Dirk Helbing (ETH Zurich)

From Computational Social Science to Global Systems Science

FuturICT

The Problems of the World Are Complex

Source: ddp images/Marcus Brandt

http://www.sueddeutsche.de/politik/streit-beigelegt-einigung-ueber-foederalismusreform-1.413140

Financial Crisis

Conflict, War

Climate Change

PERSPECTIVE

doi:10.1038/nature12047

Globally networked risks and how to respond

Dirk Helbing[1,2]

Today's strongly connected, global networks have produced highly interdependent systems that we do not understand and cannot control well. These systems are vulnerable to failure at all scales, posing serious threats to society, even when external shocks are absent. As the complexity and interaction strengths in our networked world increase, man-made systems can become unstable, creating uncontrollable situations even when decision-makers are well-skilled, have all data and technology at their disposal, and do their best. To make these systems manageable, a fundamental redesign is needed. A 'Global Systems Science' might create the required knowledge and paradigm shift in thinking.

Globalization and technological revolutions are changing our planet. Today we have a worldwide exchange of people, goods, money, information, and ideas, which has produced many new opportunities, services and benefits for humanity. At the same time, however, the underlying networks have created pathways along which dangerous and damaging events can spread rapidly and globally. This has increased systemic risks[1] (see Box 1). The related societal costs are huge.

When analysing today's environmental, health and financial systems or our supply chains and information and communication systems, one finds that these systems have become vulnerable on a planetary scale. They are challenged by the disruptive influences of global warming, disease outbreaks, food (distribution) shortages, financial crashes, heavy

'Global Systems Science', in order to understand better our information society with its close co-evolution of information and communication technology (ICT) and society. This effort is allied with the "Earth system science"[10] that now provides the prevailing approach to studying the physics, chemistry and biology of our planet. Global Systems Science wants to make the theory of complex systems applicable to the solution of global-scale problems. It will take a massively data-driven approach that builds on a serious collaboration between the natural, engineering, and social sciences, aiming at a grand integration of knowledge. This approach to real-life techno-socio-economic-environmental systems[8] is expected to enable new response strategies to a number of twenty-first century challenges.

Global Systems Science

Humans have created tightly connected systems and networked risks, which has led to a world we do not understand and cannot control well. Systemic risks and extreme events are consequences of this.

However, systemic instabilities can be understood by a change in perspective from a component-oriented to an interaction- and network-oriented view. This also entails a fundamental change in the design and management of complex dynamical systems. Establishing a "Global Systems Science" will allow us to better understand our information society with its close co-evolution of information and communication technology (ICT) and society. This effort is allied with the "earth system science" that now provides the prevailing approach to studying the physics, chemistry and biology of our planet.

Global Systems Science makes current theories of crises and disasters applicable to the solution of global-scale problems, taking a massively data-driven approach that builds on a serious collaboration between the natural, engineering, and social sciences, i.e. a grand integration of knowledge.

The Micro-Macro Problem

Dirk Helbing

and Michael Mäs

„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)

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

Enviromental Exploitation

Border between Haiti and Dominican Republic

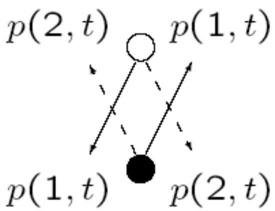
Enviromental Pollution

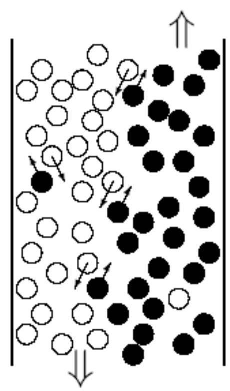
Public domain


Overfishing
© Pierre Gleizes / Greenpeace

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	0 0
right	0 0	B B

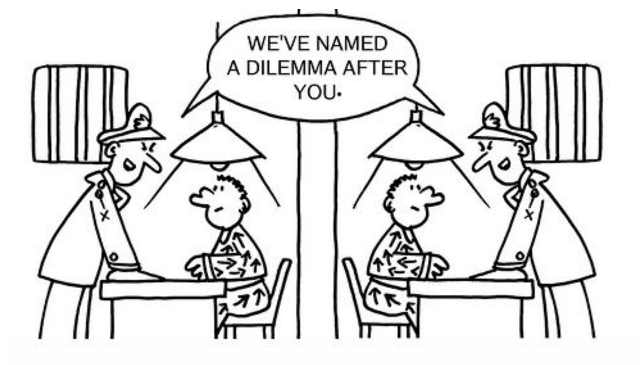
B = benefit of evading on the same side = time saved compared to one pedestrian evading to the right and the other one to the left

$dp(i,t)/dt = -2rB[p(i,t)-1/2]\ p(i,t)\ [1-p(i,t)]$ 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 Dilemma of Social Cooperation

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 1	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:

$S_1 = S_2 = S = -5$

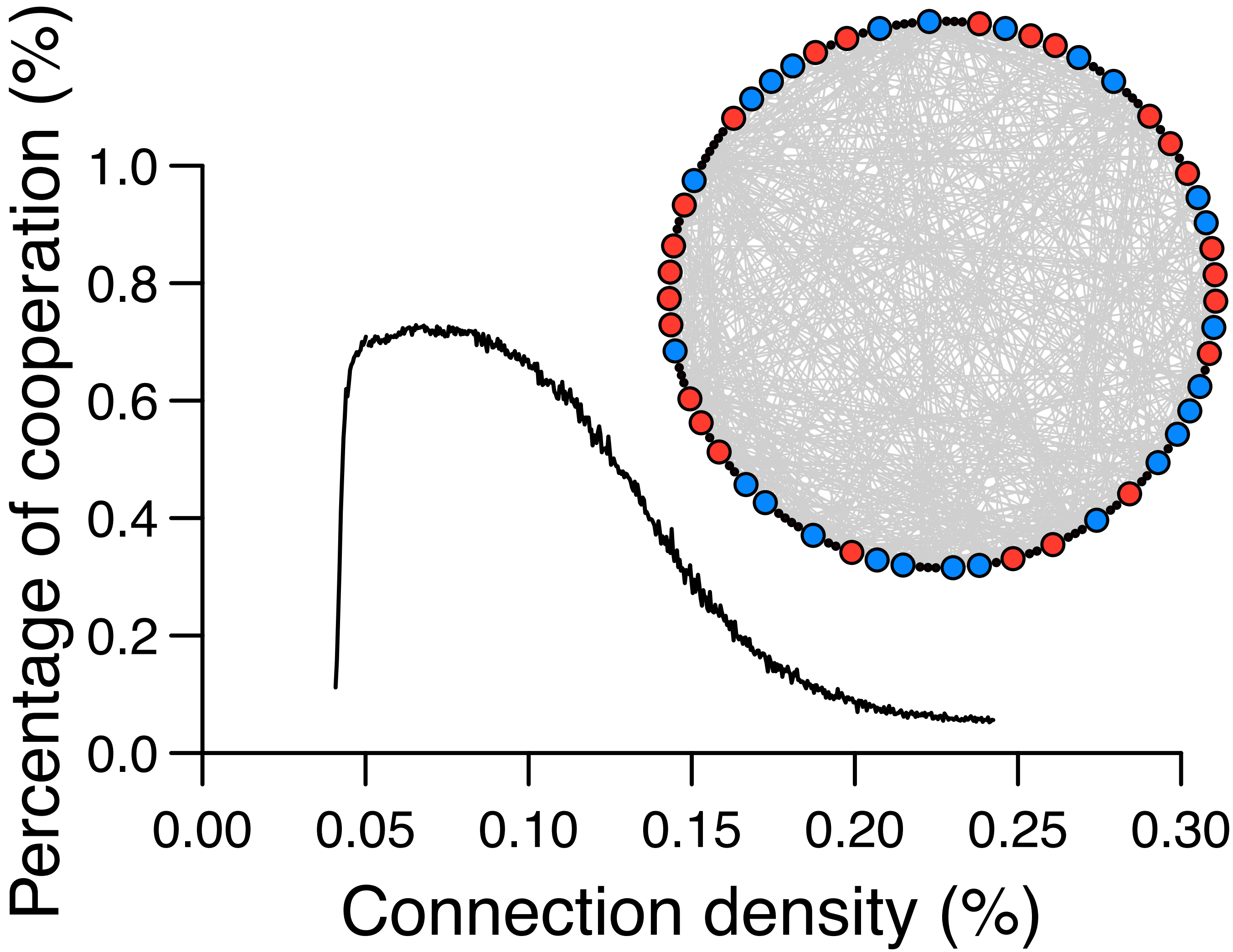
$P_1 = P_2 = P = -2$

$R_1 = R_2 = R = -1$

$T_1 = T_2 = T = 0$

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

Too Much Connectivity Is Bad



How the Banking Network Changed

Chart 1: Global Financial Network: 1985

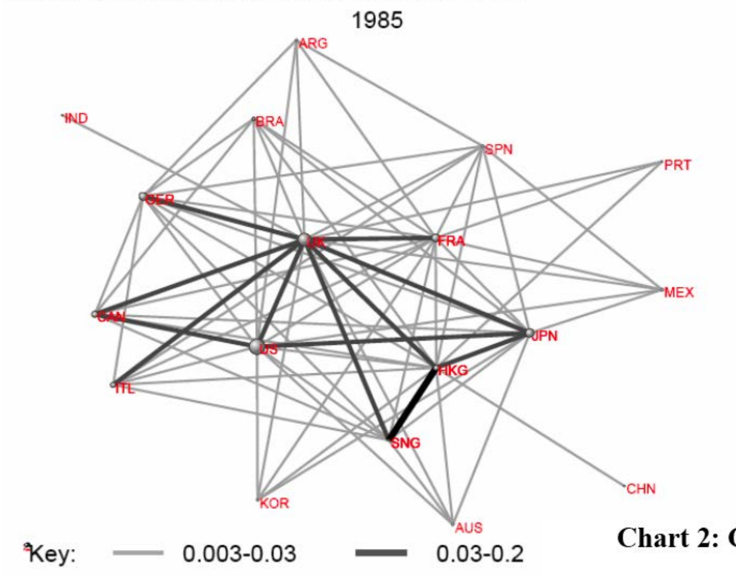


Chart 3: Global Financial Network: 2005

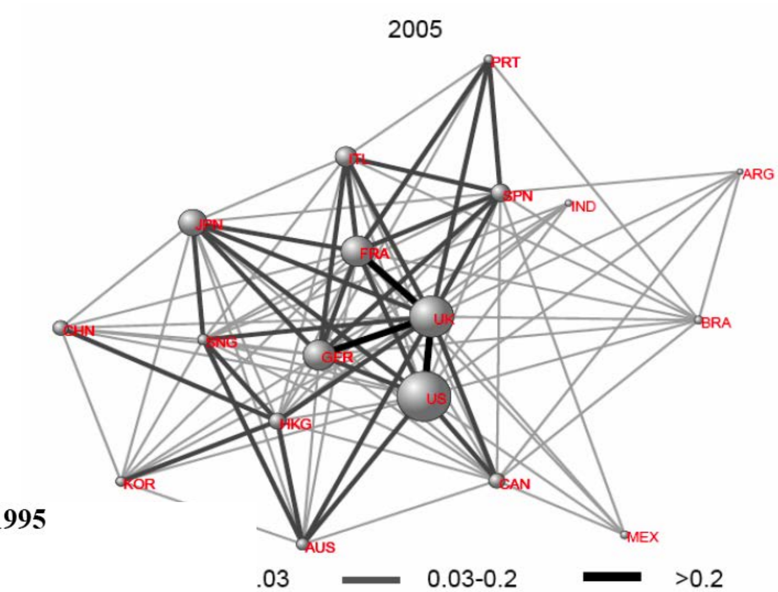
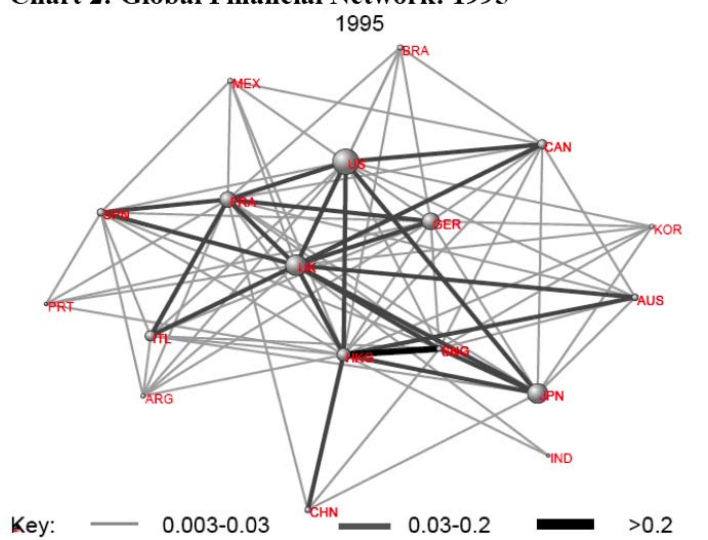


