprocity



# Pool Punishment

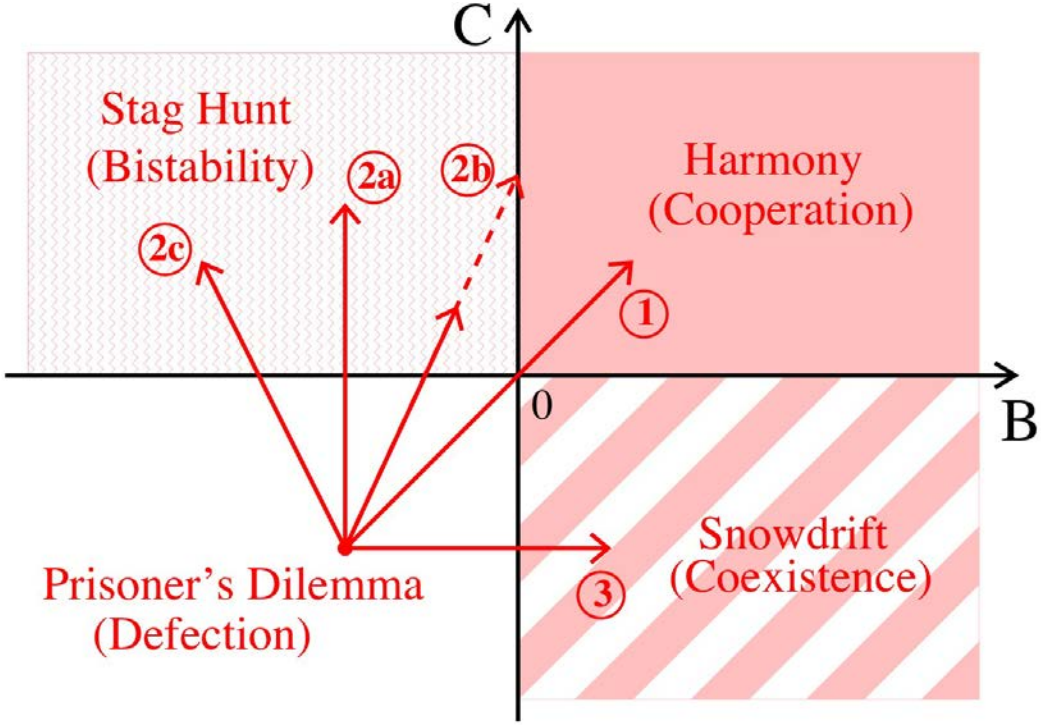
# Peer Punishment

*"We're from the Neighborhood Watch committee. We've heard you're wearing a fake Rolex."*

Leo Cullum, The New Yorker, February 23, 1998.

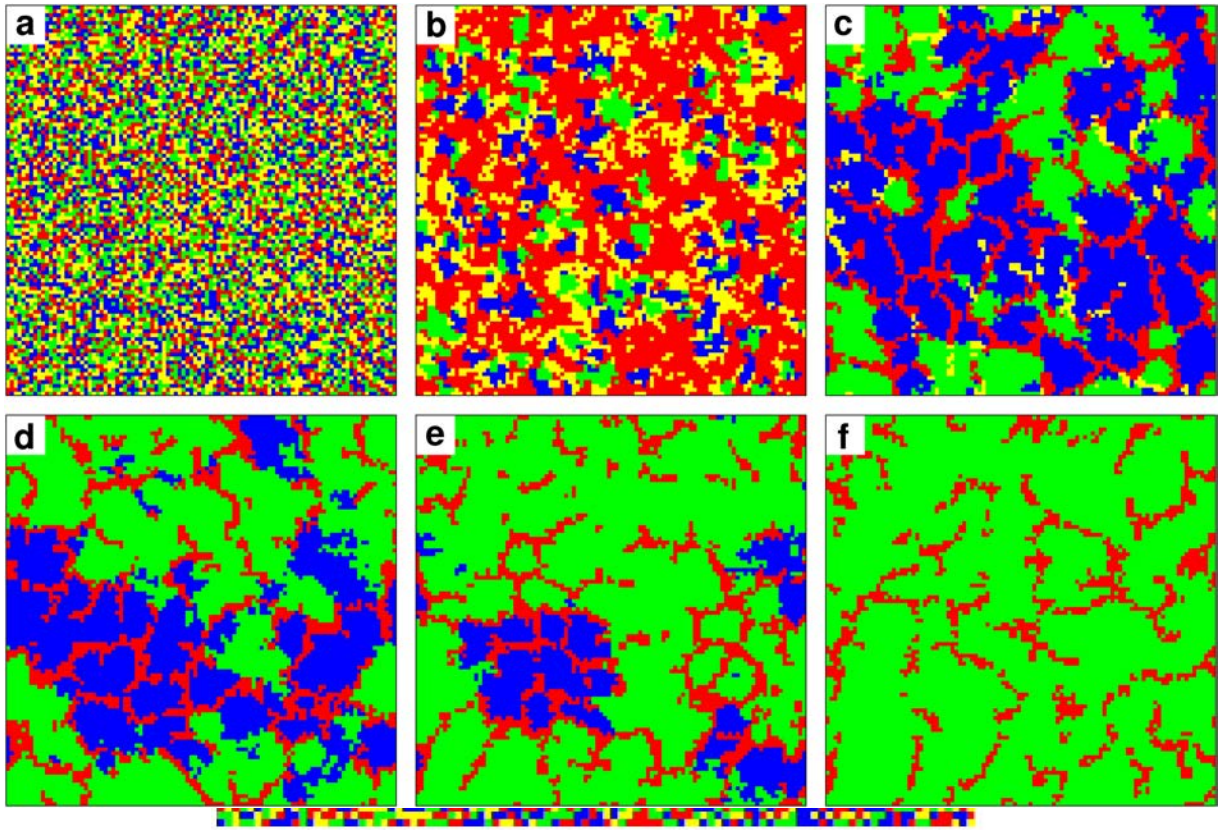
# Routes to Cooperation

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




Route 1: Kin selection 2a: Direct reciprocity, 2b: Indirect reciprocity, 2c: Costly peer punishment, 3: Network interactions

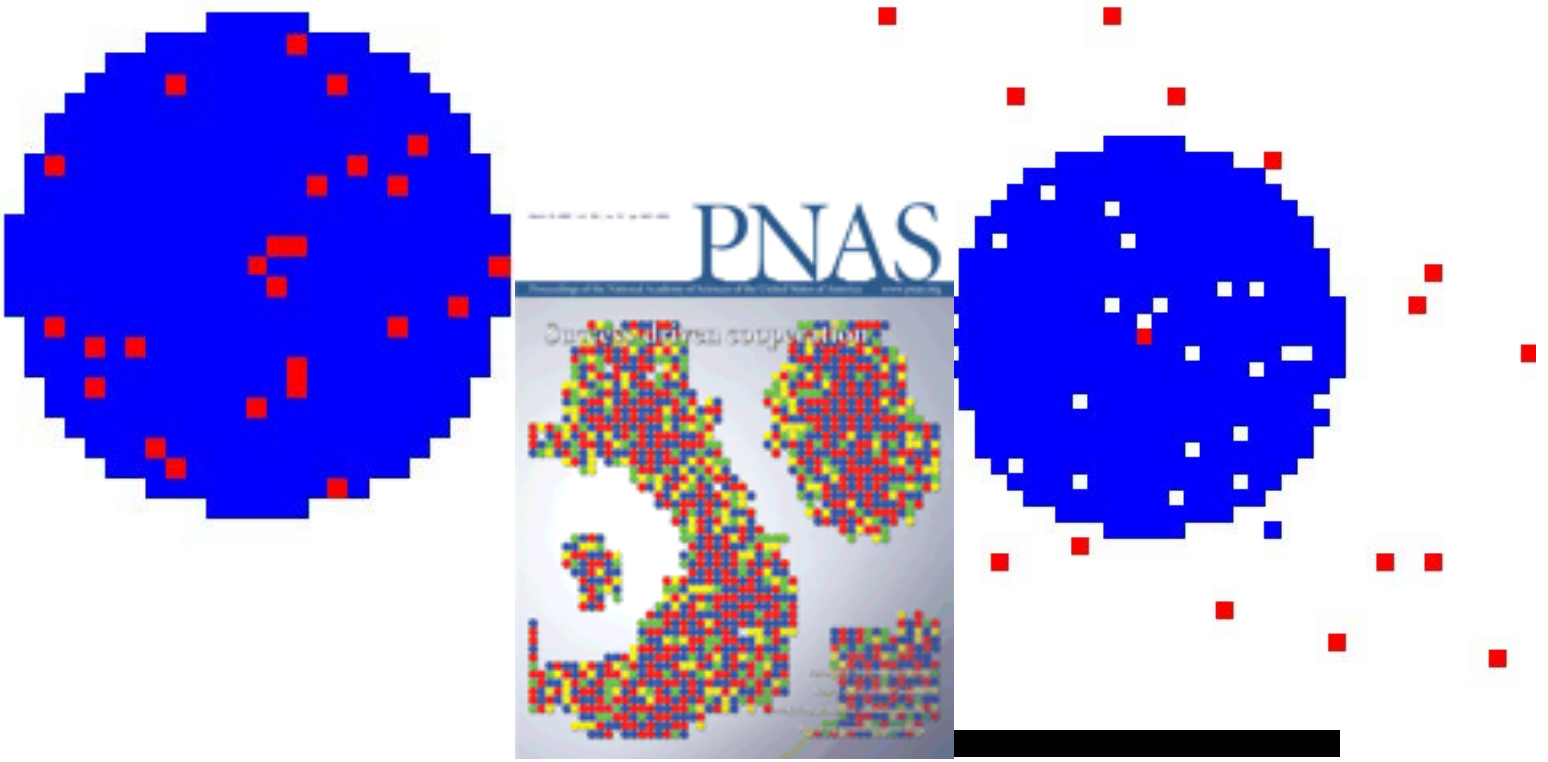
# How Second-Order Free-Riders Are Eliminated and Punishment Spreads




D = Defectors (free-riders), M = Moralists = cooperators punishing defectors, C = non-punishing Cooperators (second-order free-riders), I = Immoralists = defectors punishing other defectors

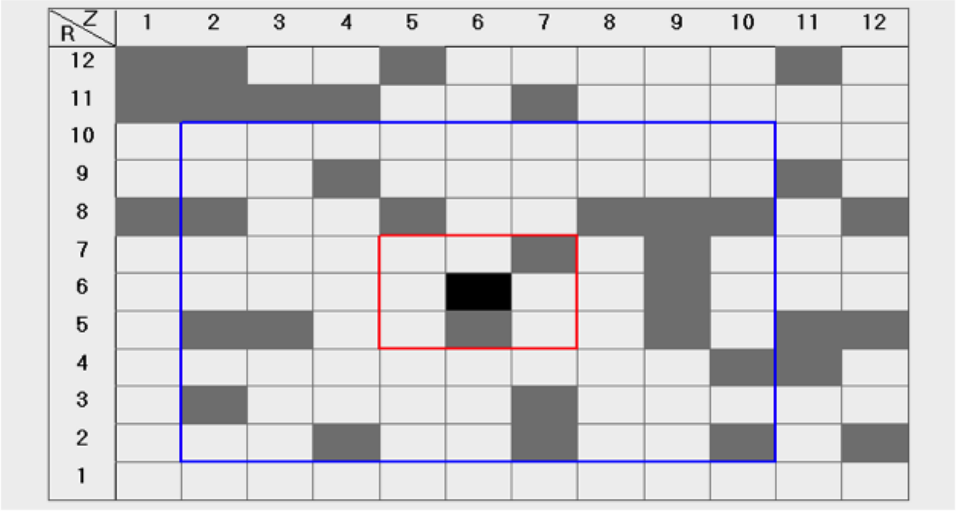
# The Breakdown and Outbreak of Cooperation with Imitation, Migration, and Noise

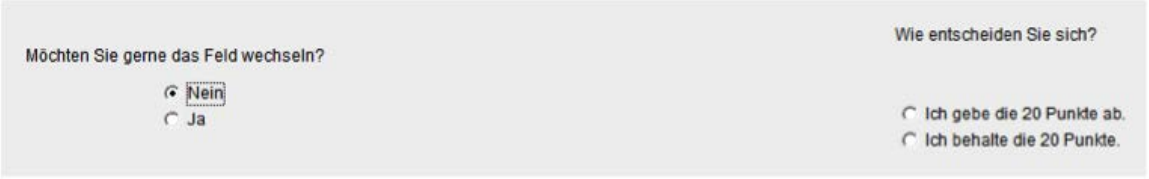
Red, yellow: defectors (cheaters)
Blue, green: cooperators
Yellow, green: changed in last time step