Chart 2: Global Financial Network: 1995



From: Haldane

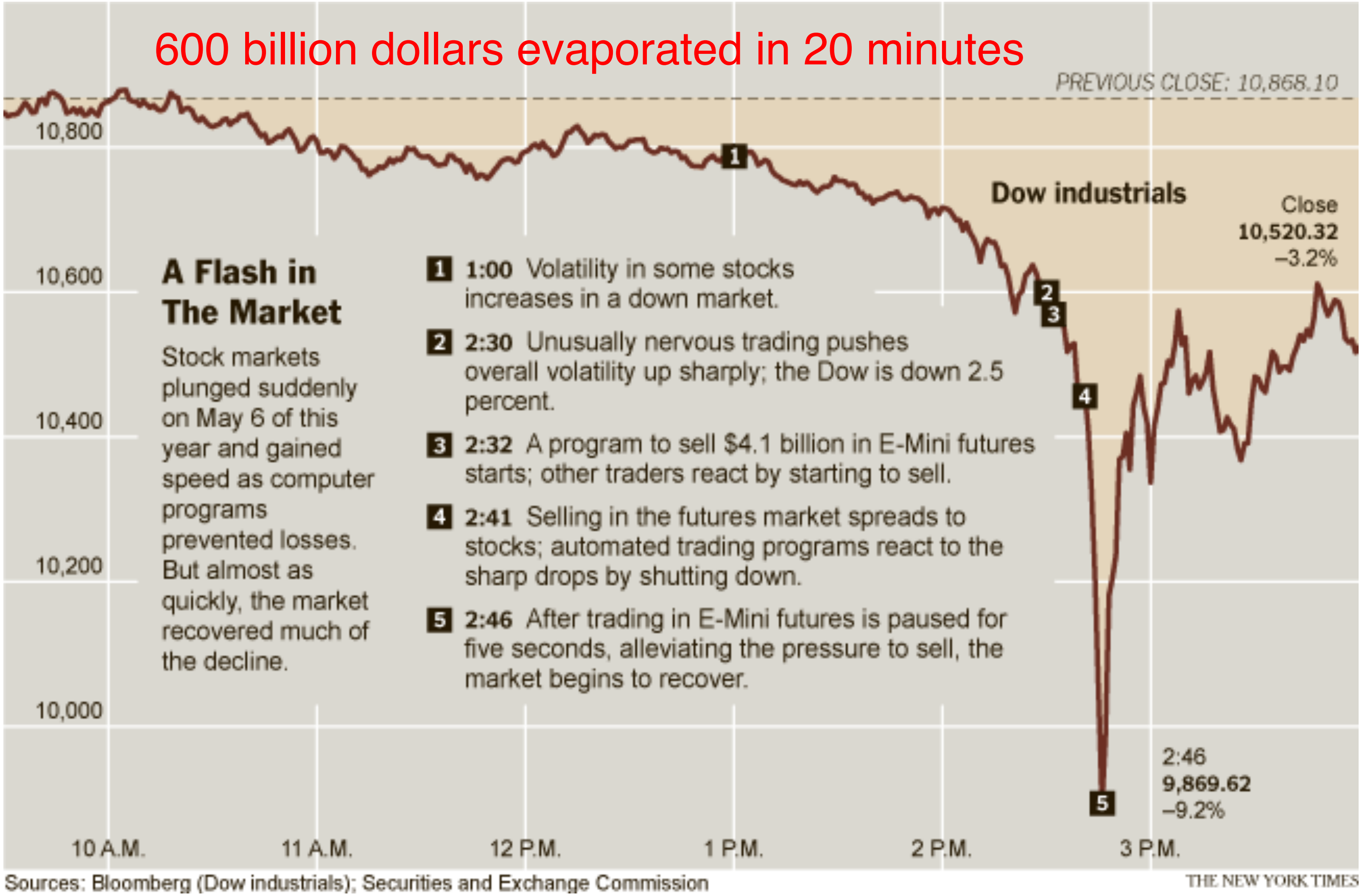
Cascading Effects During Financial Crises

Video by Frank Schweitzer et al.

Loss of Control through Cascade Effects

Mousetrap fission, by Gerhard G. Paulus, University of Jena, https://www.youtube.com/watch?v=Wiz1VVLYgl4

The Flash Crash on May 6, 2010



The flash crash turned solid assets into penny stocks within minutes.
Was an interaction effect, no criminal act, ‘fat finger’, or error.

Engineered Breaking Points to Stop Cascades

Social Mechanisms and Institutions to Promote Cooperation

Dirk Helbing

with Wenjian Yu, Matjaz Perc, Attila Szolnoki,

Gzörgy Szabo, and Sergi Lozano

Pool Punishment (and Surveillance)

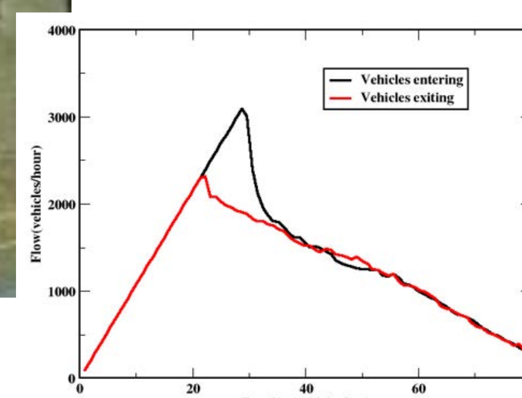
Flickr photo by nologo_photography. License: CC BY-SA 2.0.

Ferguson

„Phantom Traffic Jams“ Can‘t Be Prevented Even When Knowing the Thoughts of People!

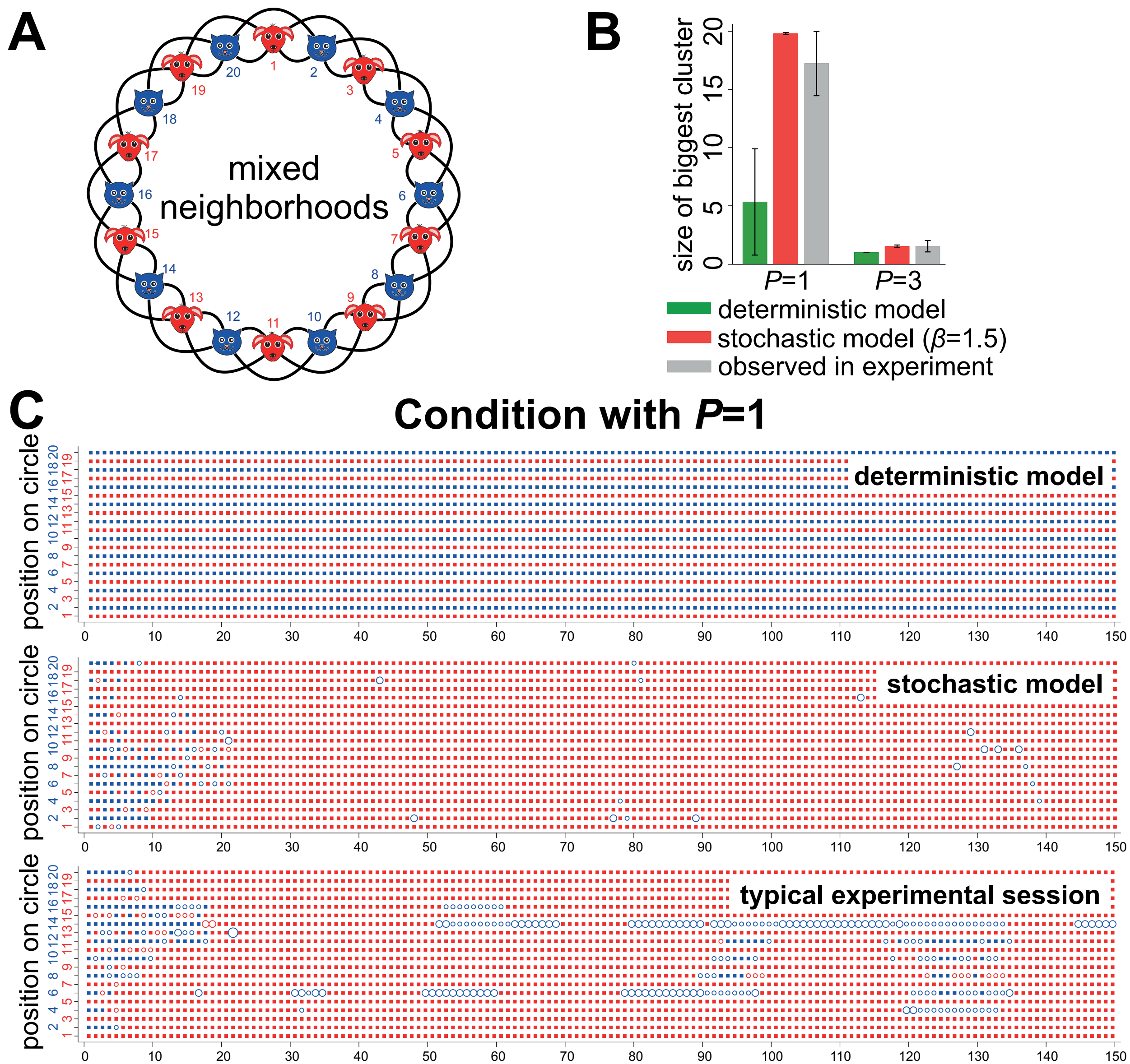
Thanks to
Yuki Sugiyama

Capacity drop,
when capacity
is most needed!



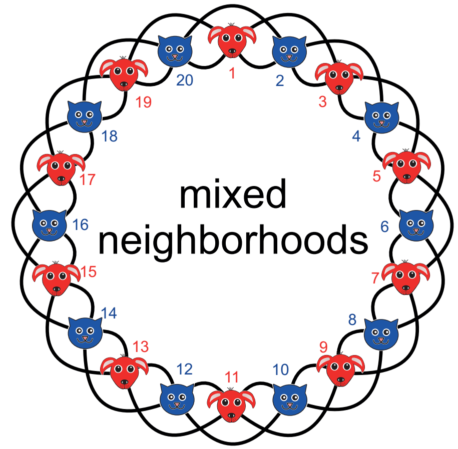
At high densities, free traffic flow is unstable:
Despite best efforts, drivers fail to maintain speed

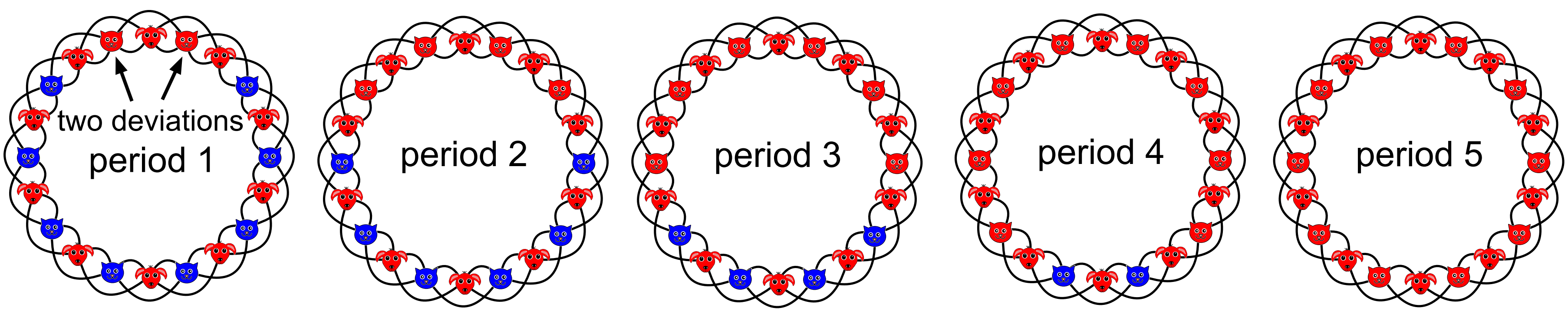
A 96% Correct Micro-Model May Not Be Able to Predict the Macro-Outcome!