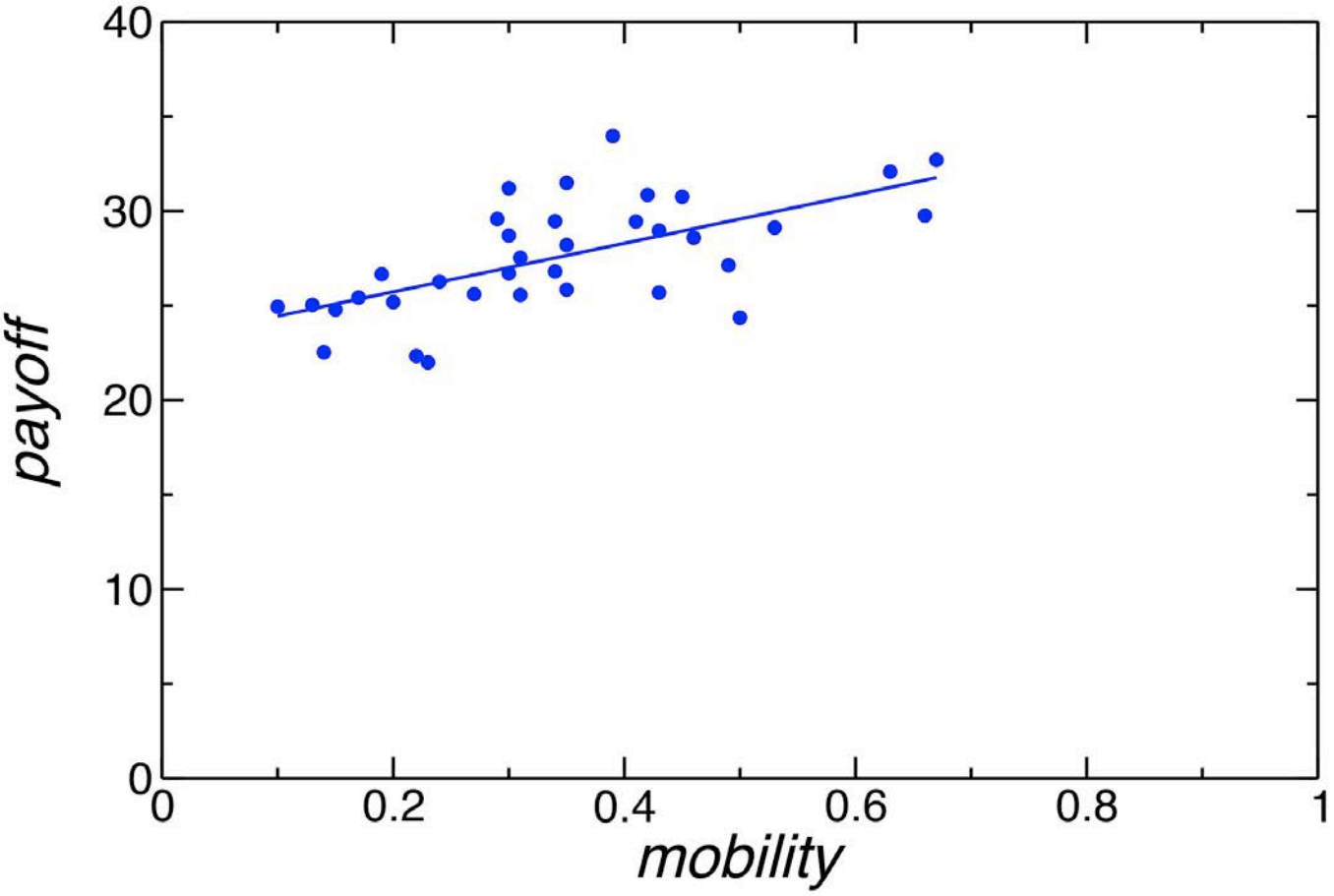
# Public Good Game with Mobility: Experimental Design


Joint work with Carlos Roca, Charles Efferson and Sonja Vogt



# Payoff as Function of Mobility




Mobility is key to success!

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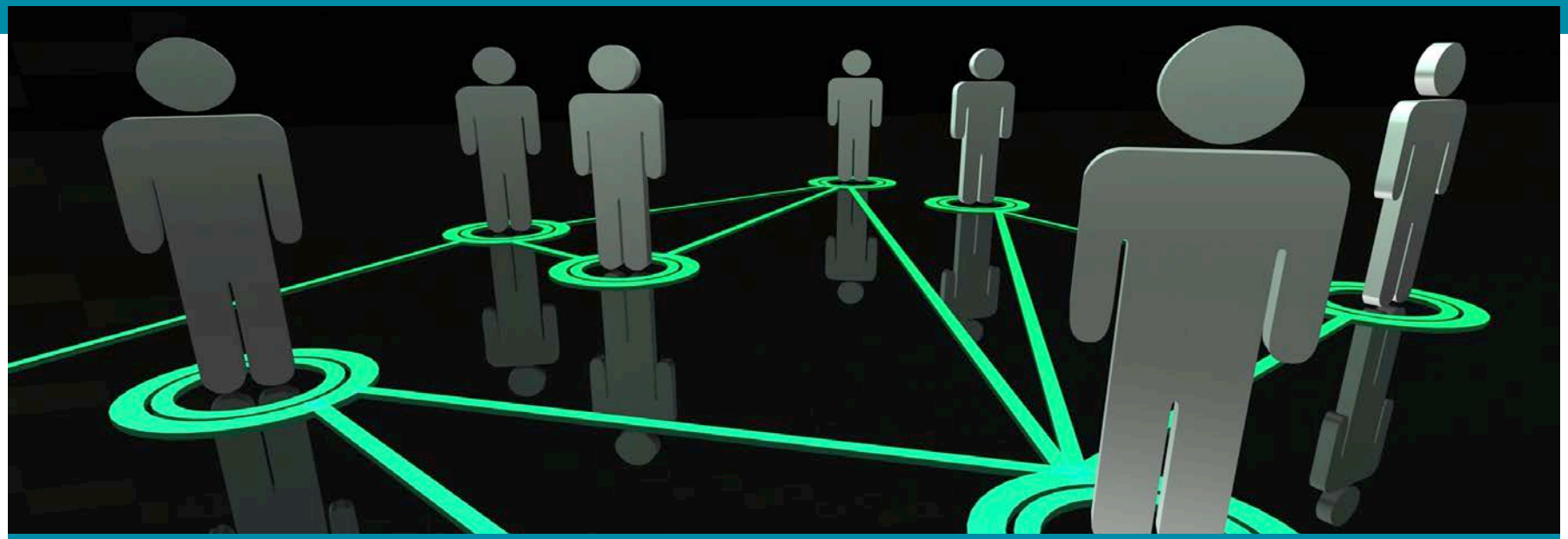

# Why Humans Are Social: The Emergence of the „Homo Socialis“

Dirk Helbing

with Thomas Grund, Christian Waloszek,

Matthias Leiss, Heinrich Nax,

and others

D GESS

# Evolutionary Model of Human Decision-Making

- Agents decide according to a best-response rule that strictly maximizes their utility function, given the behaviors of their interaction partners (their neighbors).
- The utility function considers not only the own payoff, but gives a certain weight to the payoff of their interaction partner(s). The weight is called the ``friendliness'' and set to zero for everyone at the beginning of the simulation.

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# Evolutionary Model of Human Decision-Making

- Friendliness is a trait that is inherited (either genetically or by education) to offspring. The likelihood to have an offspring increases exclusively with the own payoff, not the utility function. The payoff is assumed to be zero, when a friendly agent is exploited by all neighbors (i.e. if they all defect). Therefore, such agents will never have any offspring.

- The inherited friendliness value tends to be that of the parent. There is also a certain mutation rate, but it does not promote friendliness. (In the simulation results discussed here, mutations were specified such that they imply an average friendliness of 0.2, which cannot explain the typically observed value of 0.4.)

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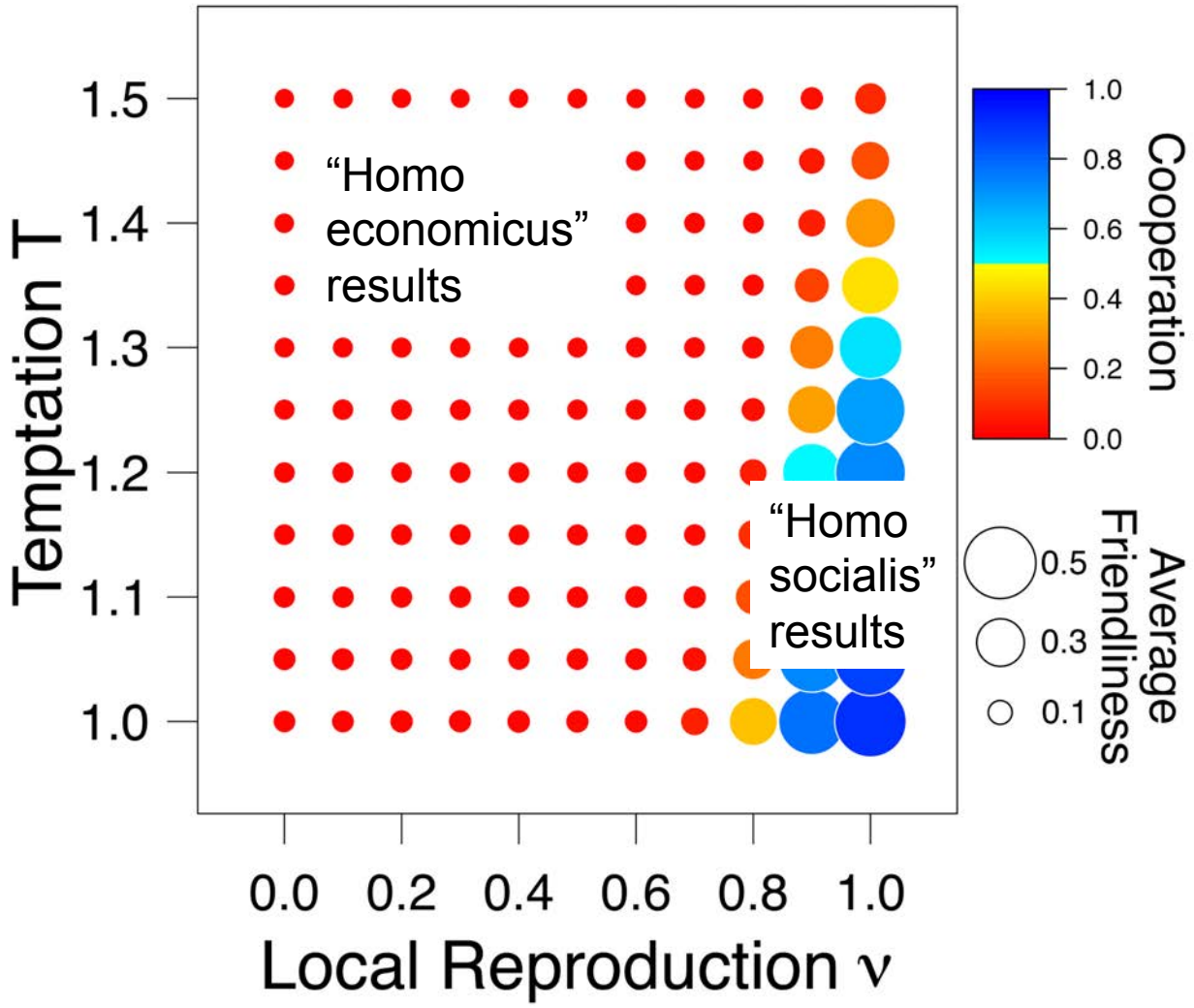
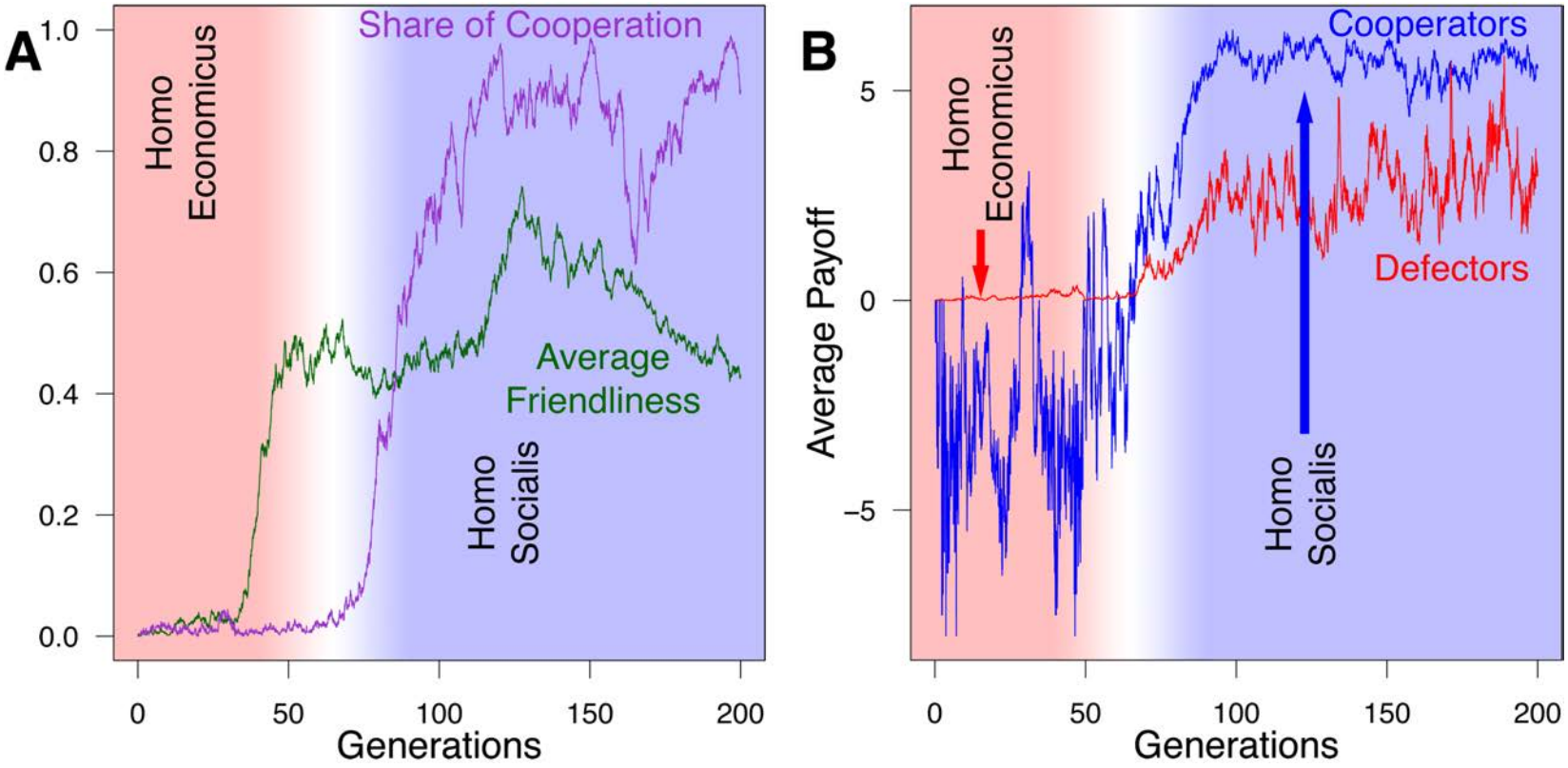
# Phase Diagram: Parameter-Dependent Outcome