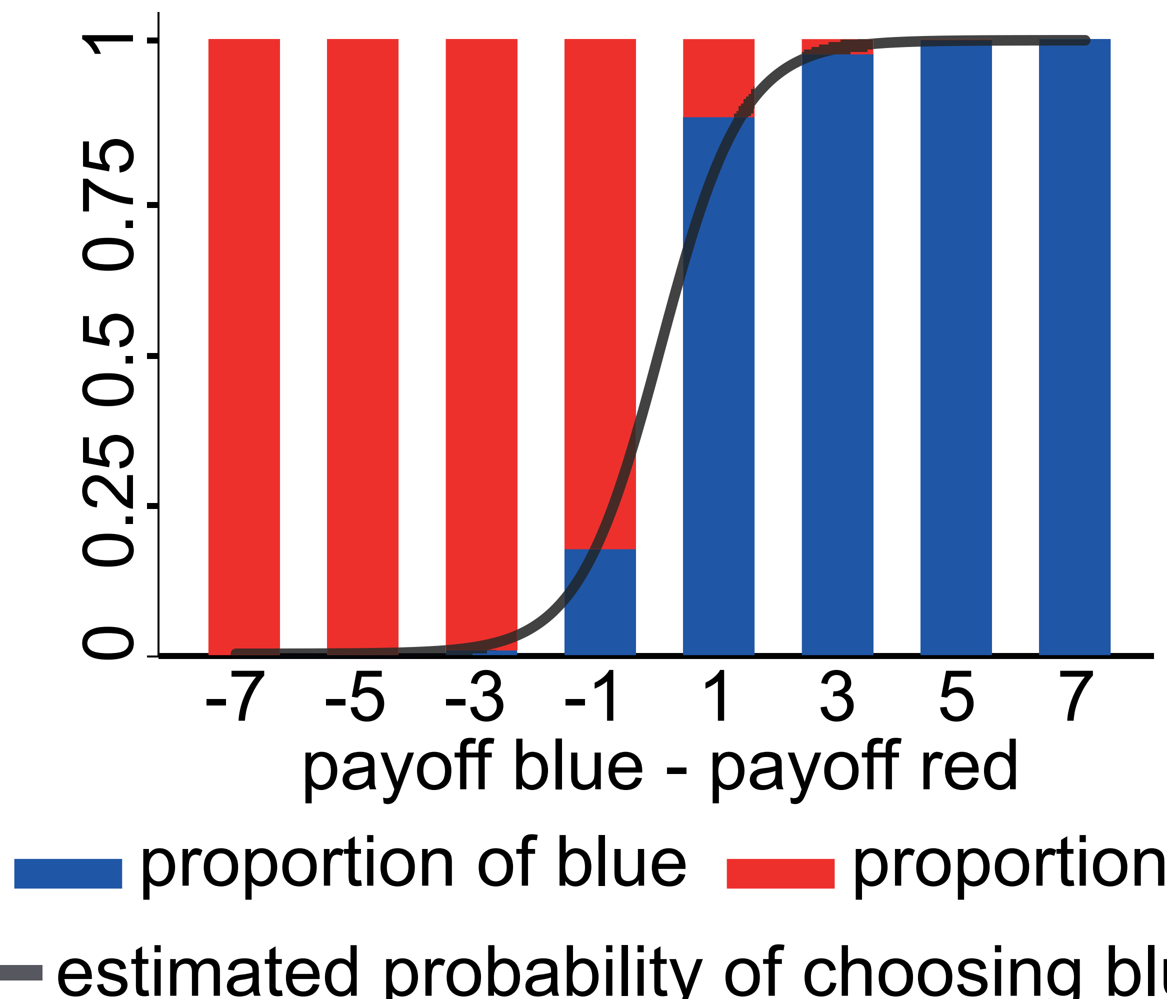
Michael Mäs and DH

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



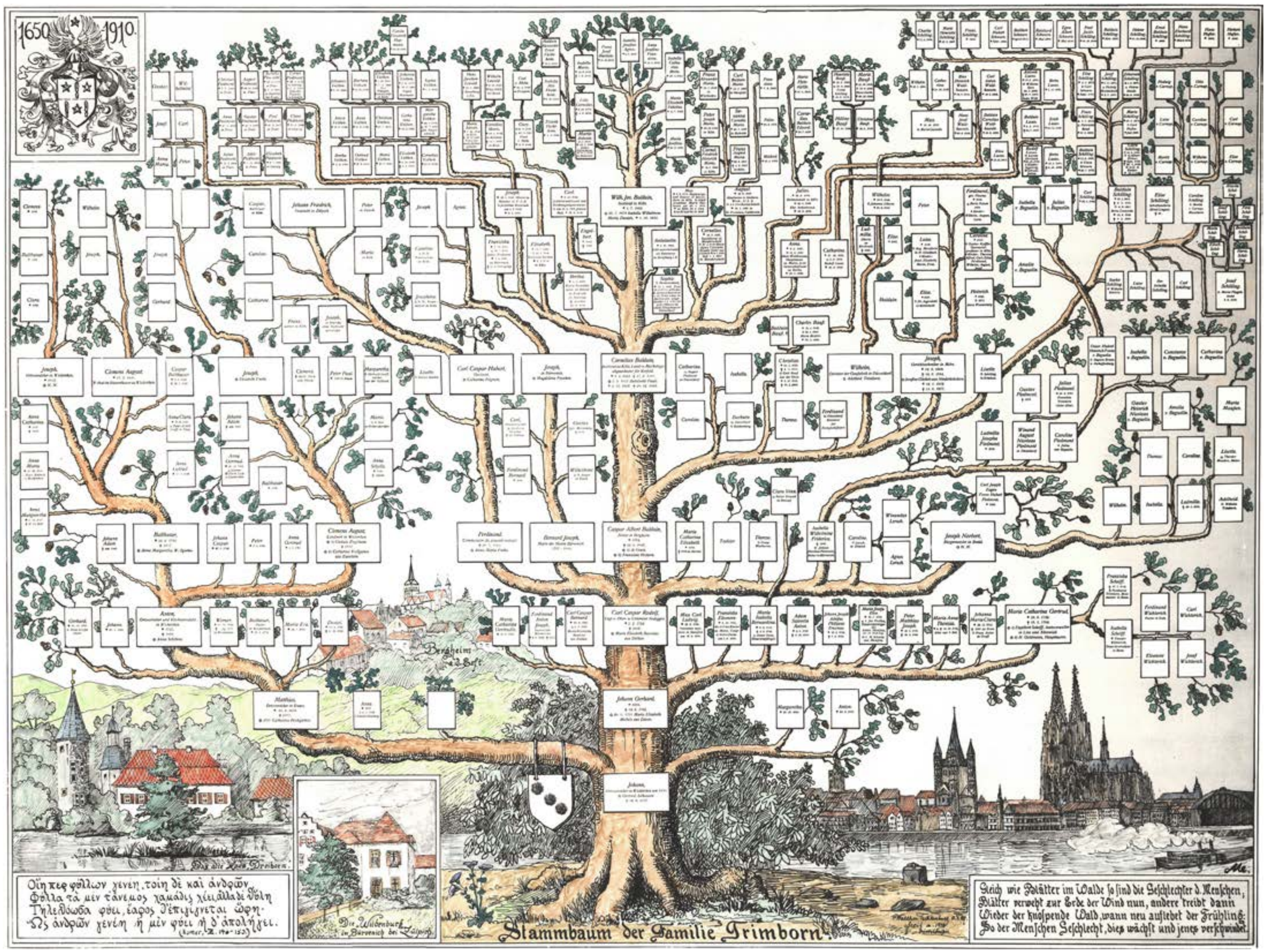


Adding "Noise" Yields Improved Results! Less Accurate Micro-Models May Reproduce Macro-Patterns Better



Michael Mäs and DH

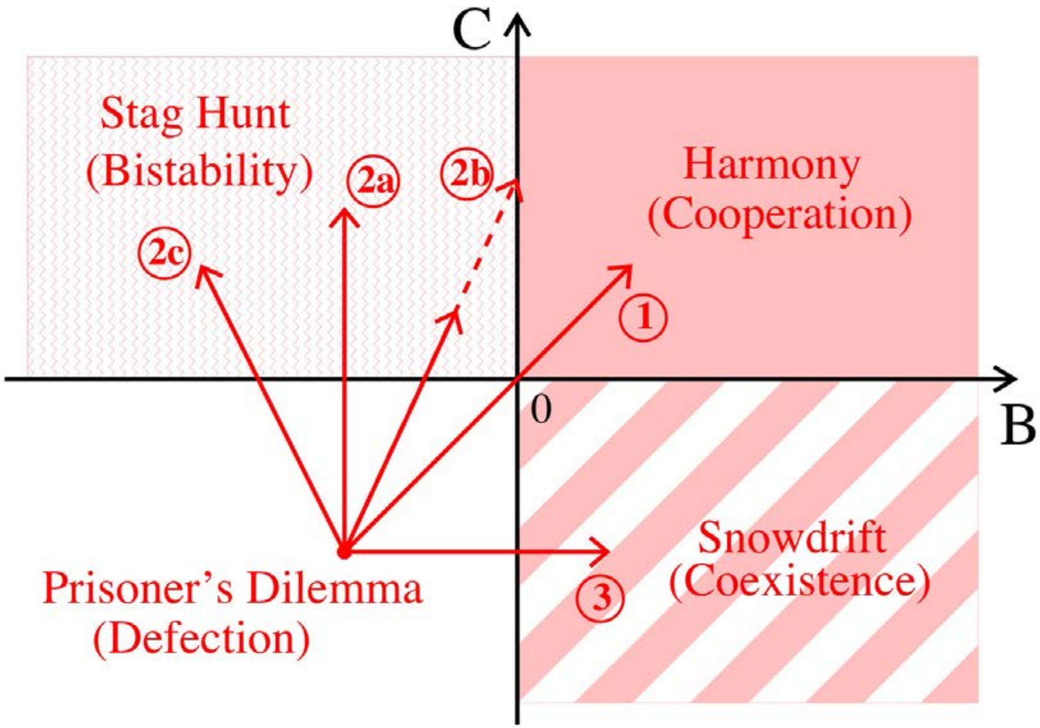
Kin Selection, Genetic Favoritism



Direct Reciprocity

Routes to Cooperation

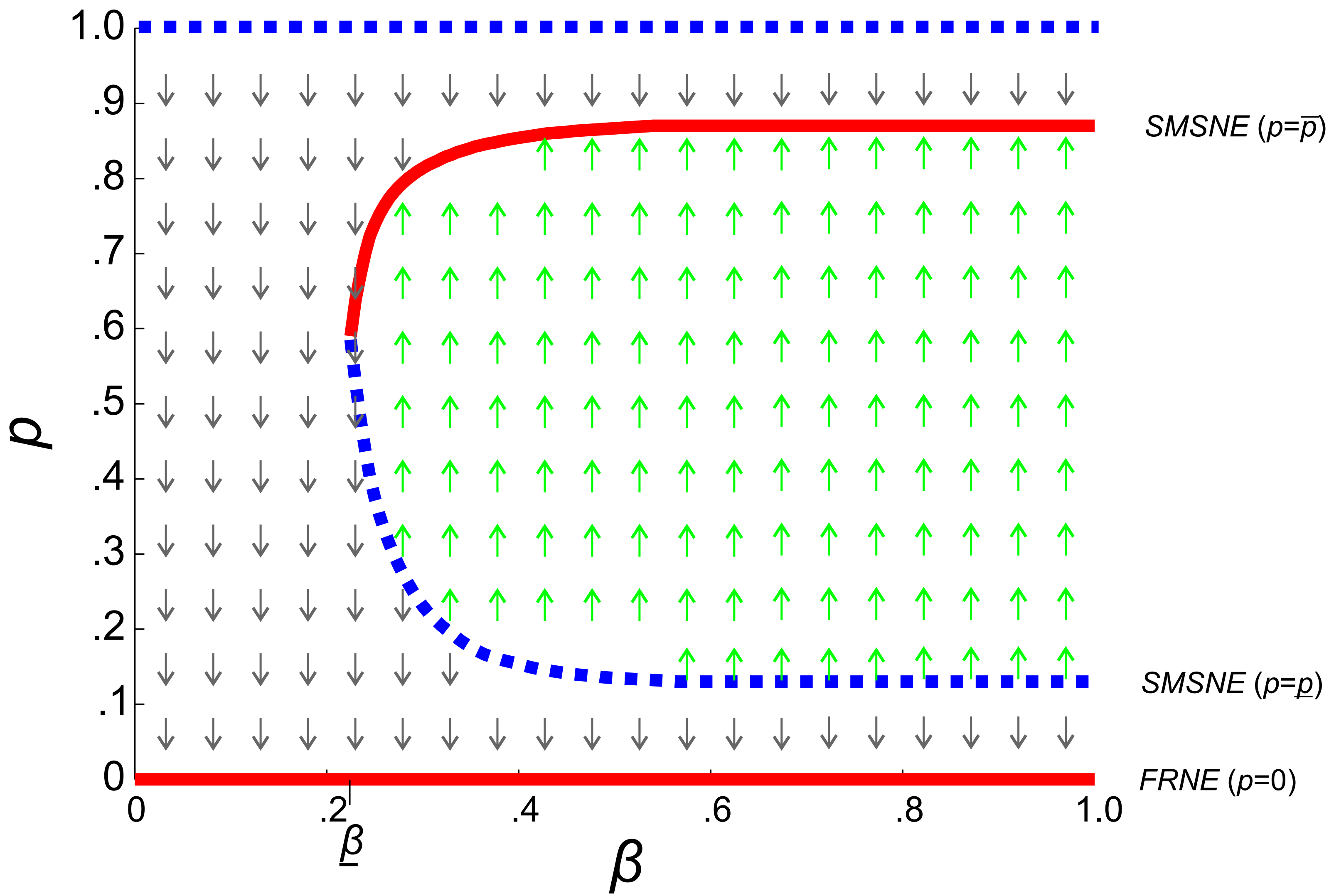
Routes to cooperation require to destabilize defection (PD --> SD) or to stabilize cooperation (PD -->SH) or both (PD -->HG)