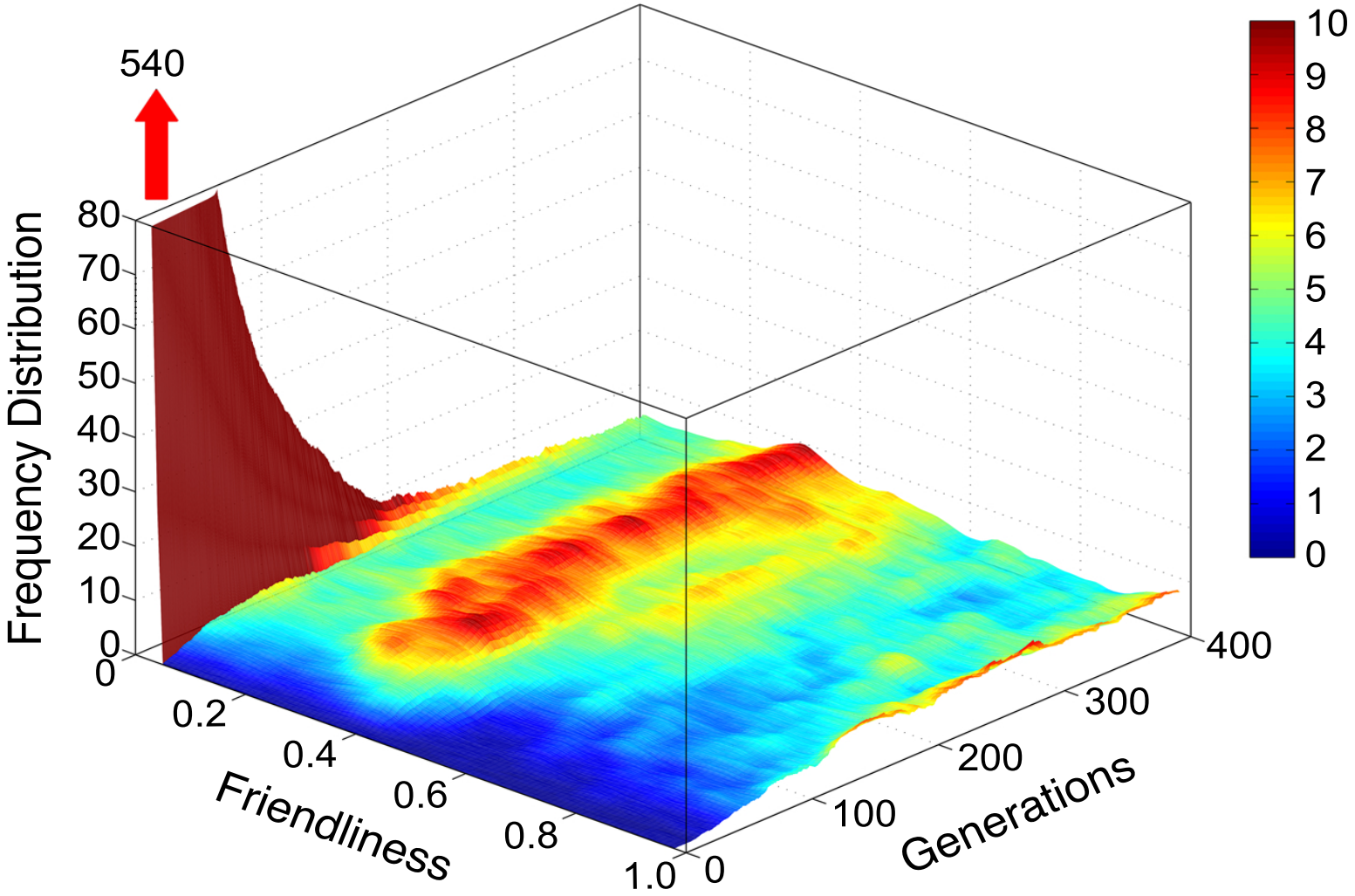
# Emergence of the „Homo Socialis“



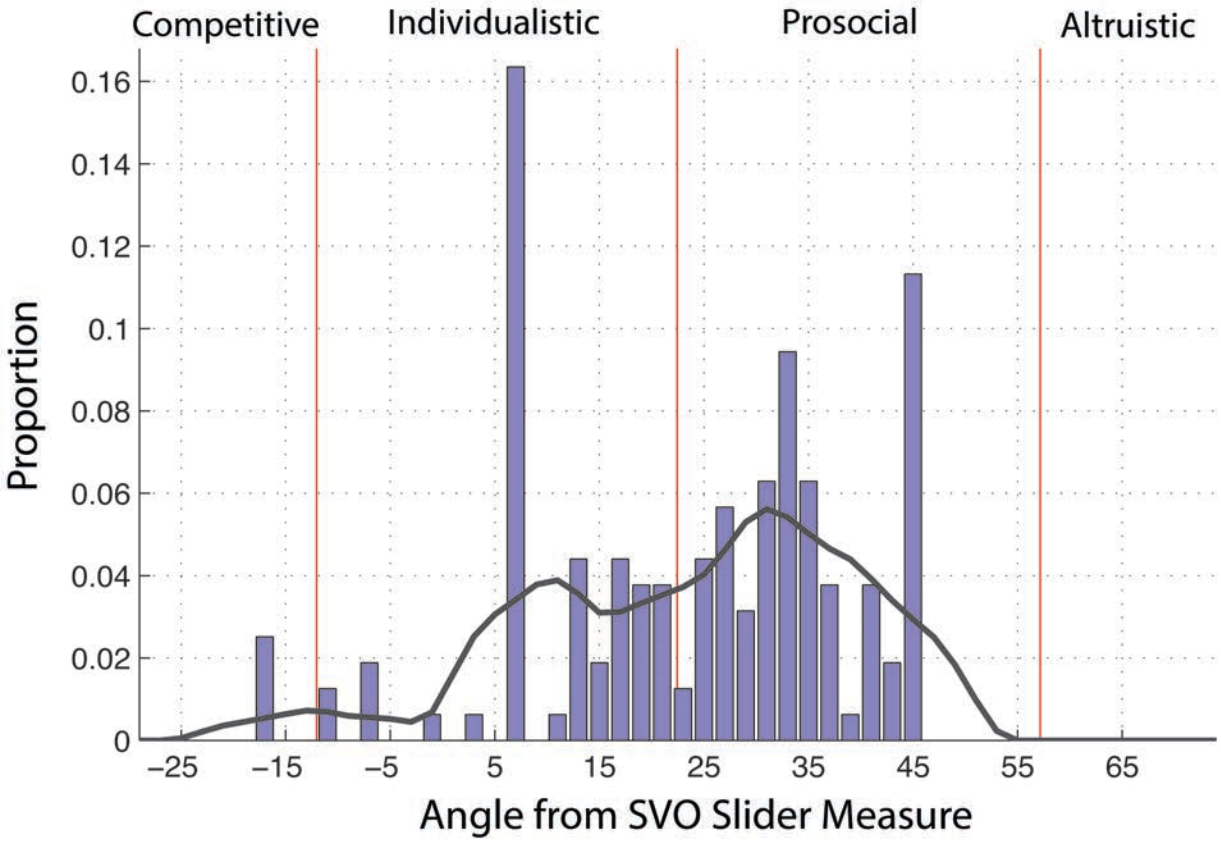

The “homo socialis” is conditionally cooperative, takes self-determined but other-regarding decisions (considering the impact on others).

This implies interdependent decisions, “networked minds”.

# Distribution of Friendliness Values



# Empirical Measurement of Prosocial Preferences




Experimental work of Ryan Murphy *et al.*

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# Modeling the Emergence of Social Norms when Preferences are Incompatible

Dirk Helbing

with Michael Mäs, Anders Johansson,

Heiko Rauhut, Fabian Winter,

and others

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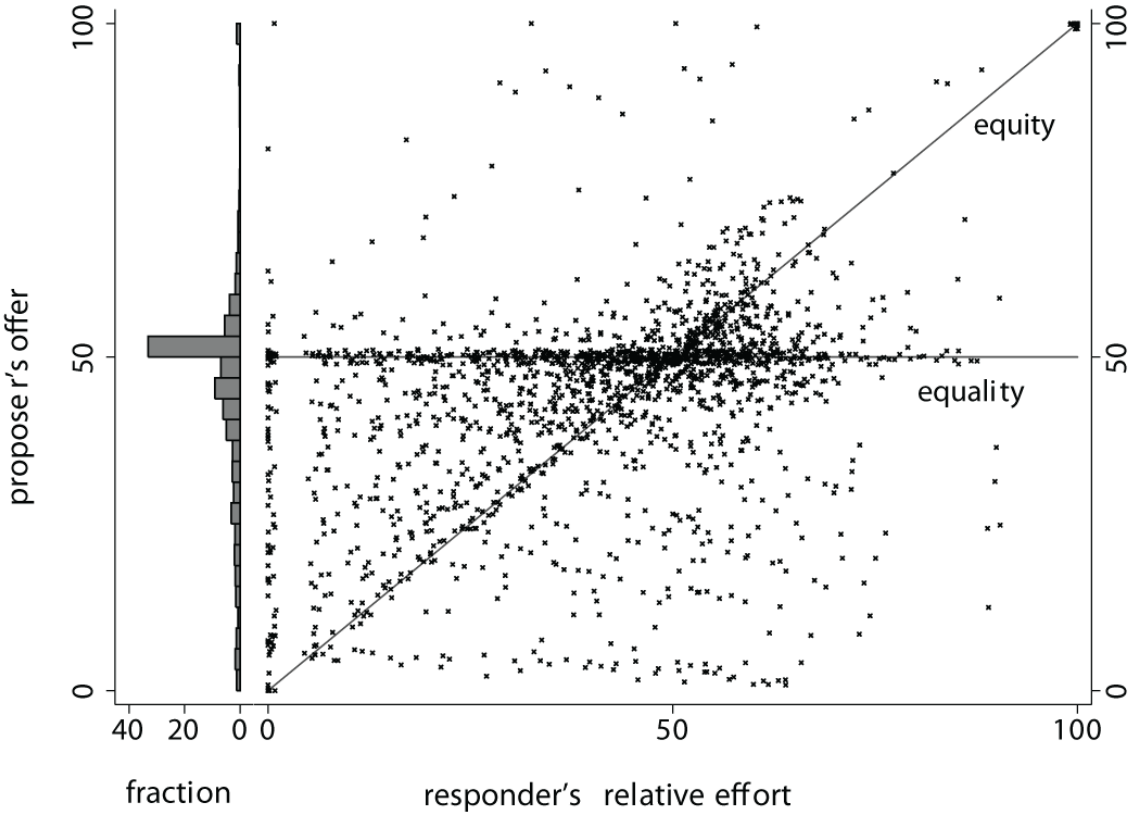
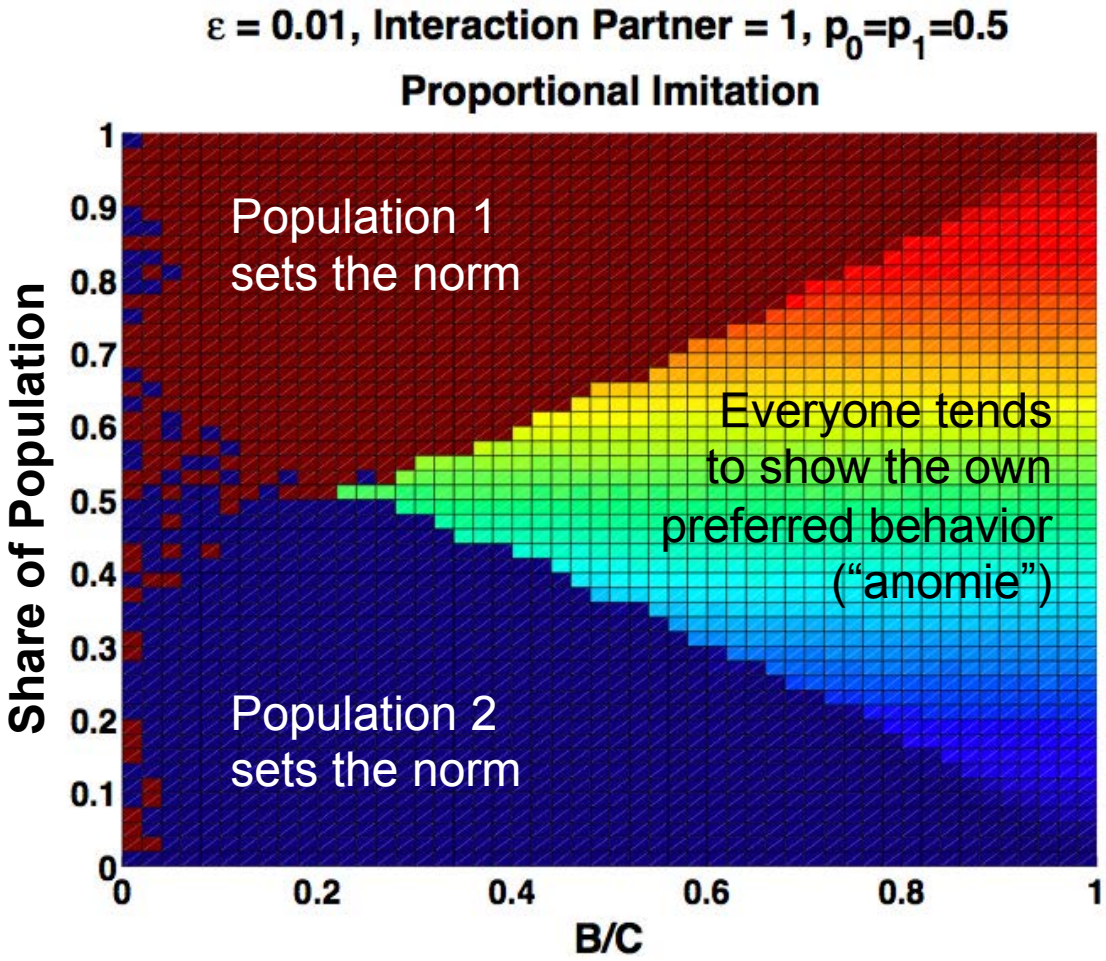
# Conflict between Individuals with Equity and Equality Preferences




Results of an Ultimatum Game Experiment

Joint work with Fabian Winter and Heiko Rauhut

# Possible Outcomes in the Two-Population Norms Game




Computer simulations:

Red = individuals preferring behavior 1

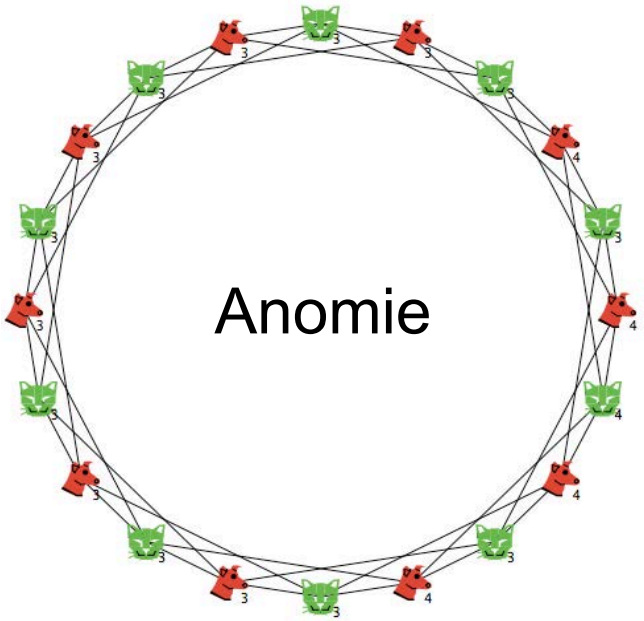
Yellow = individuals adjusting to behavior 1

Blue = individuals preferring behavior 2

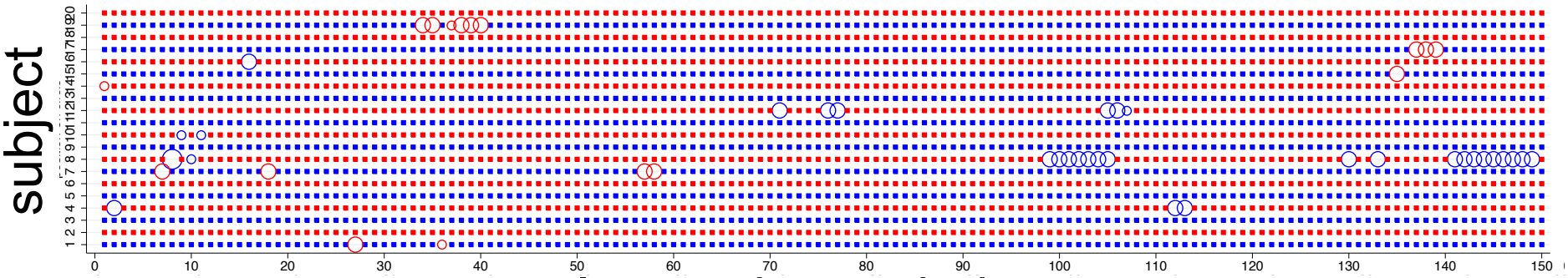
Green = individuals adjusting to behavior 2

Reward of showing preferred behavior / Reward of conforming

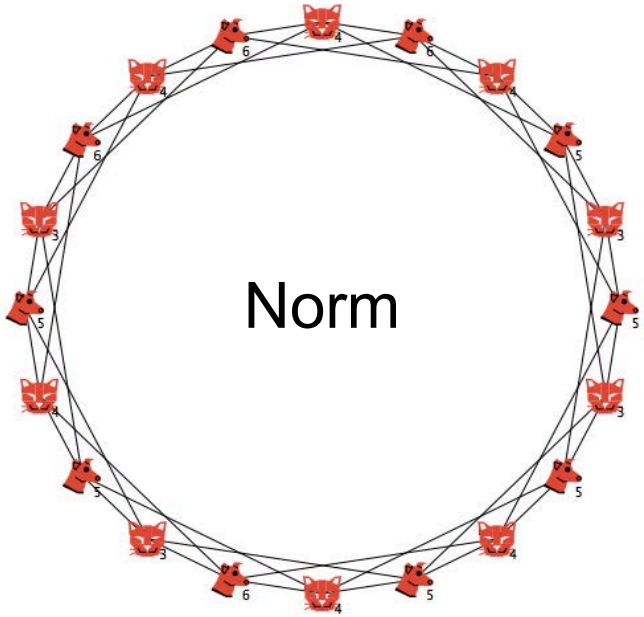
# Occurrence of Anomie: Experimental Results



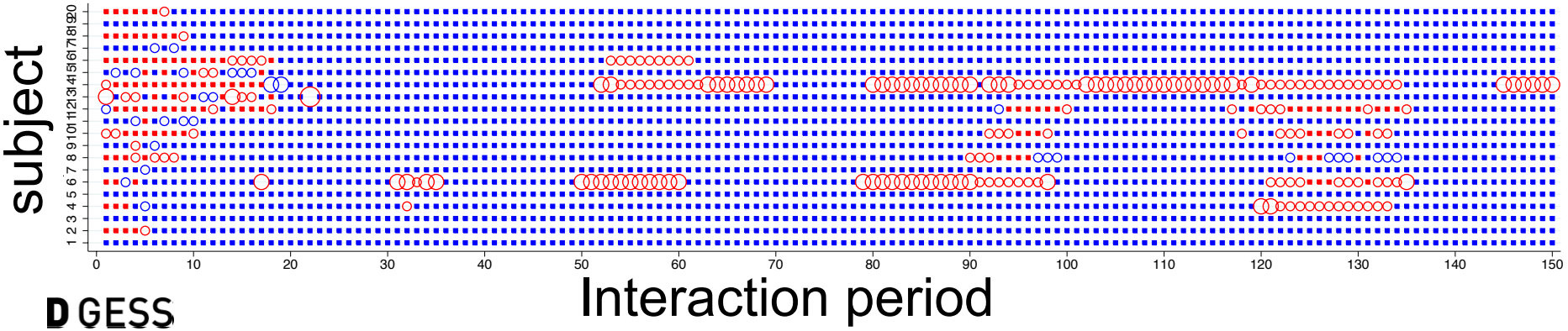

Results from the lab: anomie



# Emergence of Social Norms: Experimental Results




Results from the lab: norm



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# Studying Intercultural and International Conflict