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

Reputation, Indirect Reciprocity

Merit-Based Matching:
Everyone Can Be Better Off



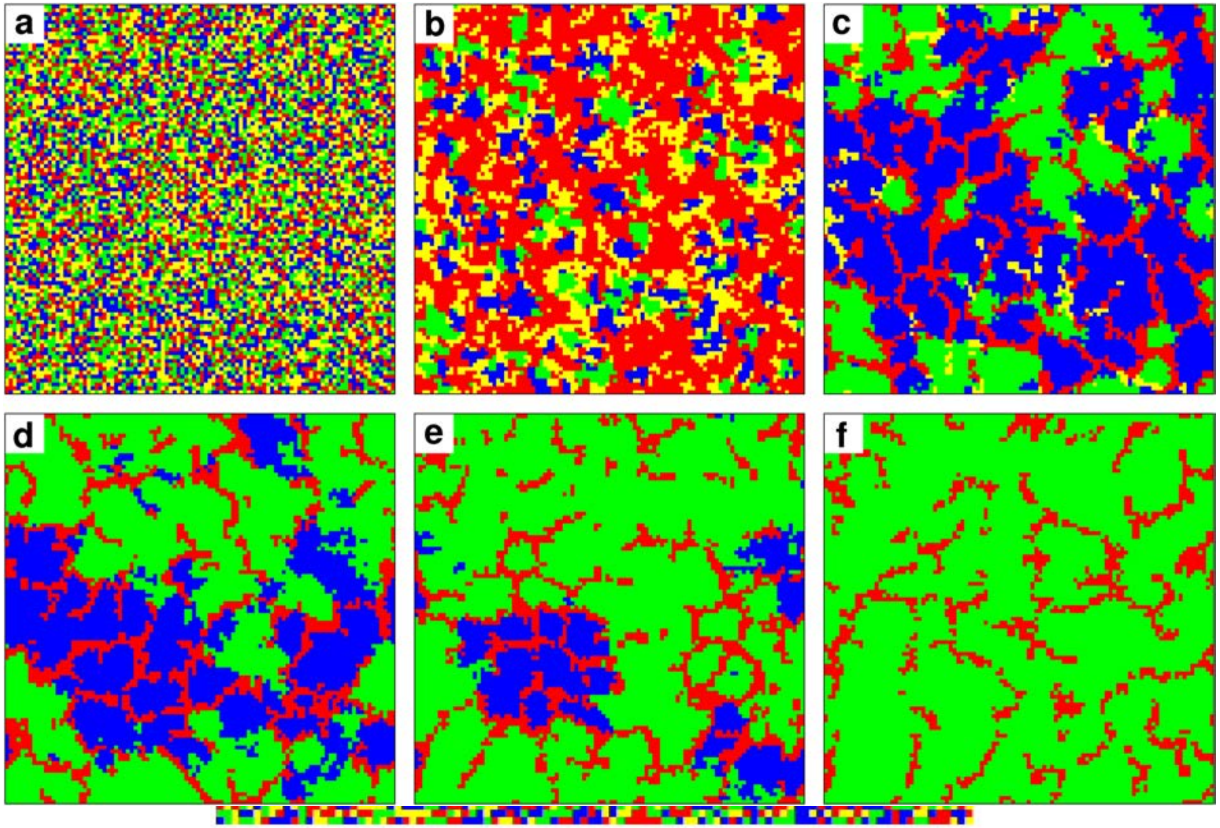
DH, with Heinrich Nax and Ryan Murphy

Competition of Mechanisms: Is Peer Punishment or Signaling Superior?

Characteristics of the game:

- Intergroup conflict
- Subjects are endowed with 1000 points in every period
- Each member of winning group gets 1000 points
- Chances of winning correspond to sum of contributions
- Nash equilibrium: 250 points per group

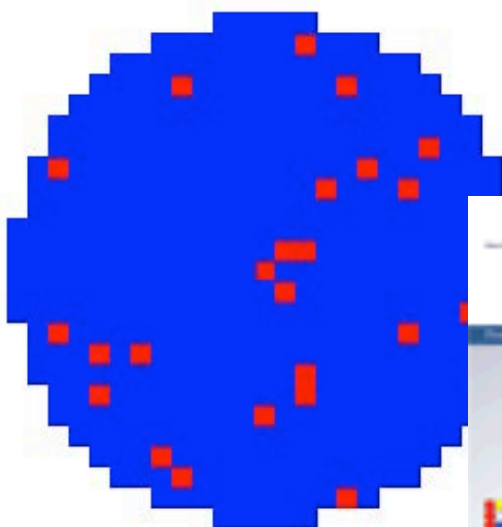
How Second-Order Free-Riders Are Eliminated and Punishment Spreads

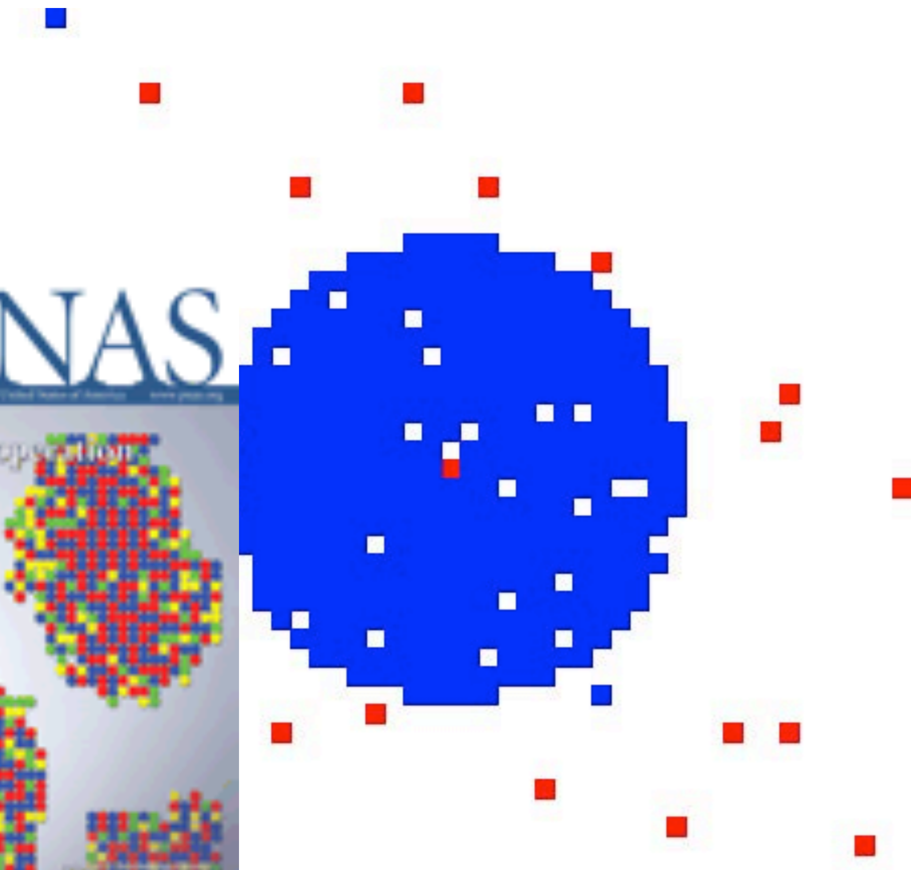


D = Defectors (free-riders), M = Moralists = cooperators punishing defectors, C = non-punishing Cooperators (second-order free-riders), I = Immoralists = defectors punishing other defectors

The Breakdown and Outbreak of Cooperation

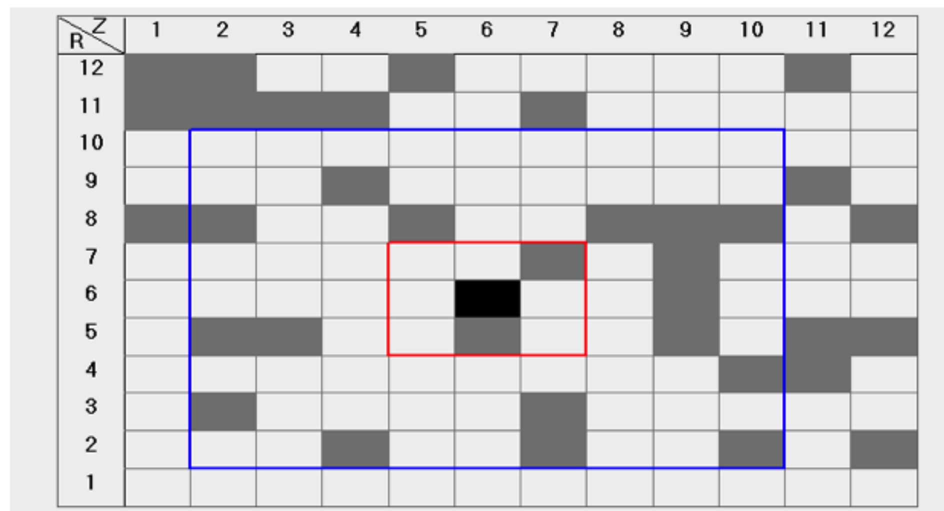
Red, yellow: defectors (cheaters)
Blue, green: cooperators

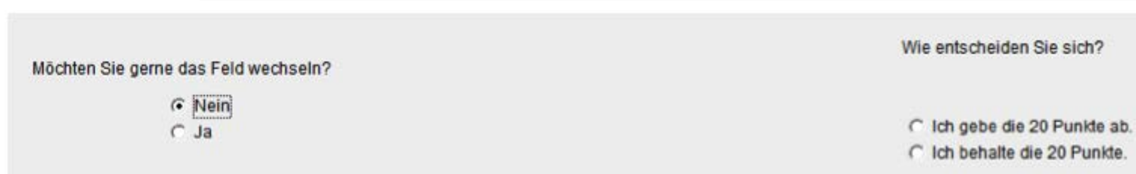




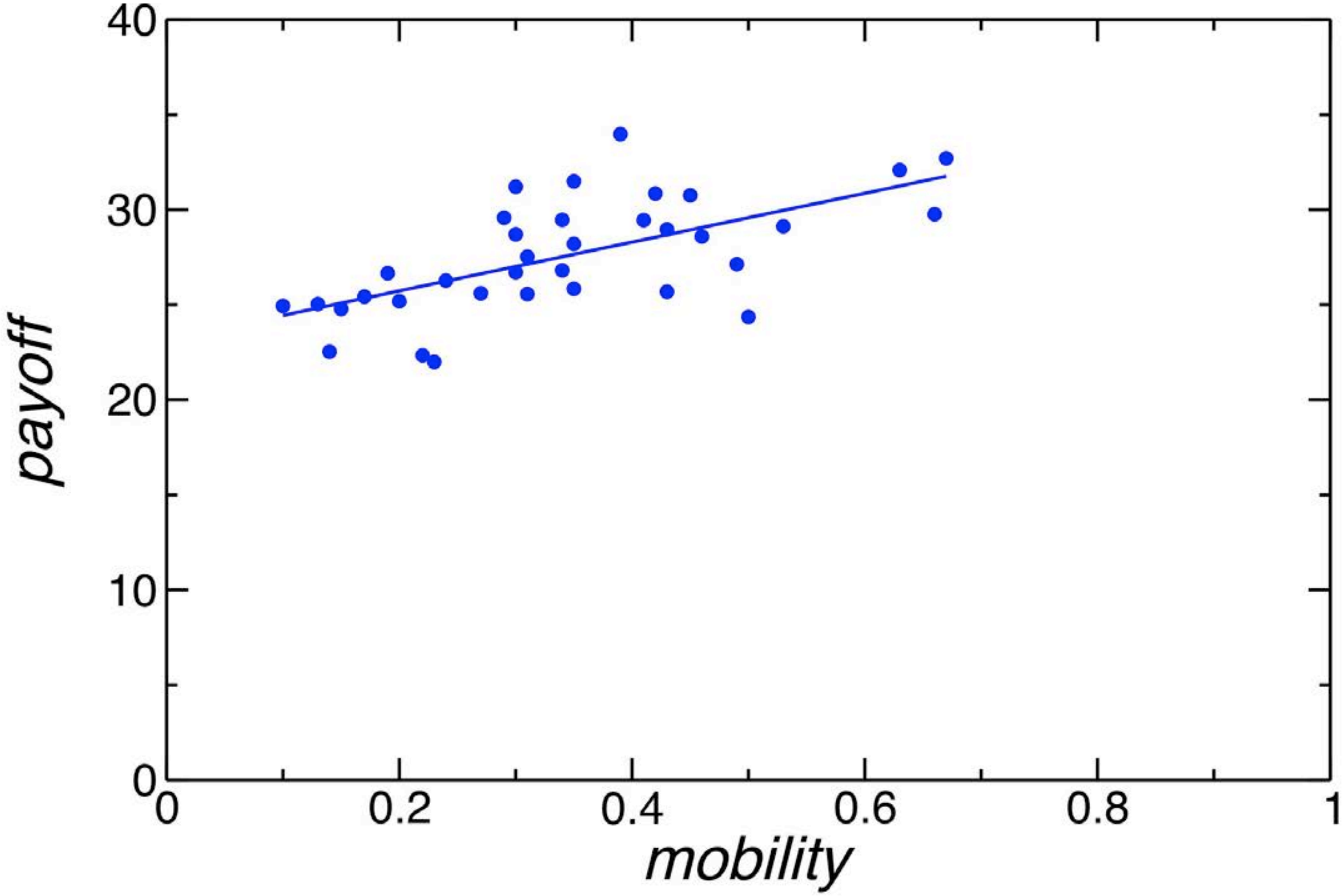
Public Good Game with Mobility: Experimental Design

Joint work with Carlos Roca, Charles Efferson and Sonja Vogt

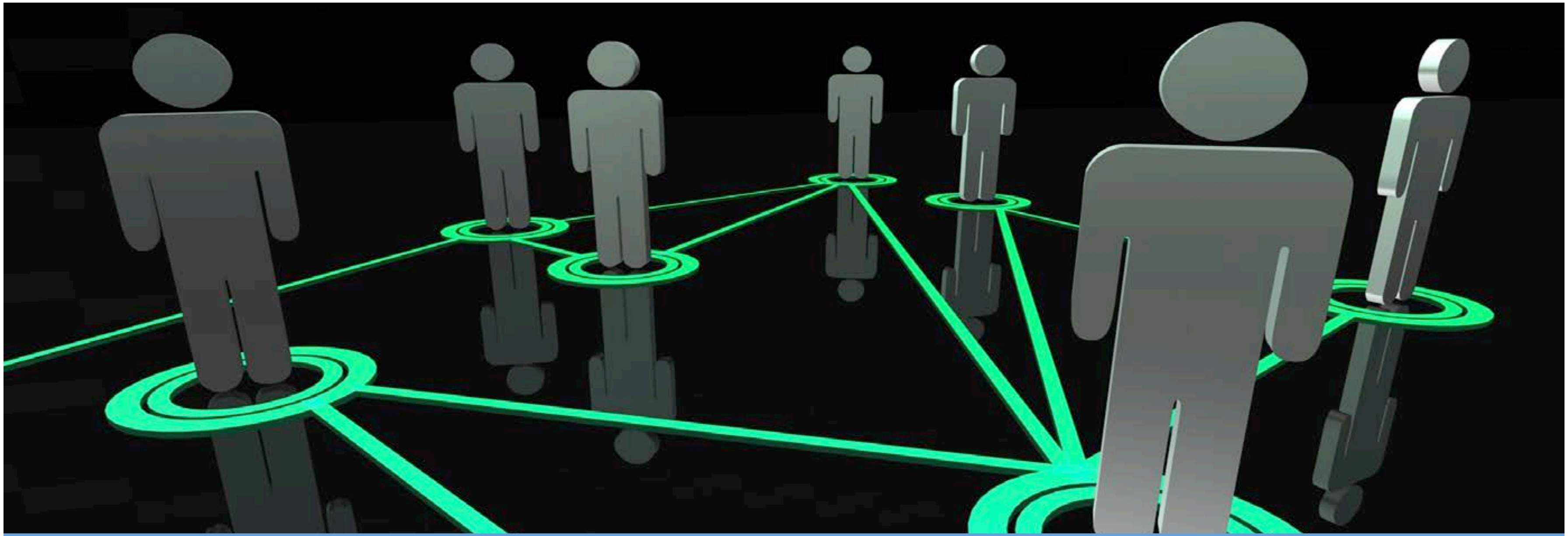




Payoff as Function of Mobility



Mobility is key to success!



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

Dirk Helbing

with Thomas Grund, Christian Waloszek,

Matthias Leiss, Heinrich Nax,

and others

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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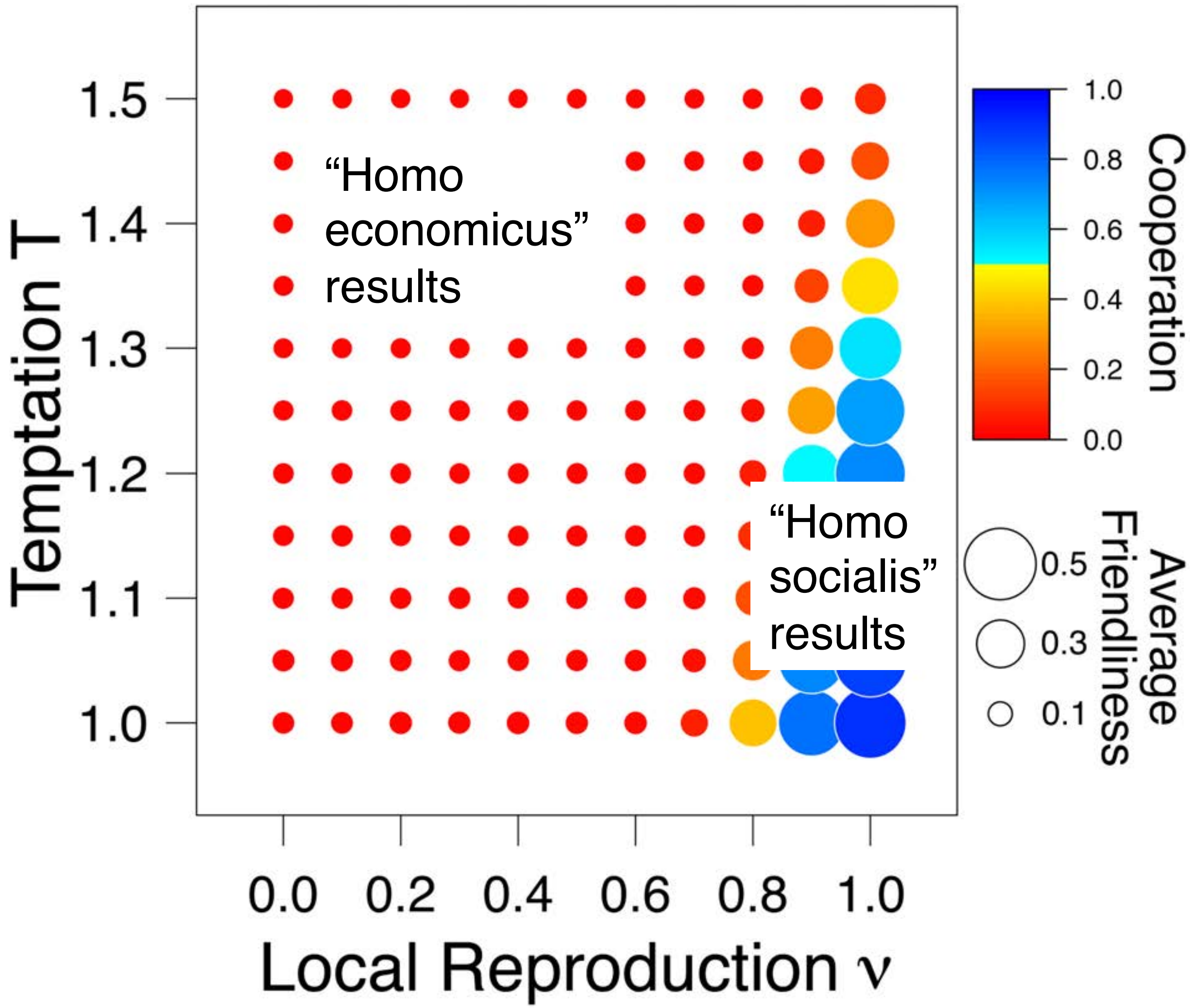
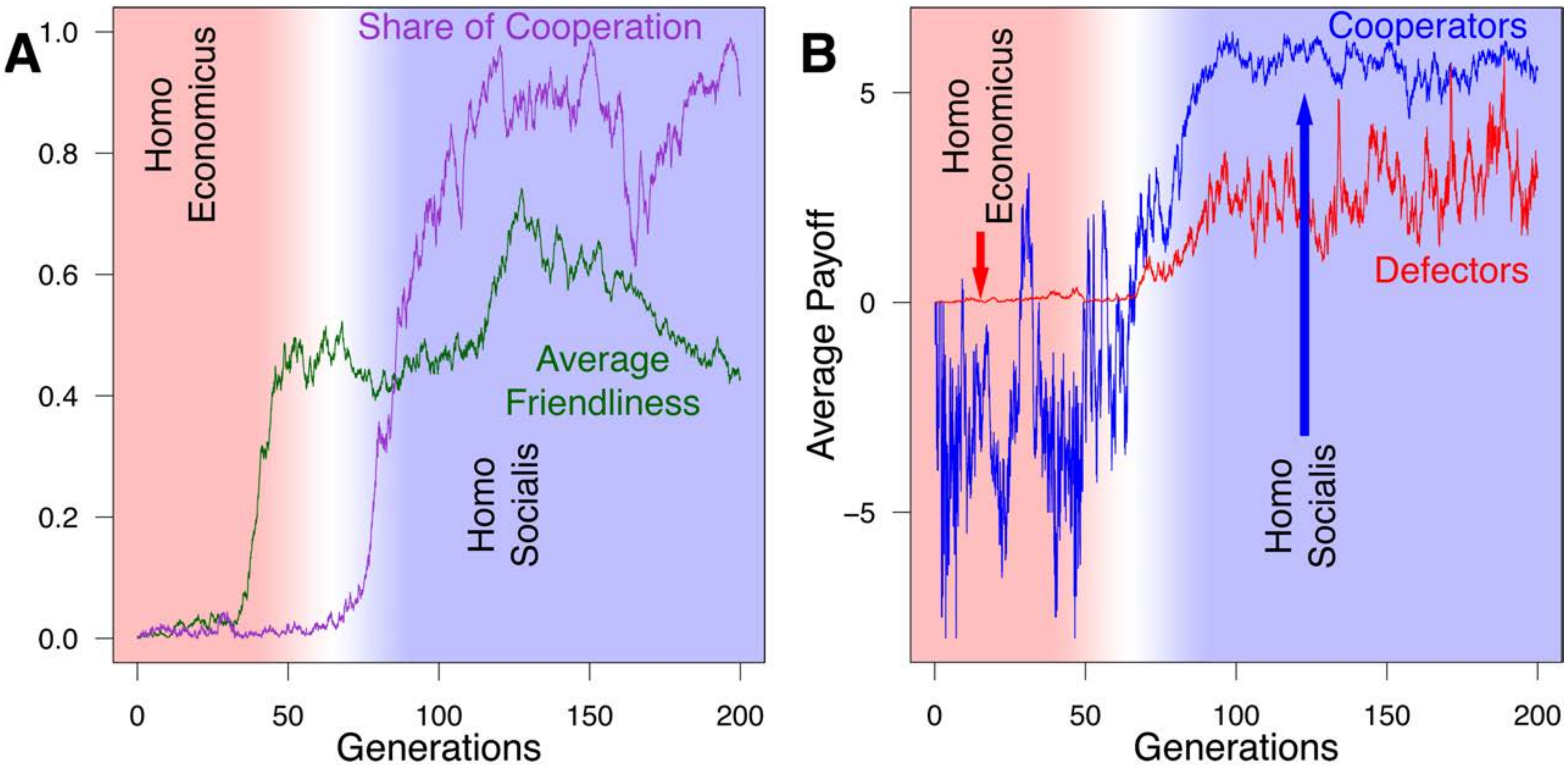
Homo Economicus vs. Homo Socialis



Surprisingly, evolution has made (many of) us other-regarding. It’s the reason for our superior position in the animal kingdom and for the existence of our society.