Dirk Helbing

with Karsten Donnay, Thomas Chadefaux,

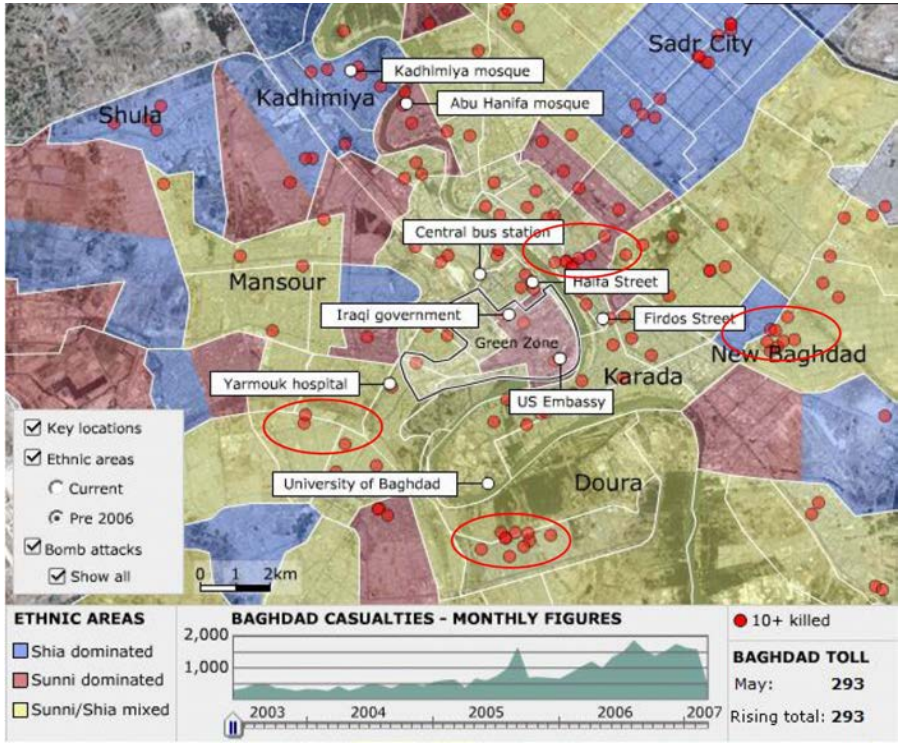
Ravi Bhavnani, Dan Miodownik,

and others

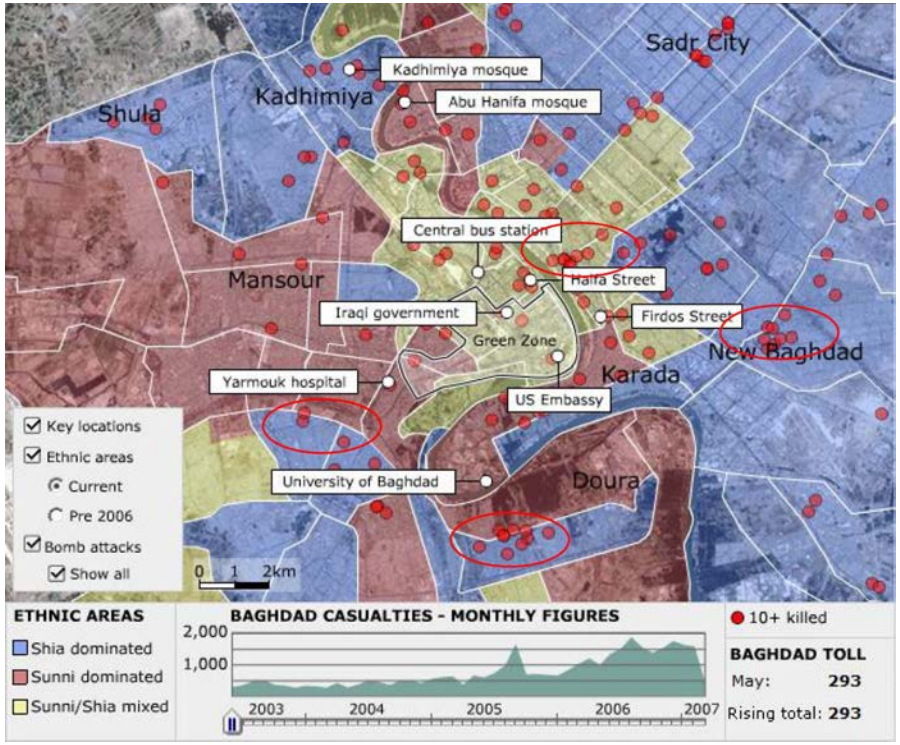
D GESS

# Interrelation of Spatial Interaction, Conflict, and Migration

Source: BBC



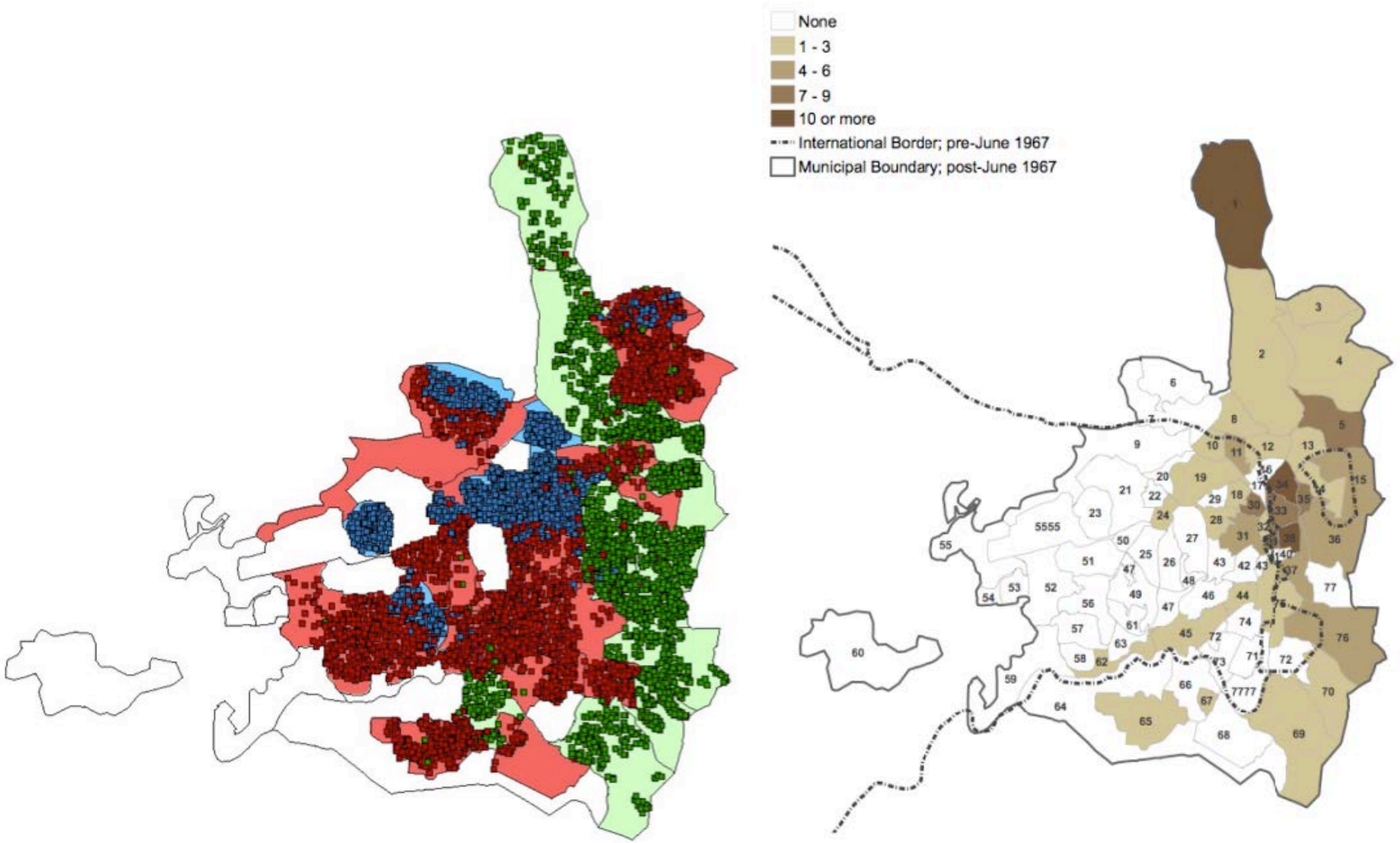

Ethnic areas and bomb attacks before 2006



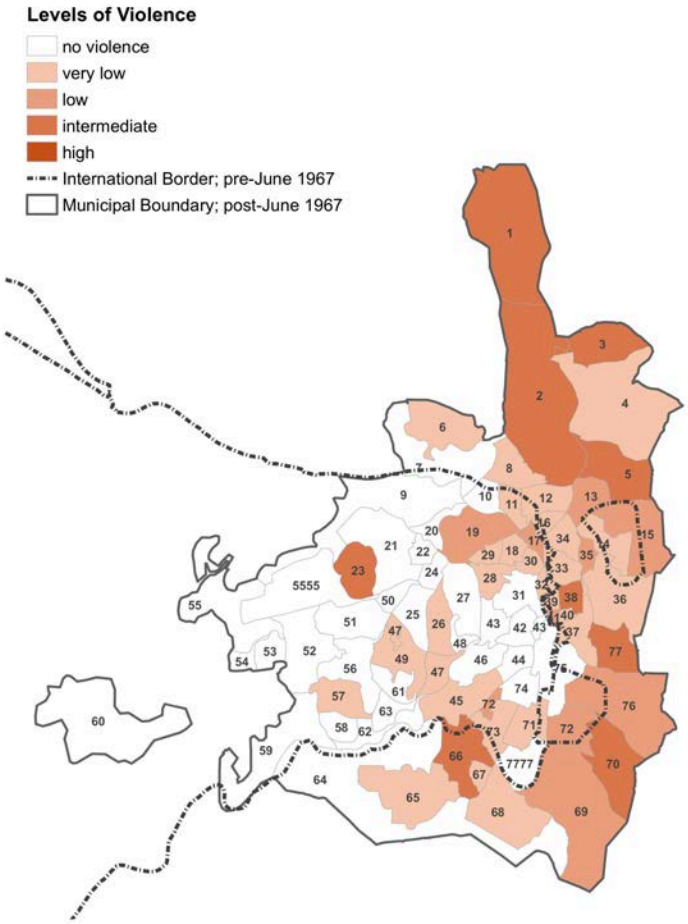

Ethnic areas and bomb attacks after 2006

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

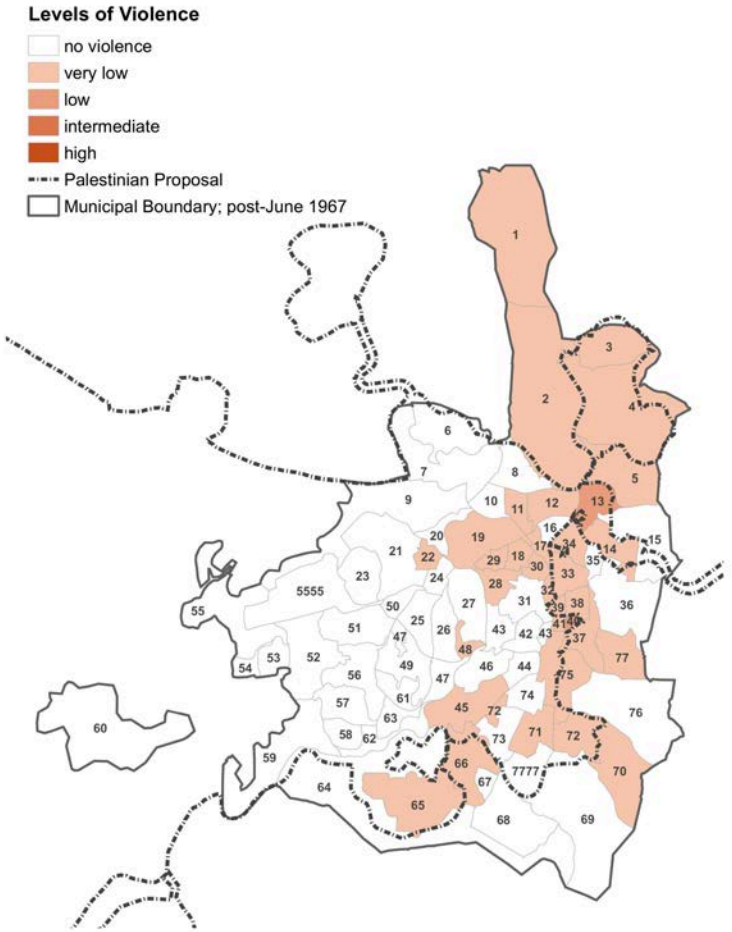
# Agent-Based Model of Conflict in Jerusalem



# Conflict in the Jerusalem: Possible Future Scenarios

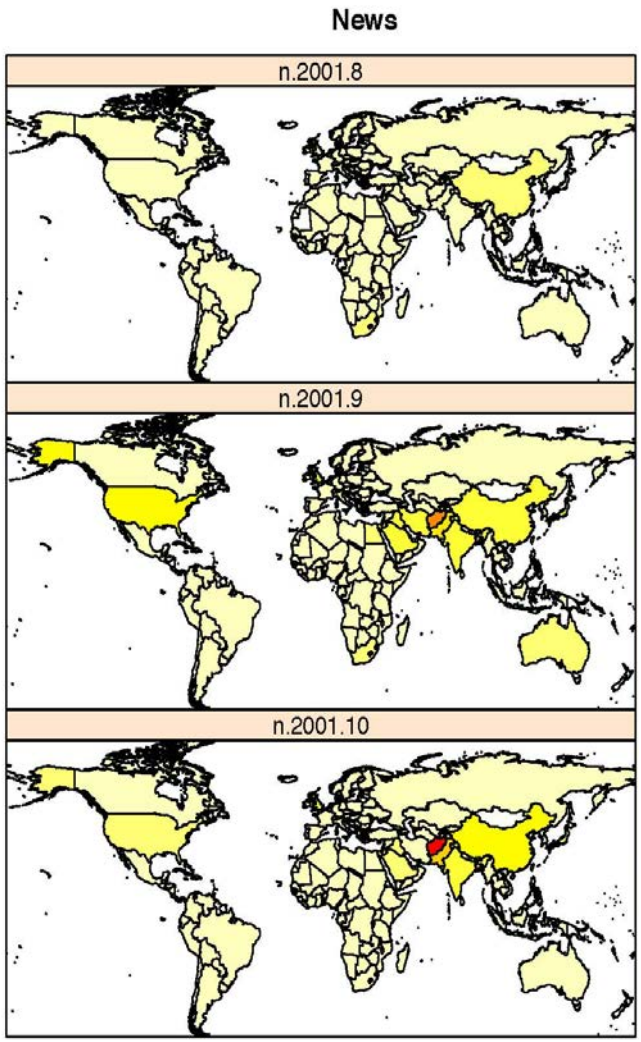


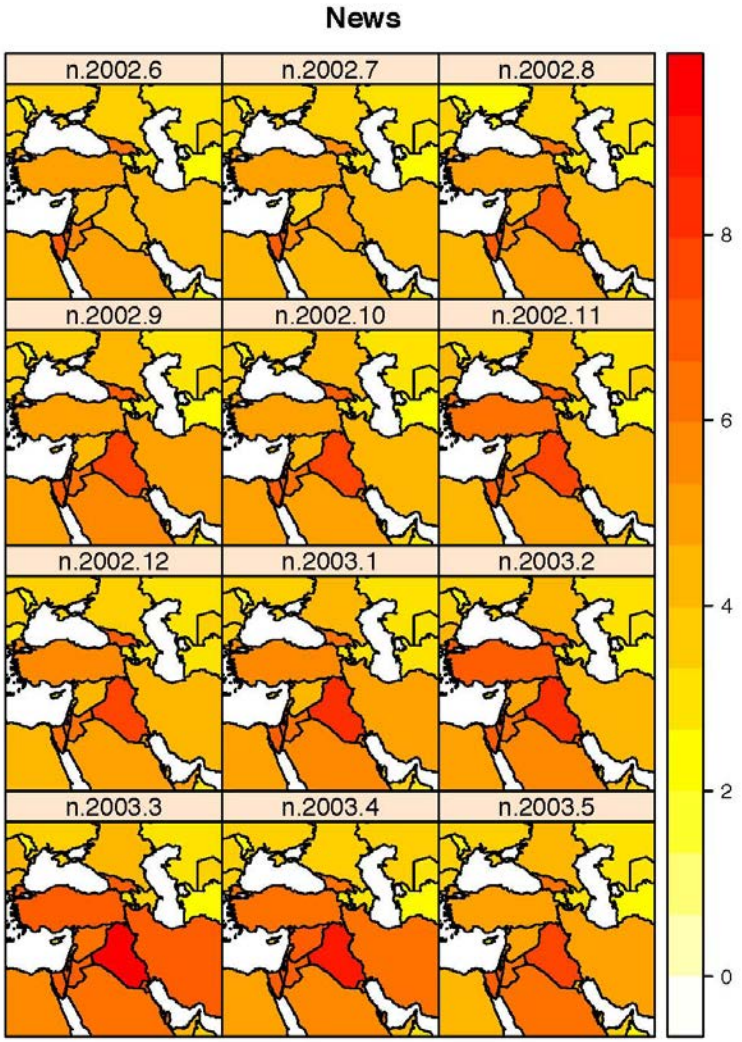

‘Business as Usual’




Clinton Parameters

# Spreading of International Tensions



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# Understanding Social Dynamics by Analyzing Human Activity Data

Dirk Helbing

with Dirk Brockmann, Maximilian Schich,

Laszlo Barabasi, Bogdan State,

and others

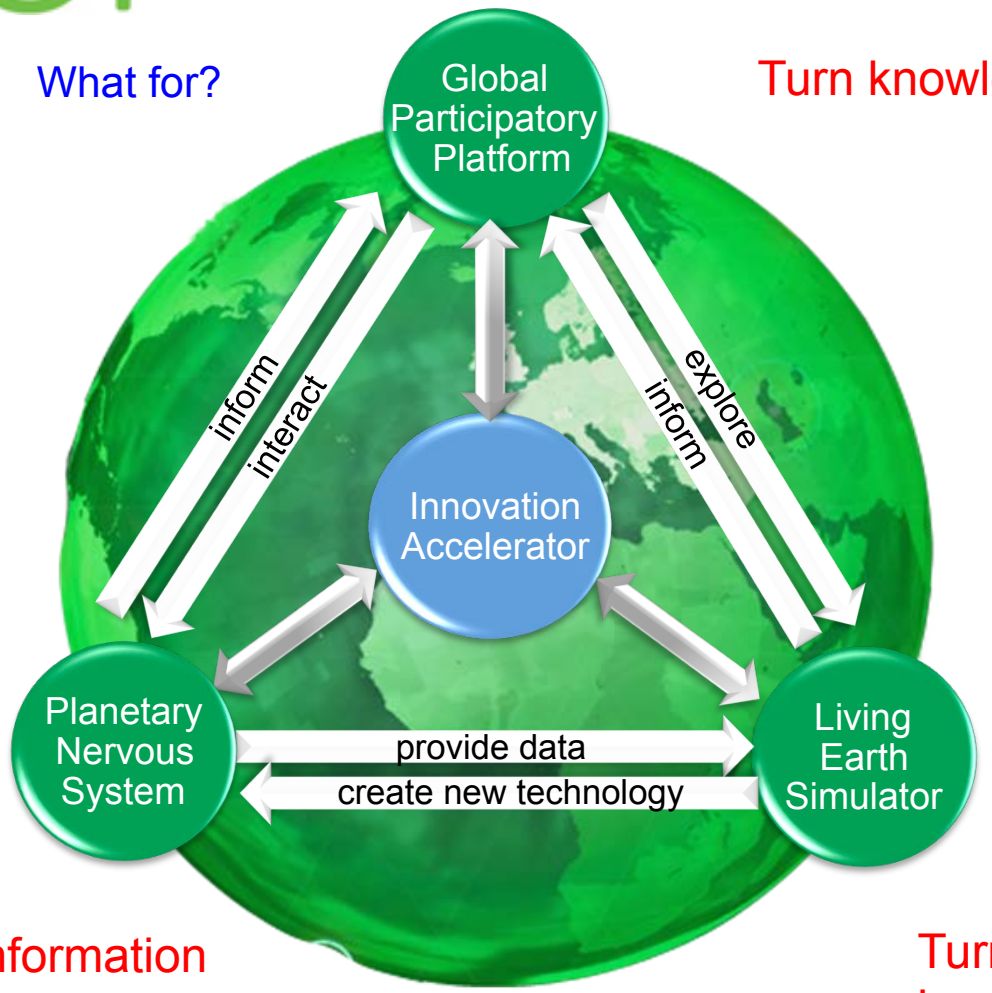
D GESS

FuturICT

Build platforms
to explore & interact

What for?

Turn knowledge into wisdom




What is?

Create systems
to sense &
understand

Turn data into information

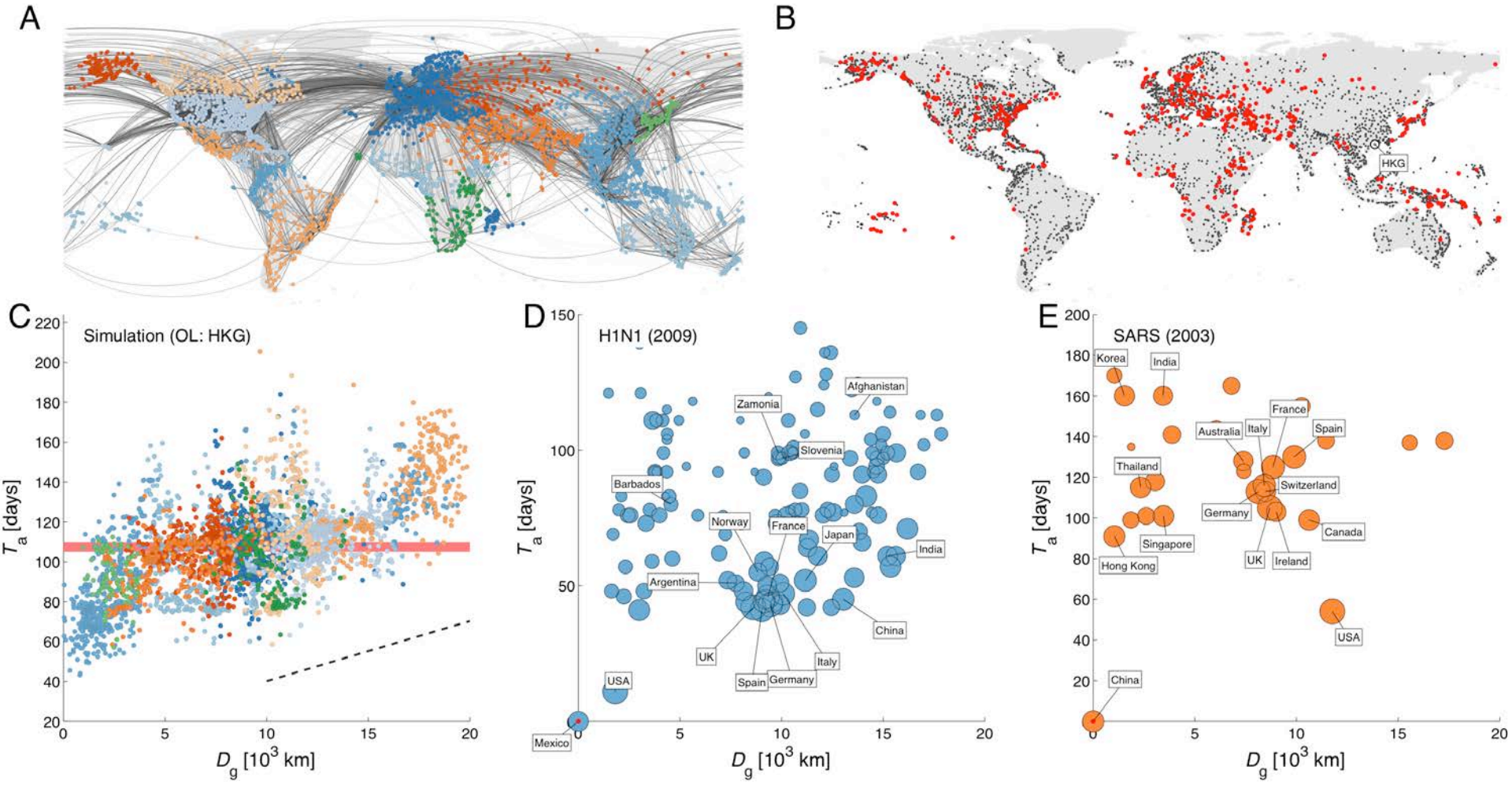
What if?

Develop models
to simulate &
predict

Turn information into knowledge

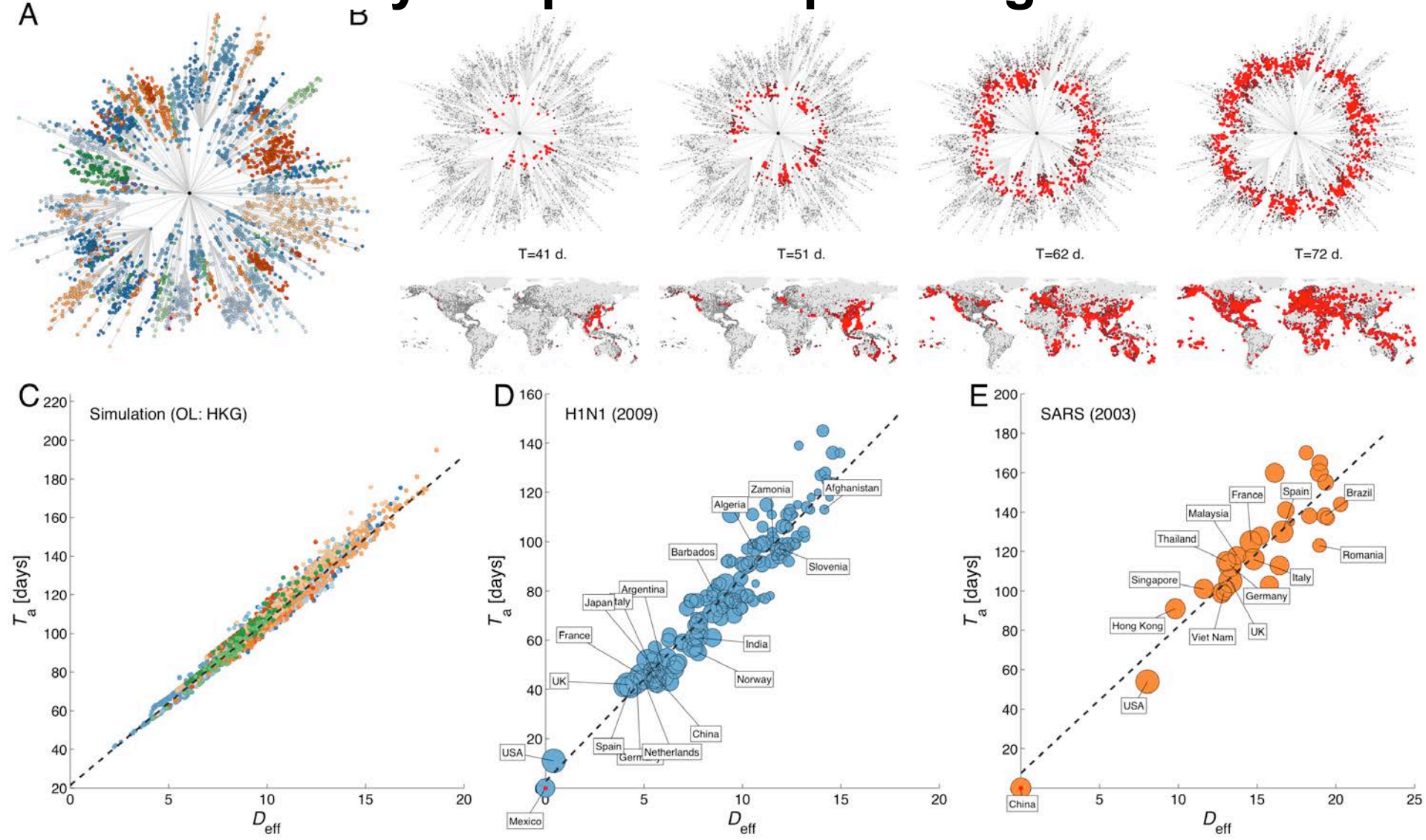
DGESS

# Complexity of Epidemic Spreading




Dirk Brockmann and DH (2013) in print.

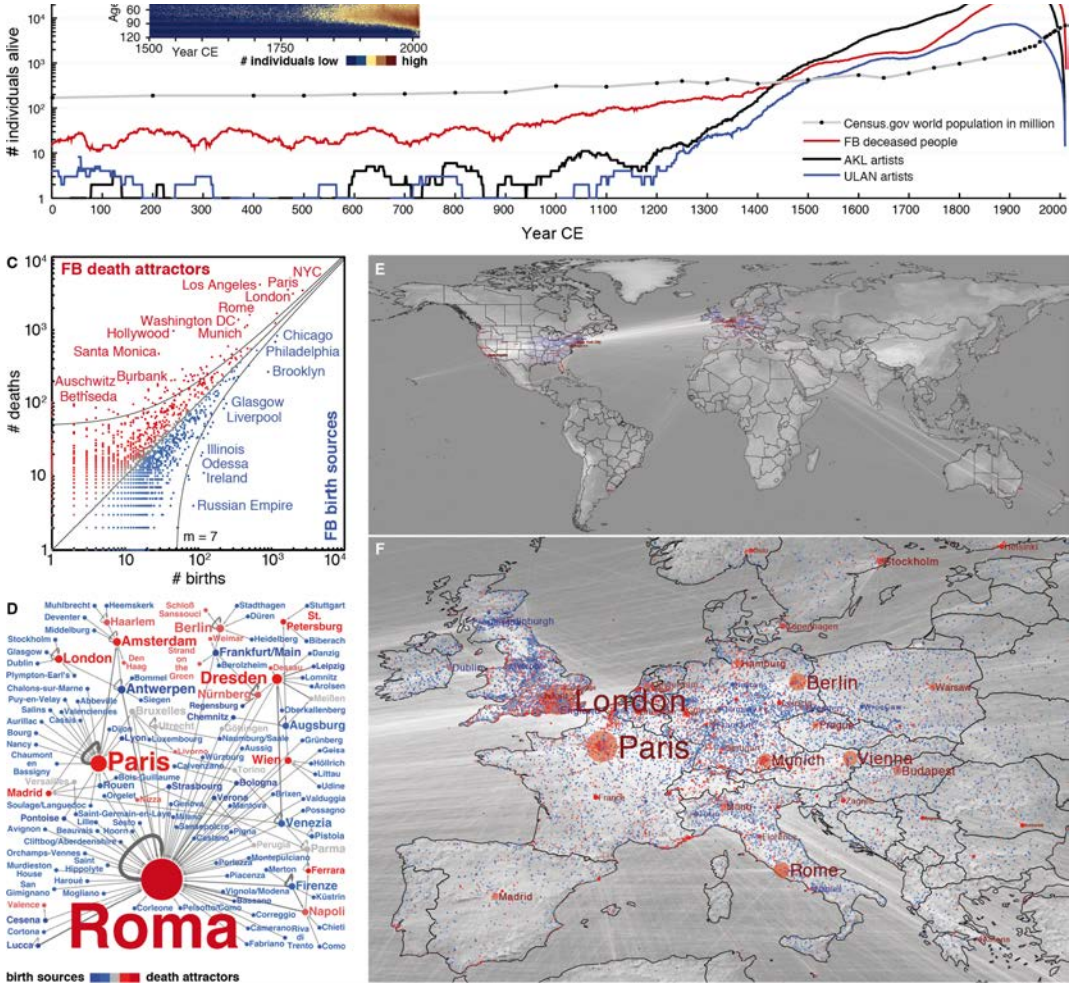
# Predictability of Epidemic Spreading





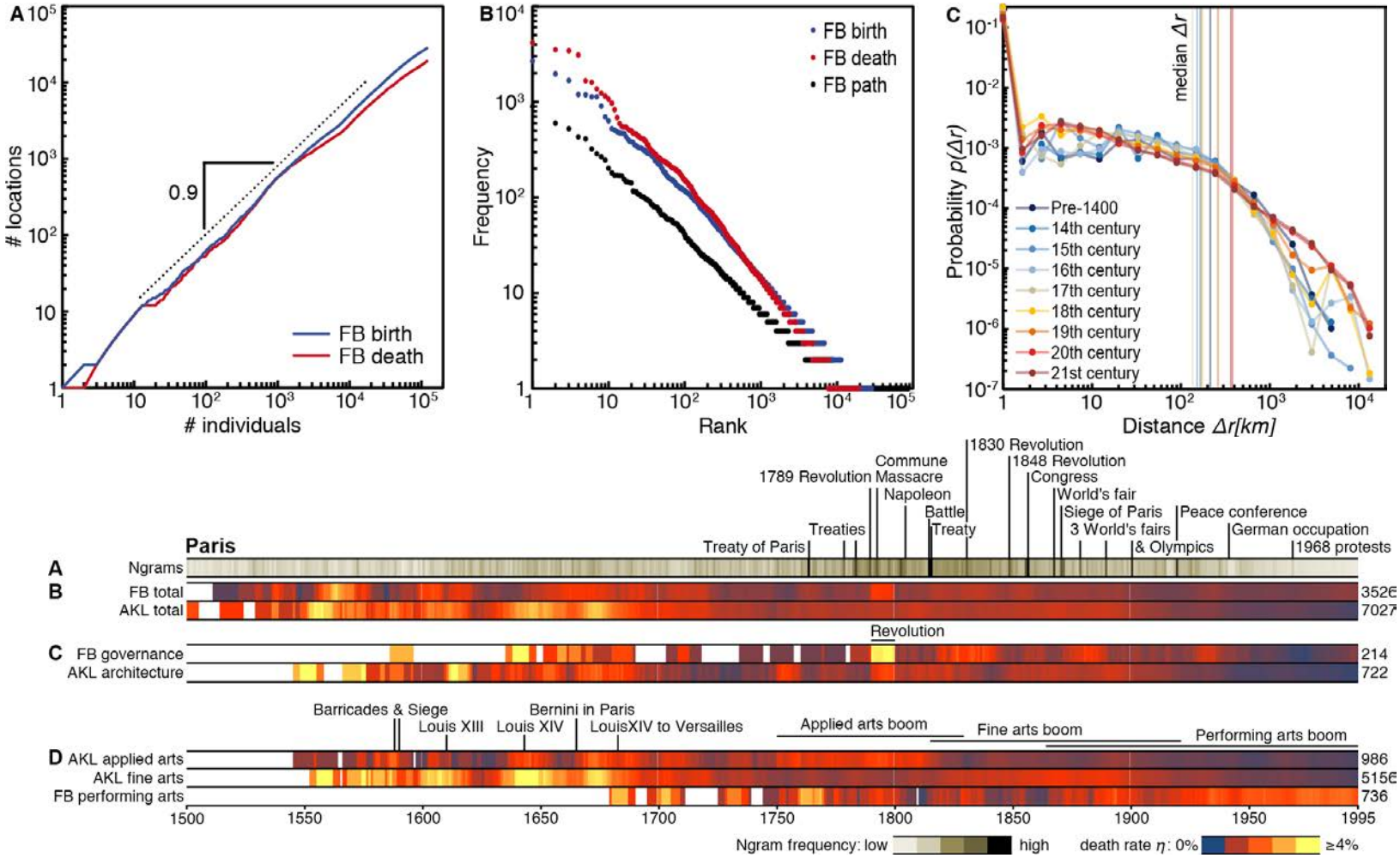

Dirk Brockmann and DH (2013) in print.