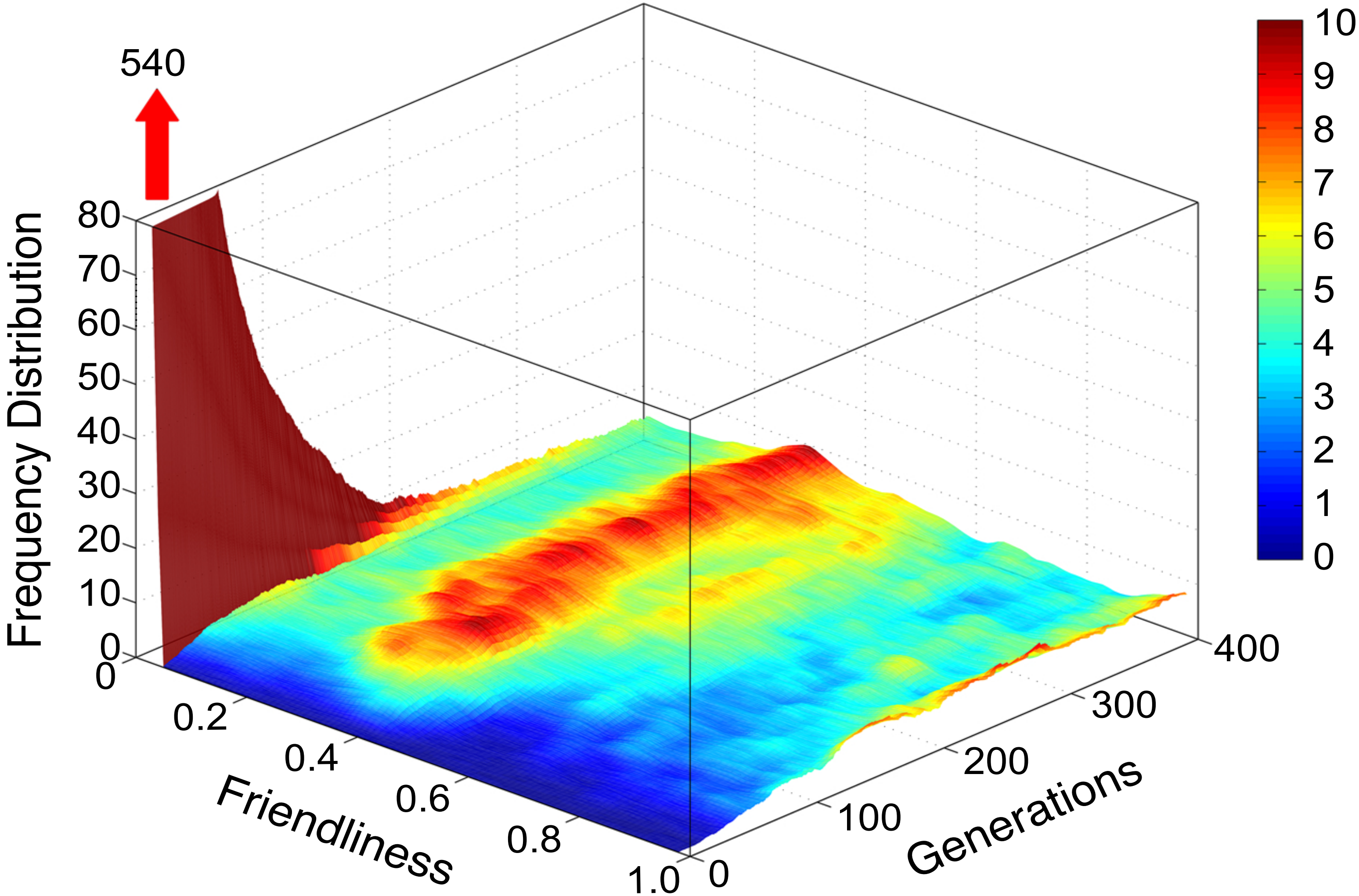
Emergence of the Homo Socialis



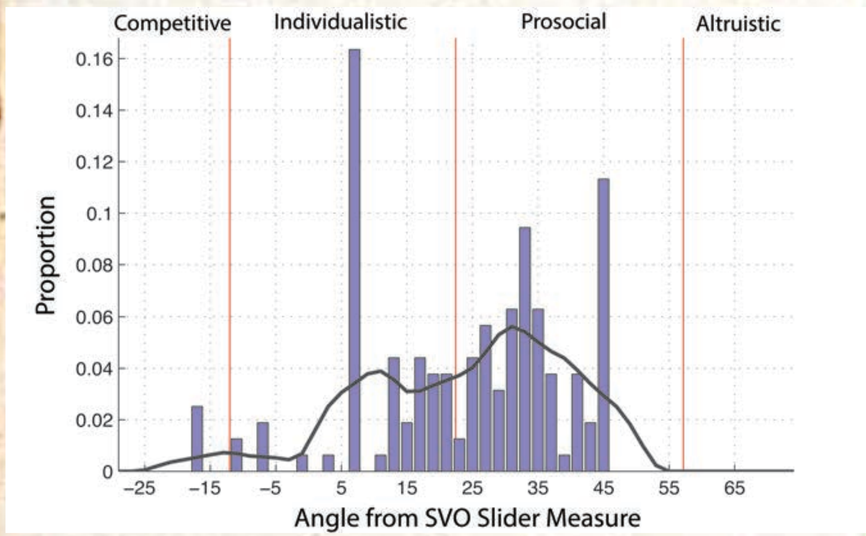
The “homo socialis” is conditionally cooperative, takes self-determined but other-regarding decisions (considering the impact on others).

This implies interdependent decisions, “networked minds”.

Distribution of Social Preferences („Friendliness“)



"How ever selfish man may be supposed, there are evidently some principles in his nature, which interest him in the fortune of others, and render their happiness necessary to him, though he derives nothing from it."



R.O. Murphy, K.A. Ackermann, M.J.J. Handgraaf (2011) *Judgment and Decision Making* **6**(8), 771–781.

THE

THEORY

OF

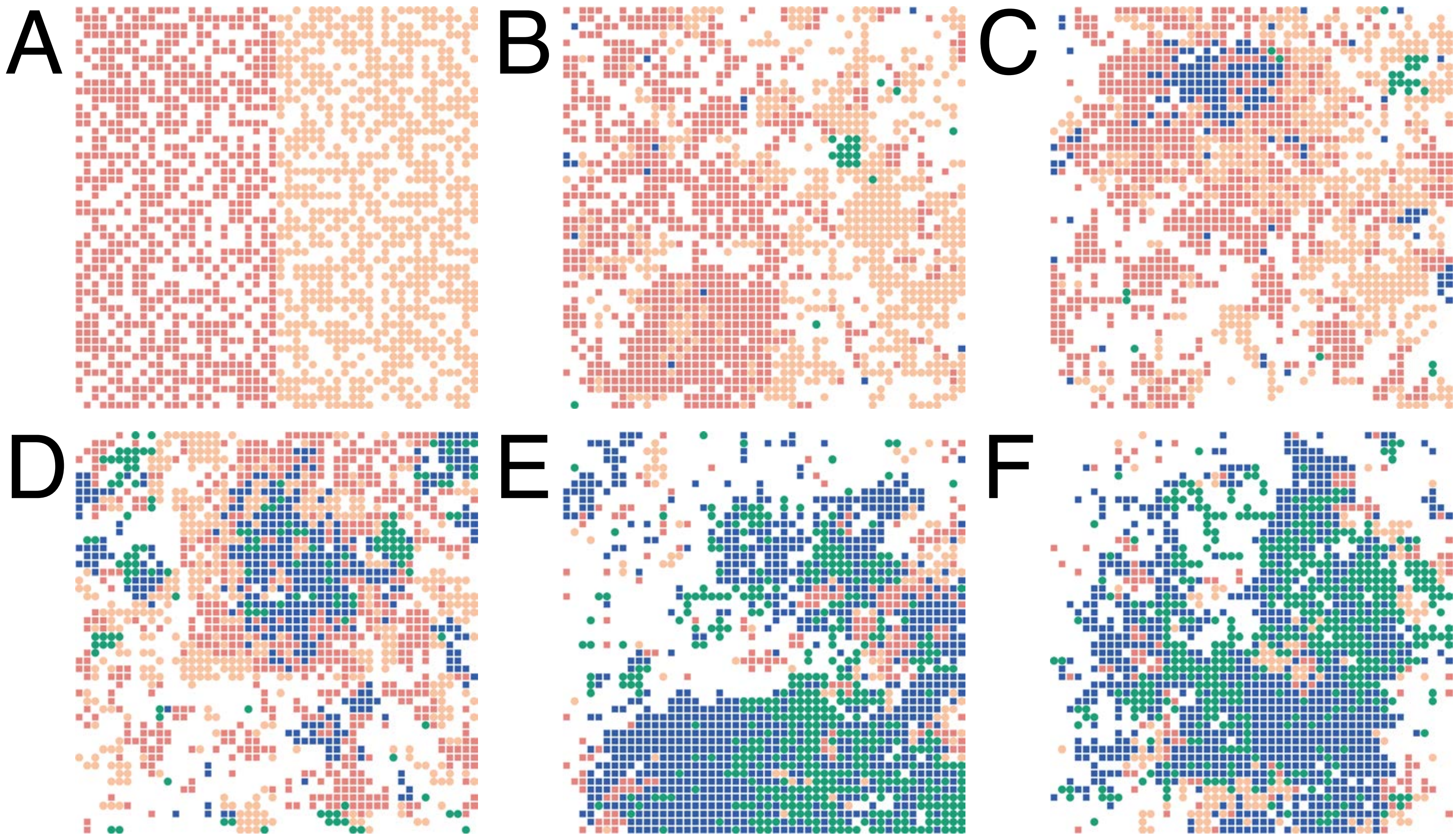
MORAL SENTIMENTS.

By ADAM SMITH,
Professor of Moral Philosophy in the University of Glasgow.

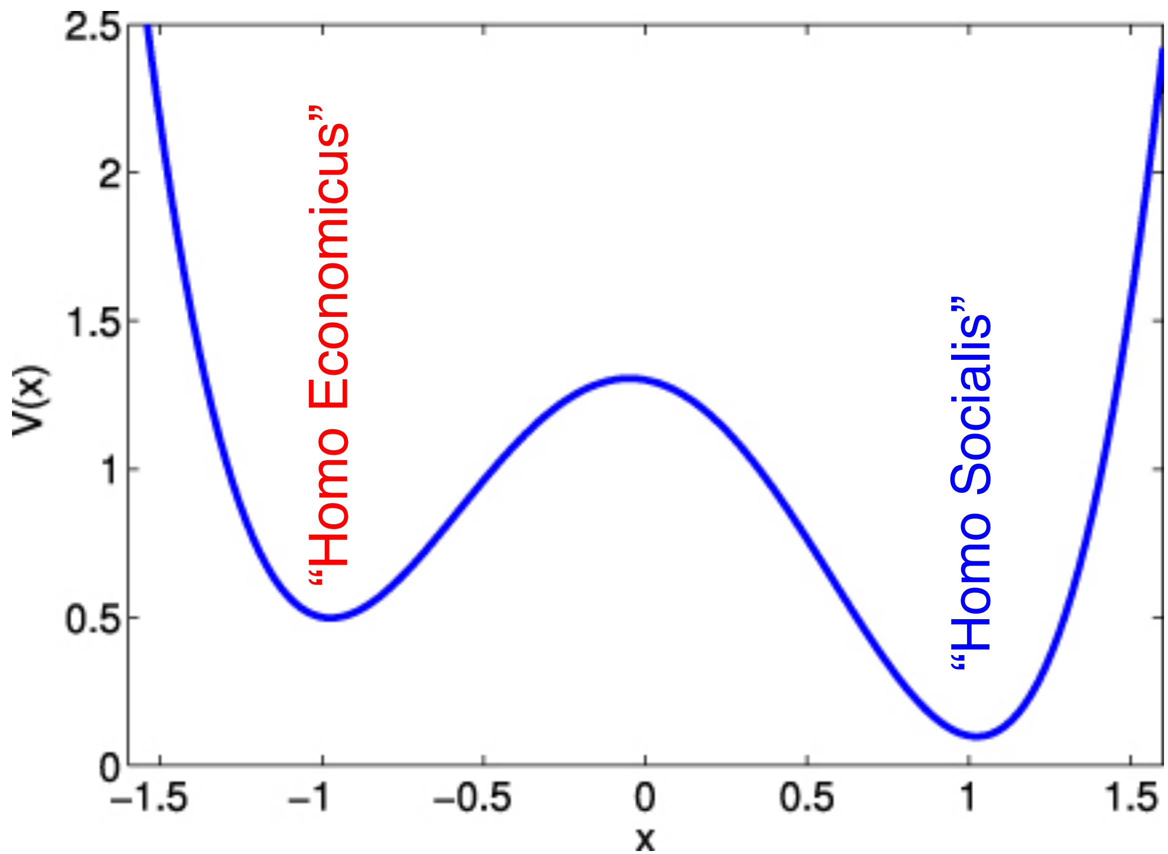
LONDON:
Printed for A. Millar, in the Strand;
And A. Kincaid and J. Bell, in Edinburgh.
M DCC LIX.