# Digital Humanities – What Birth Death Data Reveal



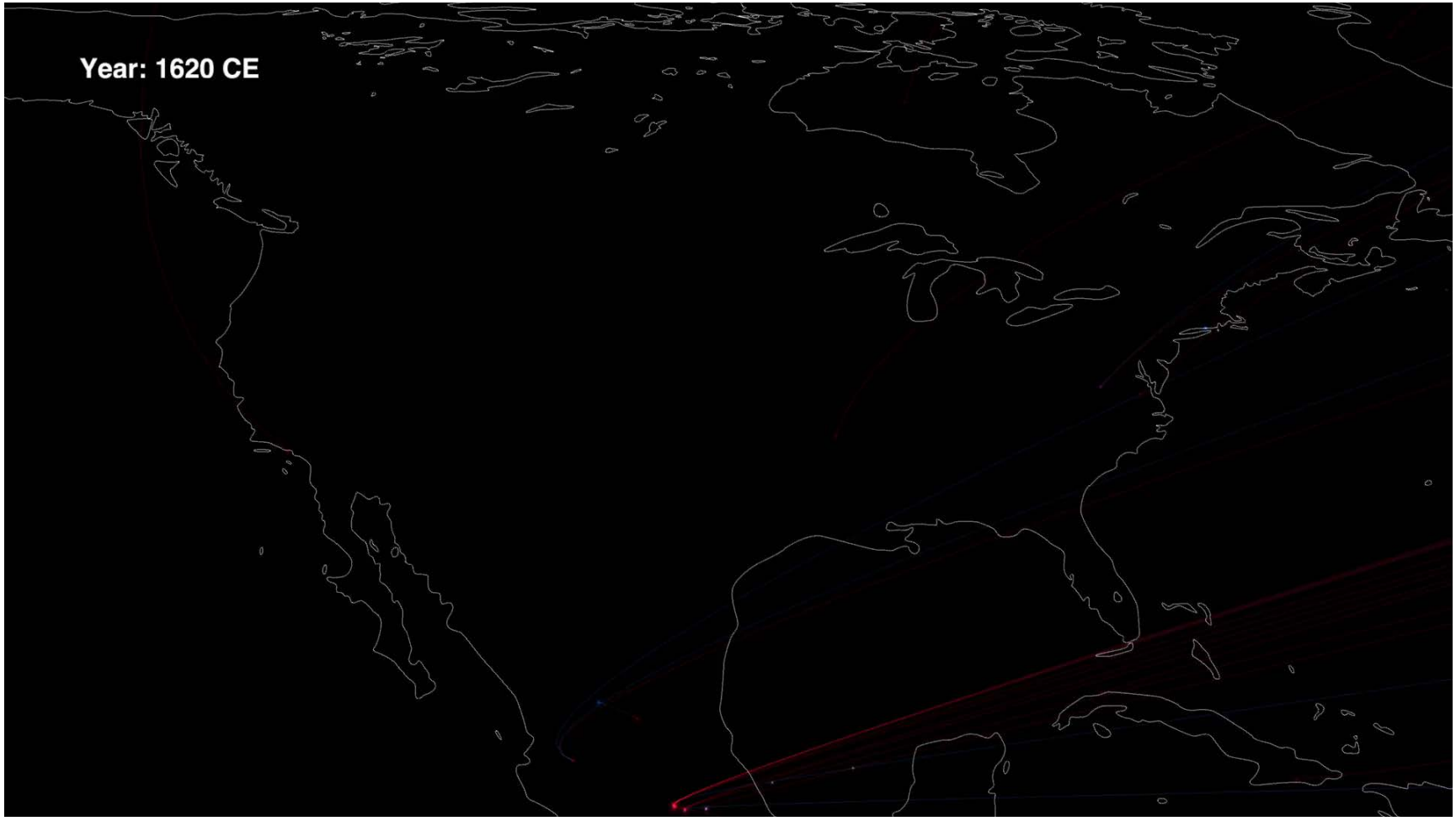

M. Schich, C. Song, Y.-Y. Ahn, A. Mirsky, M. Martino, A.L. Barabasi, DH, submitted (2013)

# Regularities vs. Specifics



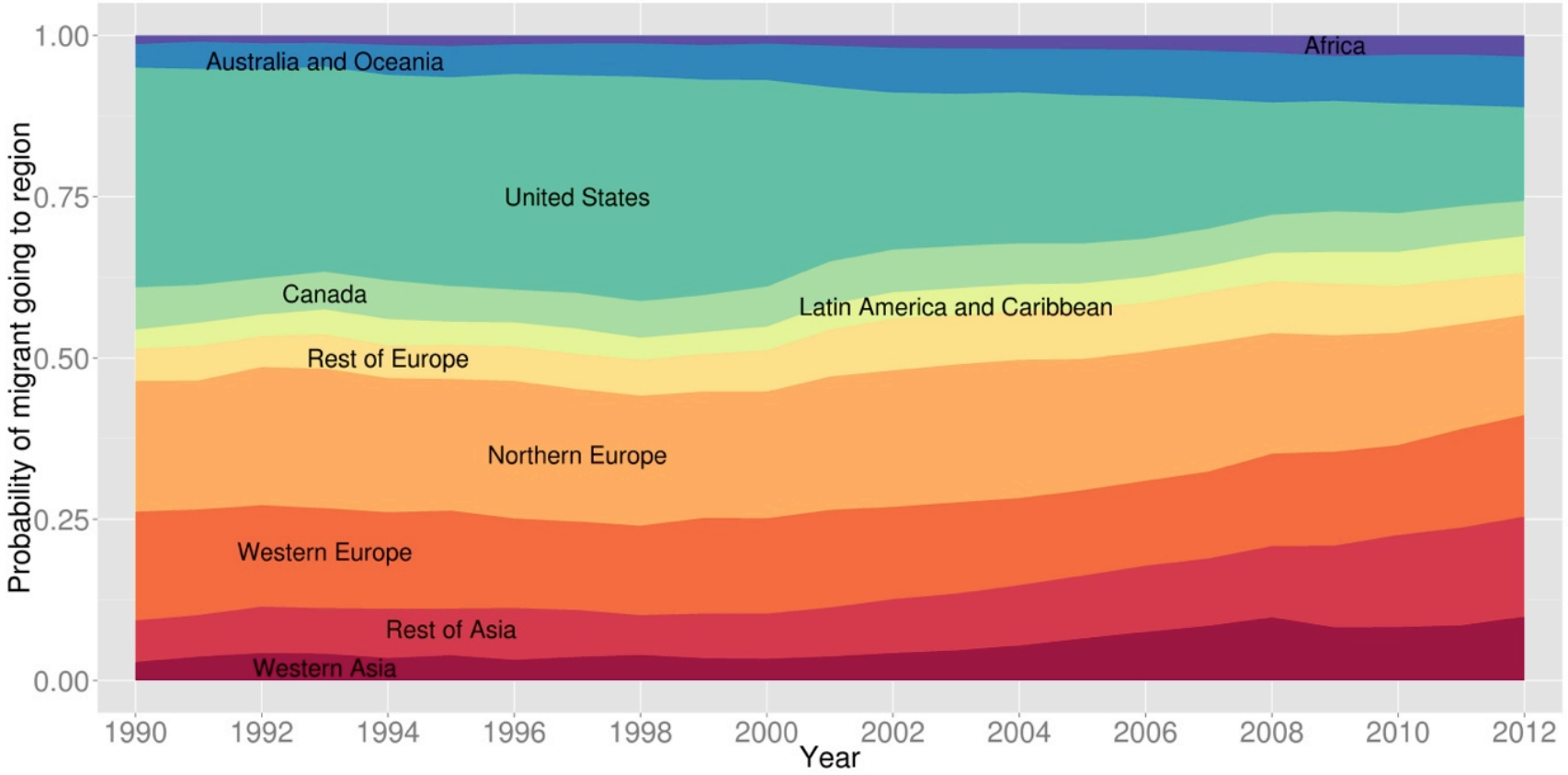

M. Schich, C. Song, Y.-Y. Ahn, A. Mirsky, M. Martino, A.L. Barabasi, DH, submitted (2013)

# „Braindrain of Artists“ in the US




M. Schich, C. Song, Y.-Y. Ahn, A. Mirsky, M. Martino, A.L. Barabasi, DH, submitted (2013)

# Global Migration Reflects the Development of a Multi-Polar World




LinkedIn

B. State, M. Rodriguez, DH, E. Zagheni, submitted (2013)

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# Techno-Social Systems: Creating an Innovation Accelerator

Dirk Helbing

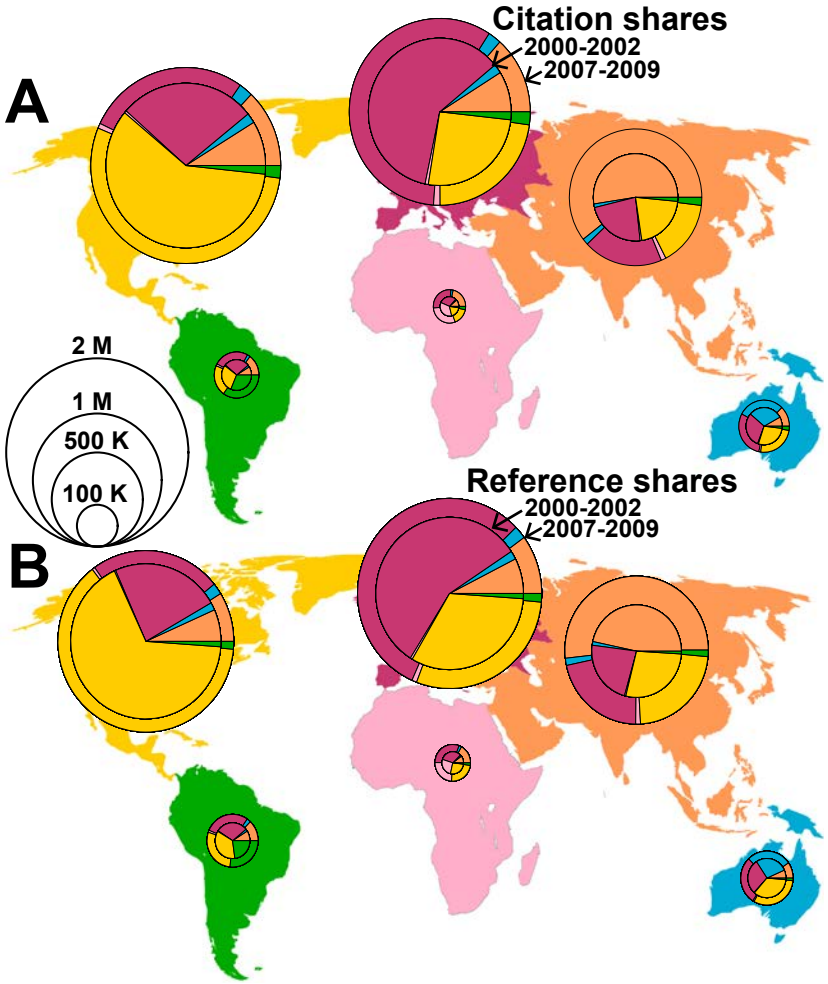
with Stefano Balietti, Tobias Kuhn,

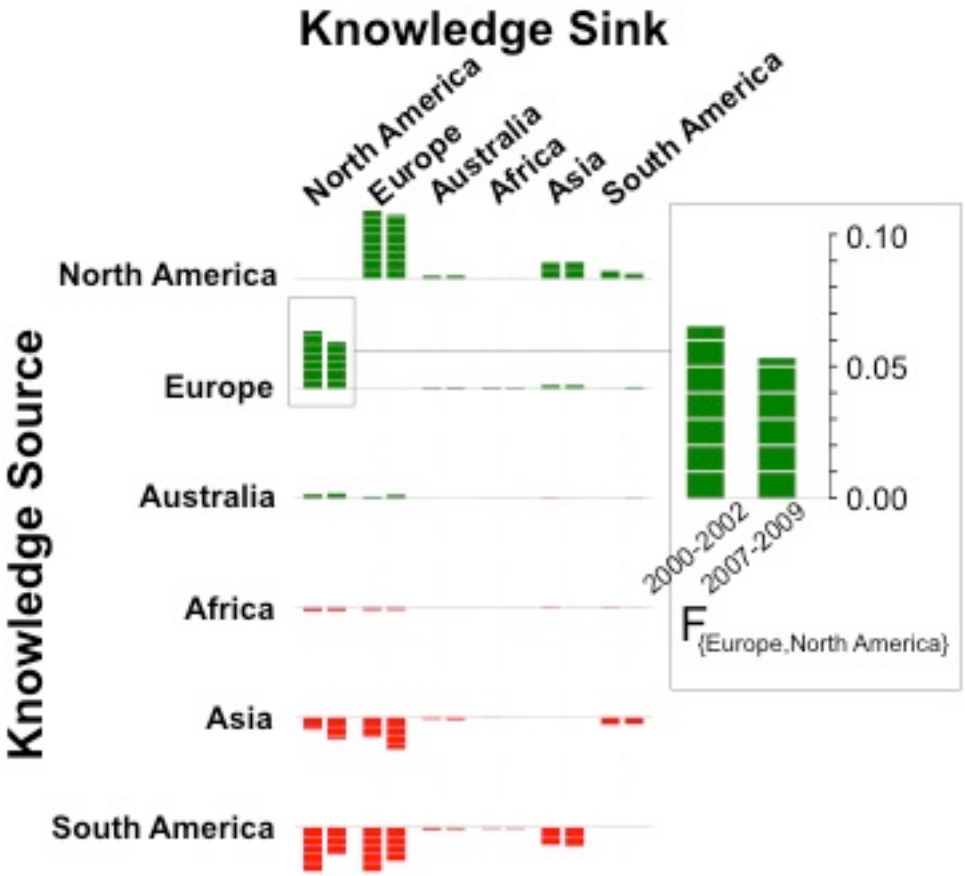
Amin Mazloumian, Christian Schulz, Rob Goldstone,

and others

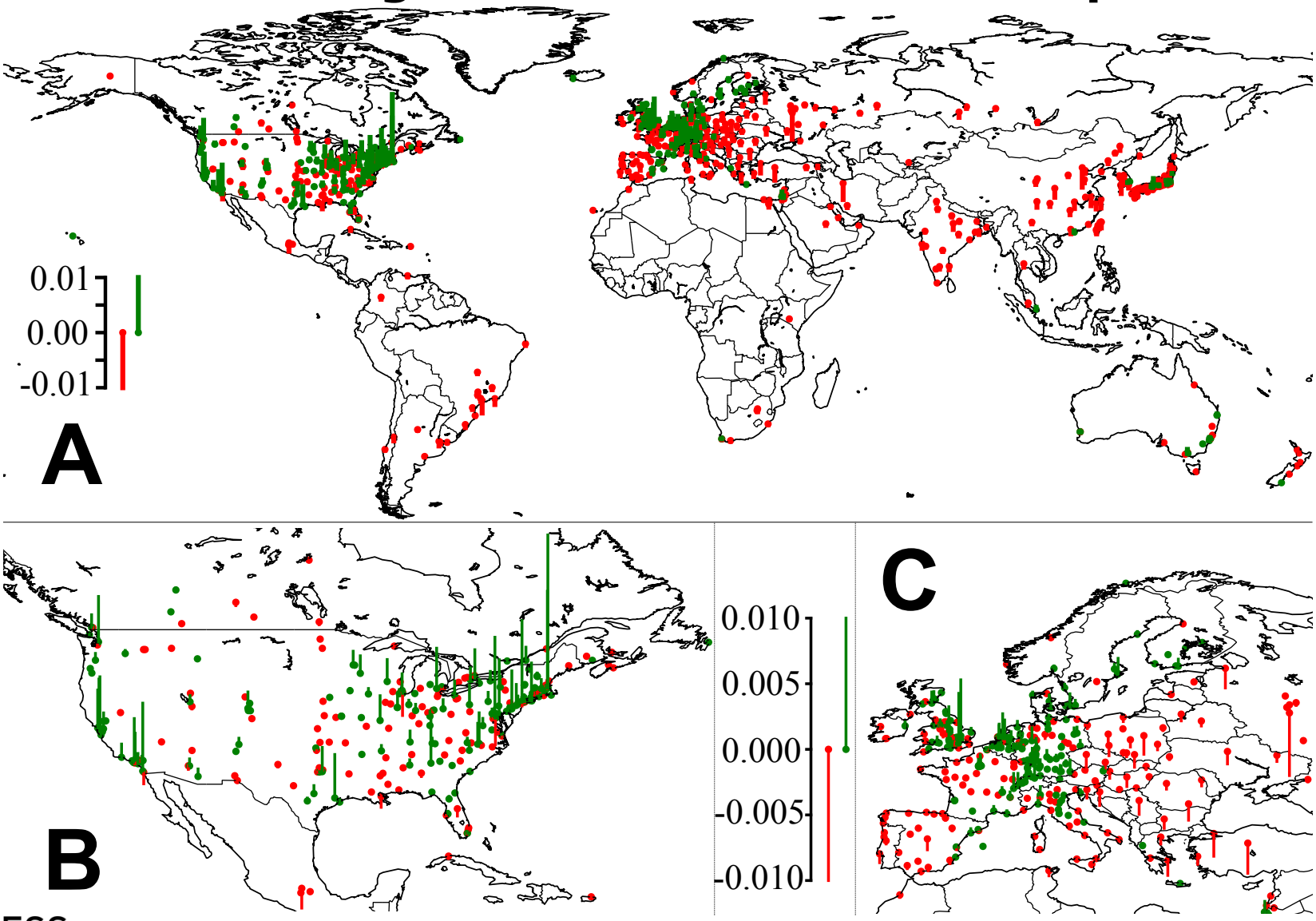
D GESS

# Scientific Productiveness, Impact, and Flow of Ideas



# Global Knowledge Production and Consumption



# Living Archive

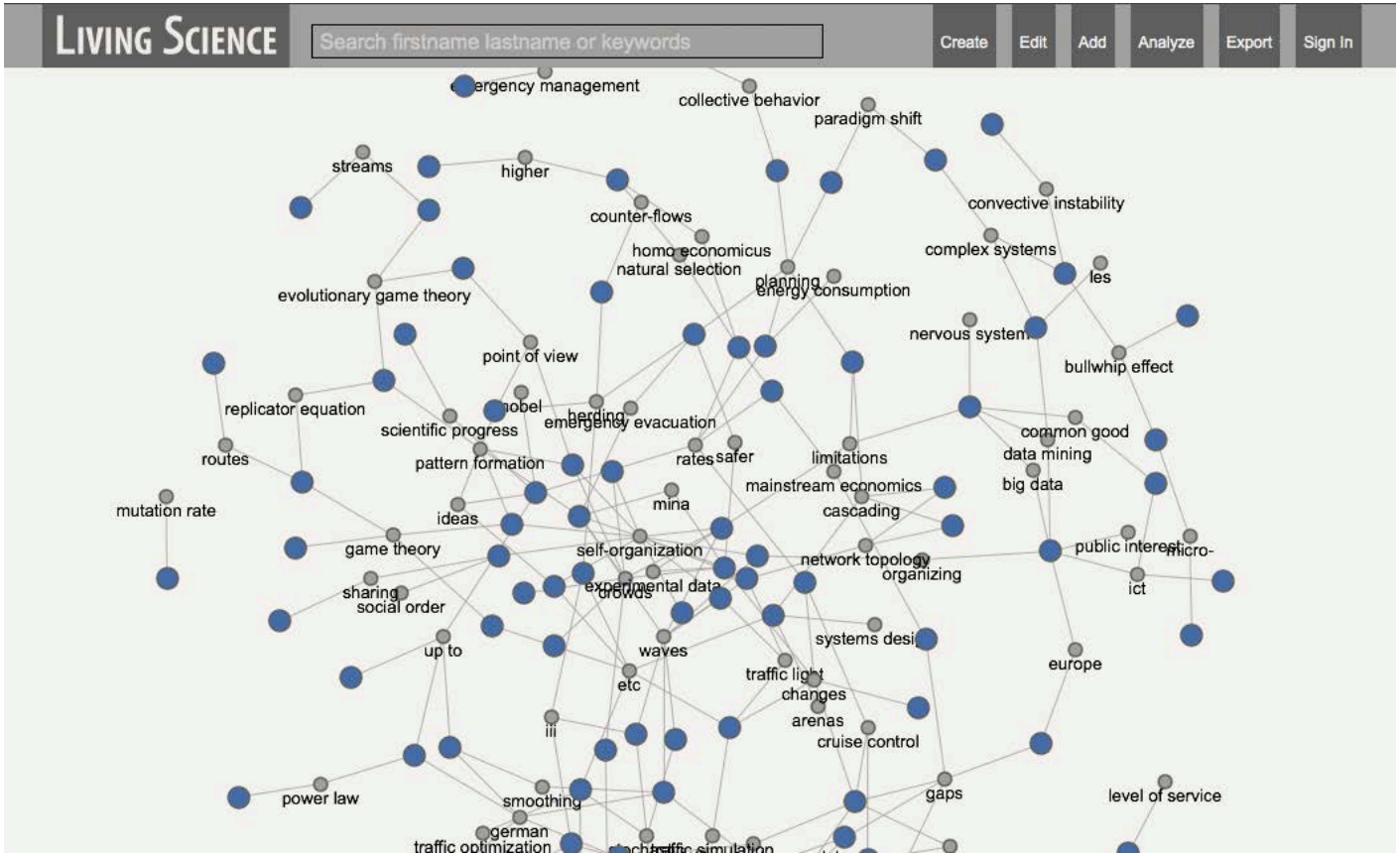
Search engine for open scientific datasets

http://livingarchive.inn.ac

# Living Science

Open database for publication data

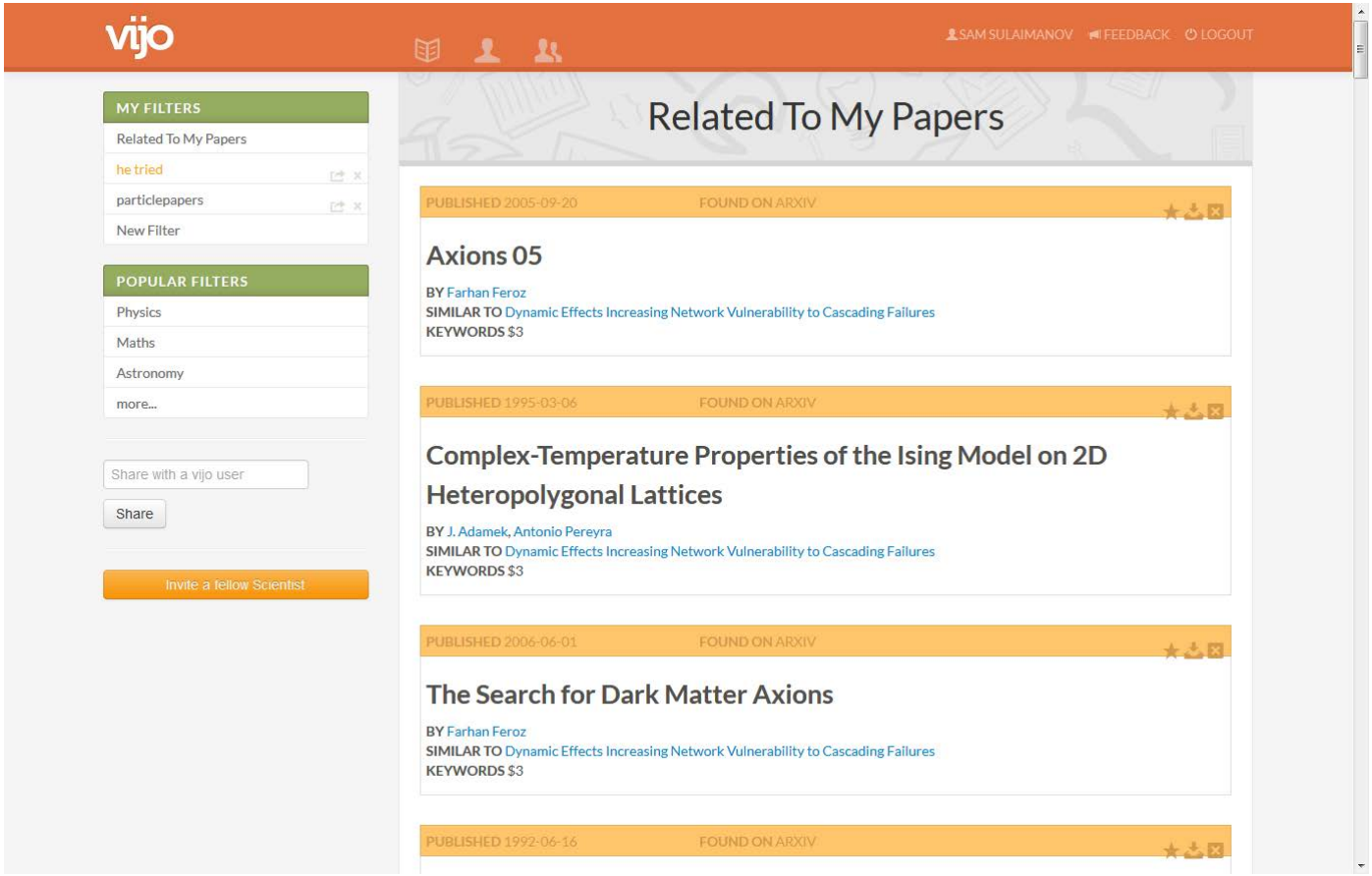
http://livingscience.inn.ac



# Virtual Journal (ViJo)

Create your own search filters and recommender system

http://vijo.inn.ac



# Take Home Messages

The Chair of Sociology, in particular of Modeling and Simulation has:

- developed and published various models of social behavior (pedestrian crowds, opinion formation, social coordination, cooperation, norms, and conflicts),
- performed lab and web experiments to test our models,
- developed models to better understand contagious spreading processes and human activity patterns on a global scale, and
- created platforms to support researchers in their daily work.

The multi-disciplinary work enjoys high scientific impact and public visibility. Some of it helps to save lives of people.