Adam Smith: The Theory of Moral Sentiments. 1759.

Cooperation between Strangers



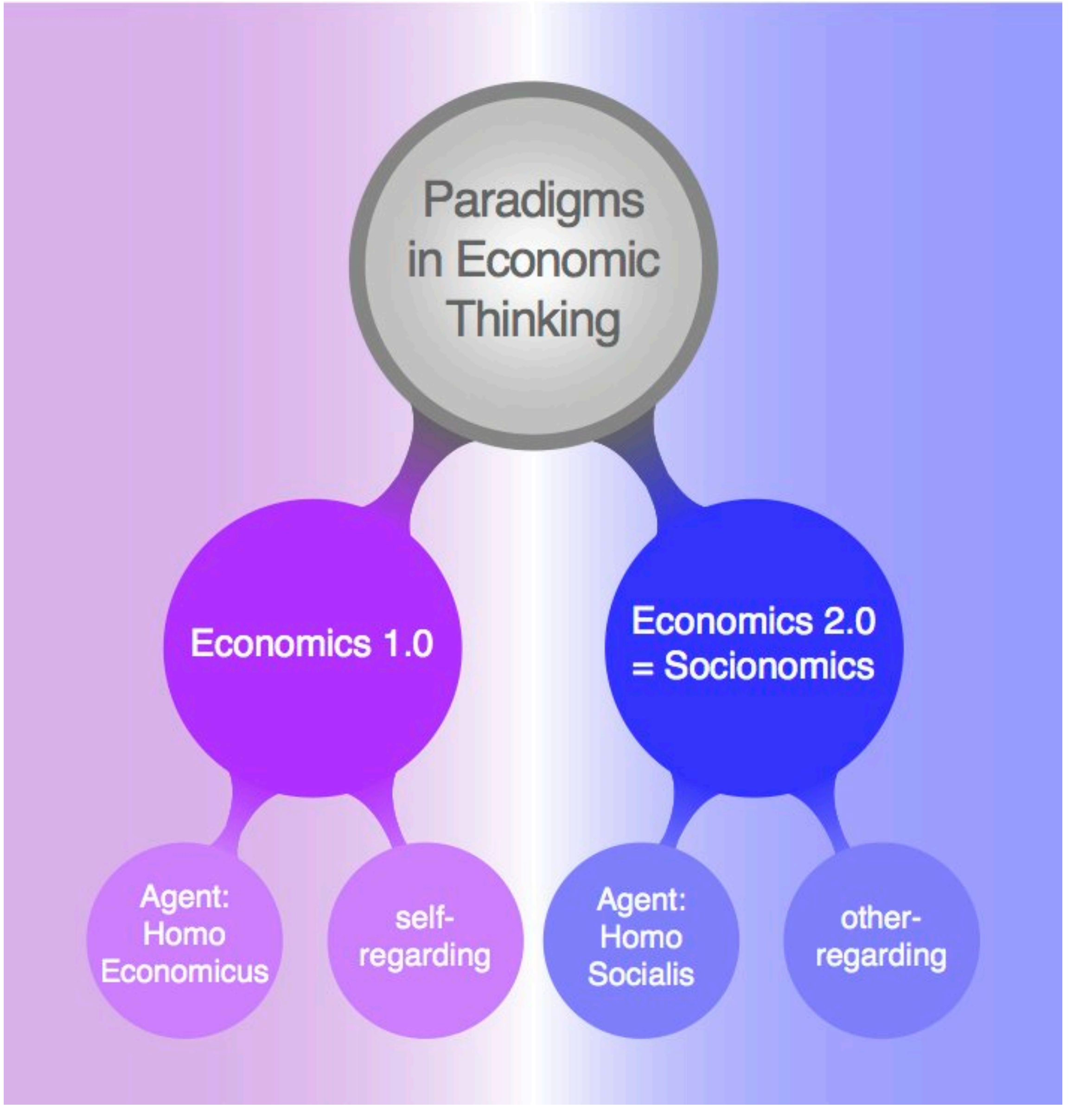
The „Homo Socialis“ Cannot Be Understood as a Small Deviation from the „Homo Economicus“, Which Can Be Approximated by Him.



Statistically independent decisions of the „homo economicus" may be handled with standard econometric methods. Interdependent decisions of the „homo socialis" require a complexity science description.

Therefore, it’s wrong to assume that other-regarding preferences would not change rational choice theory. But it can be extended by considering complex dynamics.

New Economic Thinking



Modeling the Emergence of Social Norms when Preferences are Incompatible

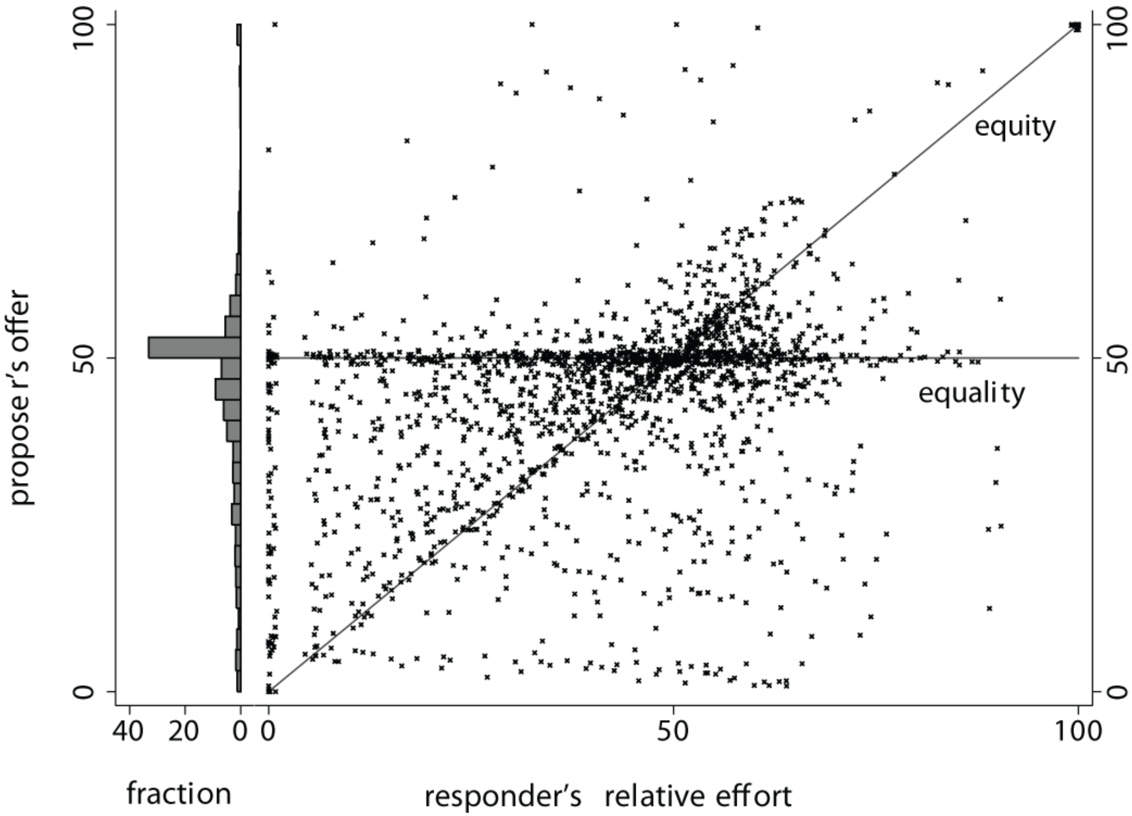
Dirk Helbing

with Michael Mäs, Anders Johansson,

Heiko Rauhut, Fabian Winter,

and others

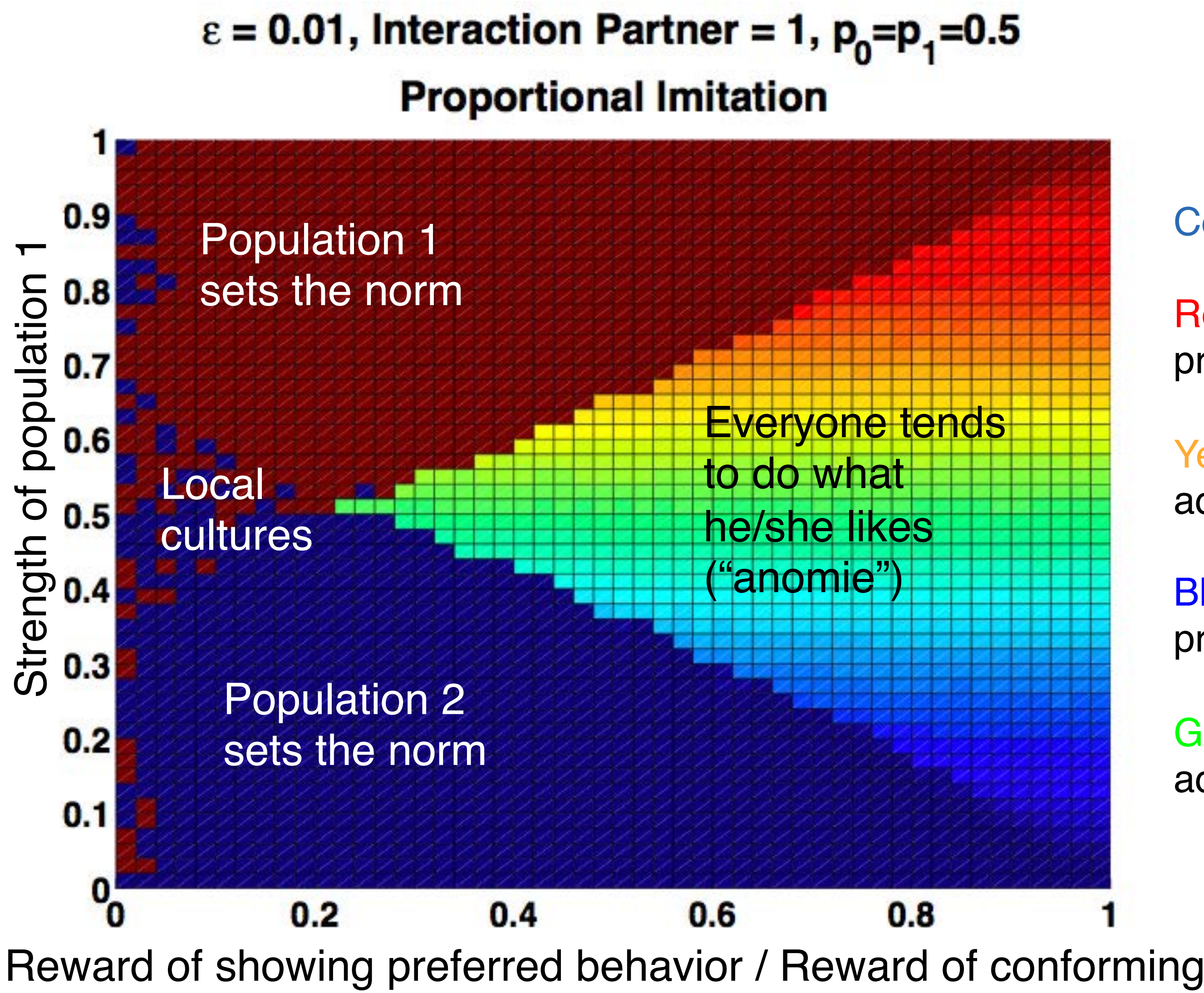
Conflict between Individuals with Equity and Equality Preferences



Results of an Ultimatum Game Experiment

Joint work with Fabian Winter and Heiko Rauhut

Emergence of Social Norms: Theoretical Results



Computer simulations:

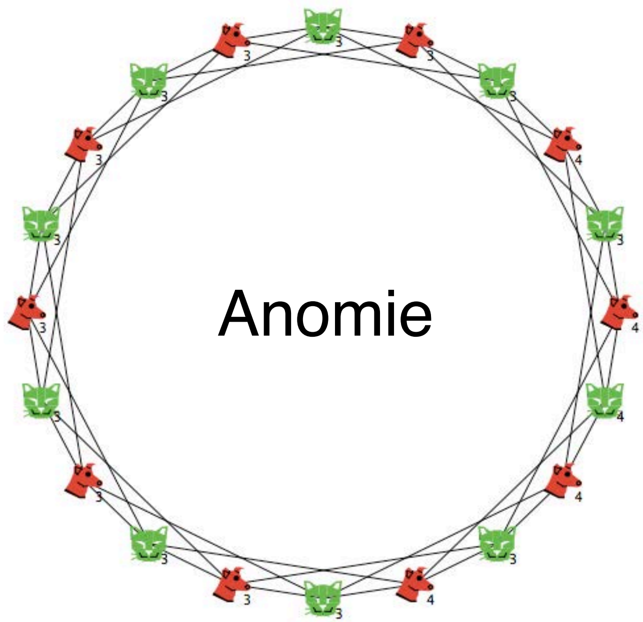
Red = individuals preferring behavior 1

Yellow = individuals adjusting to behavior 1

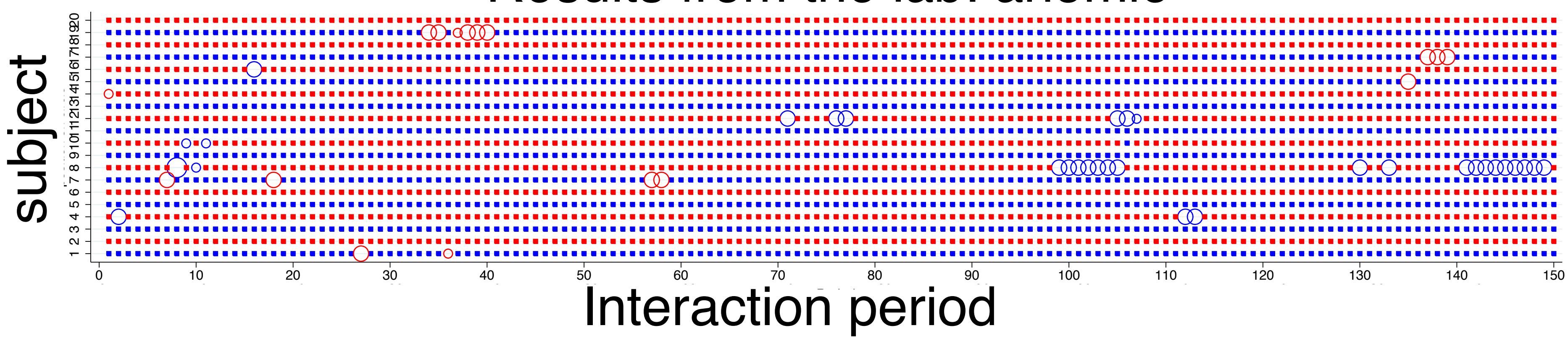
Blue = individuals preferring behavior 2

Green = individuals adjusting to behavior 2

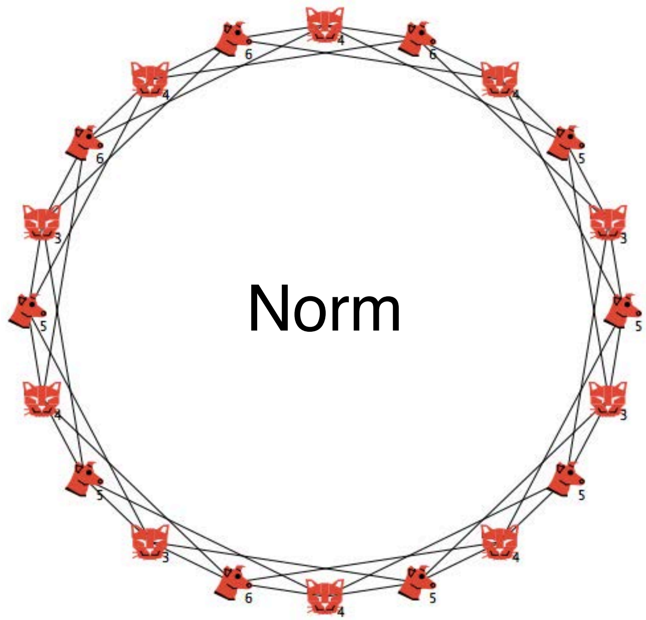
Occurrence of Anomie: Experimental Results



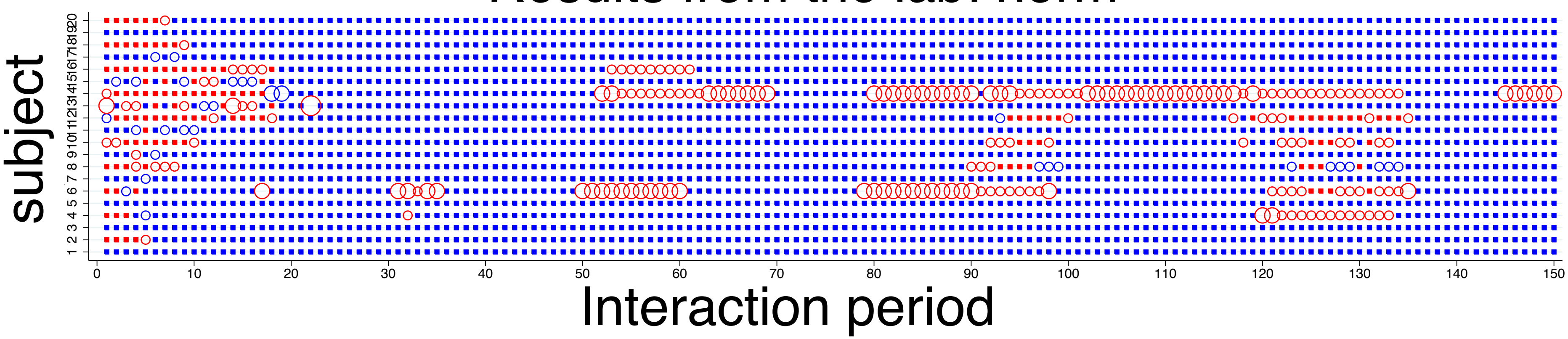
Results from the lab: anomie



Occurrence of Social Norms: Experimental Results

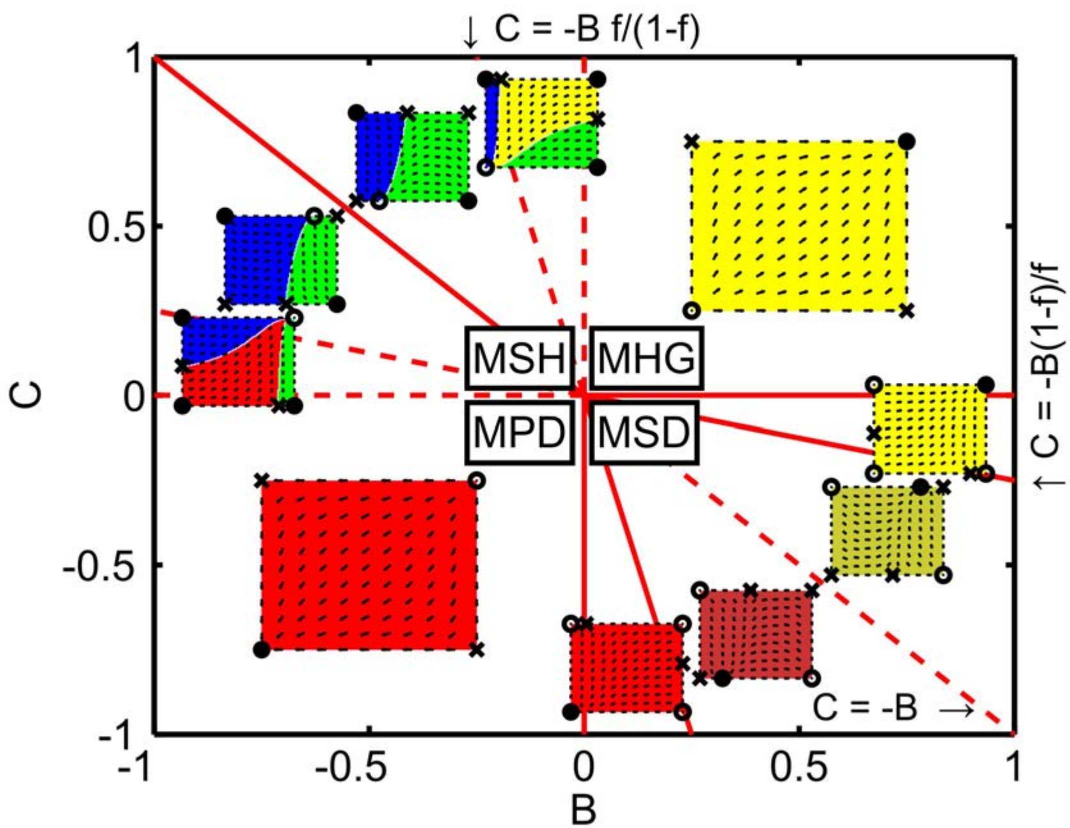


Results from the lab: norm

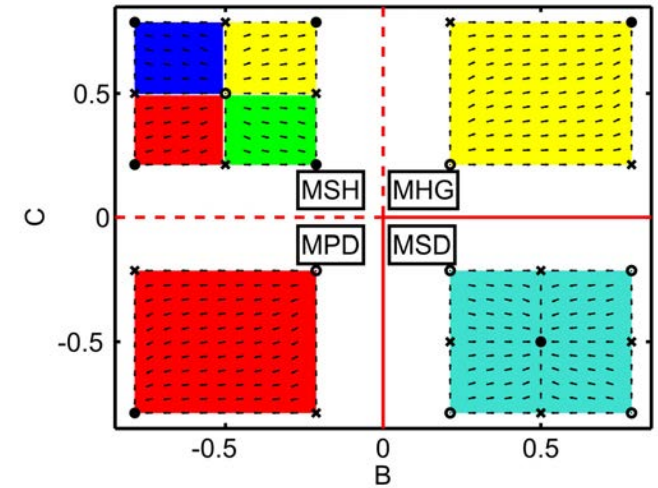


2 Populations with Incompatible Preferences

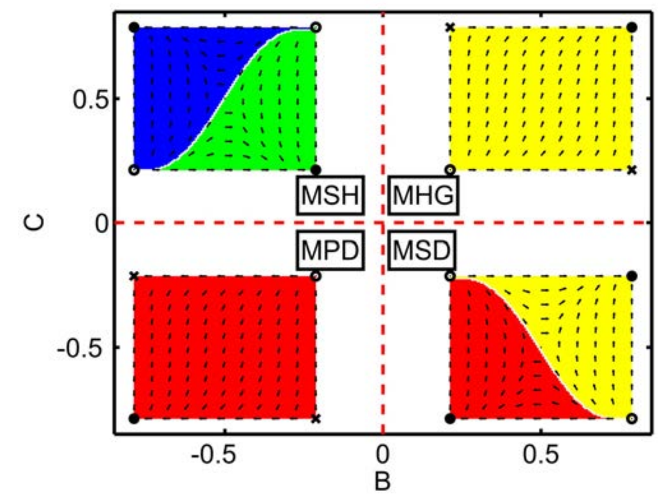
with interactions and self-interactions



without interactions



without self-interactions



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

Studying Intercultural and International Conflict

Dirk Helbing

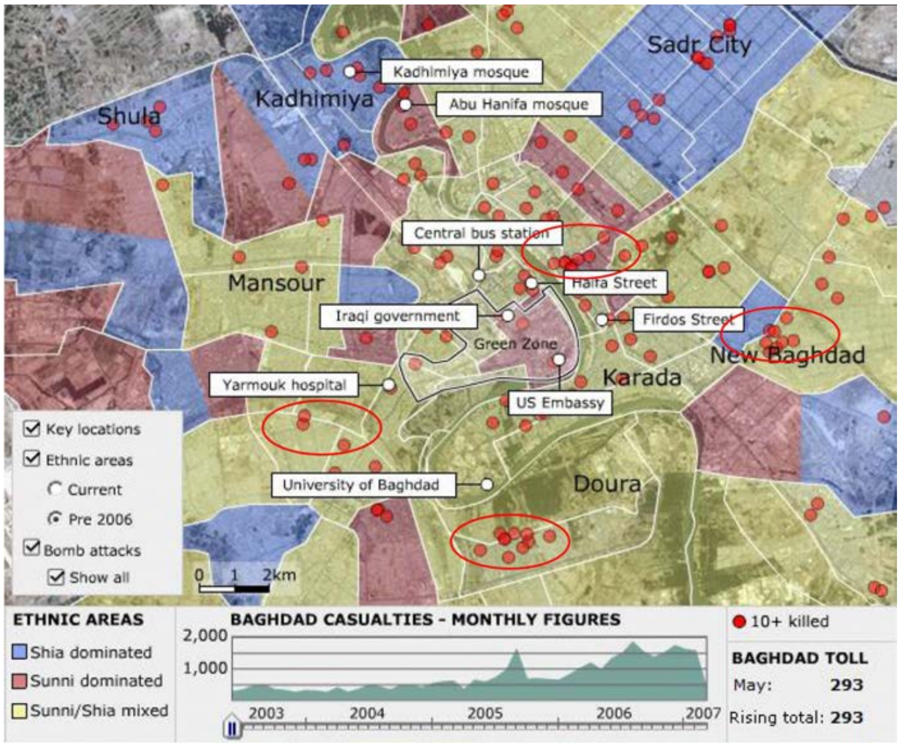
with Karsten Donnay, Thomas Chadefaux,

Ravi Bhavnani, Dan Miodownik,

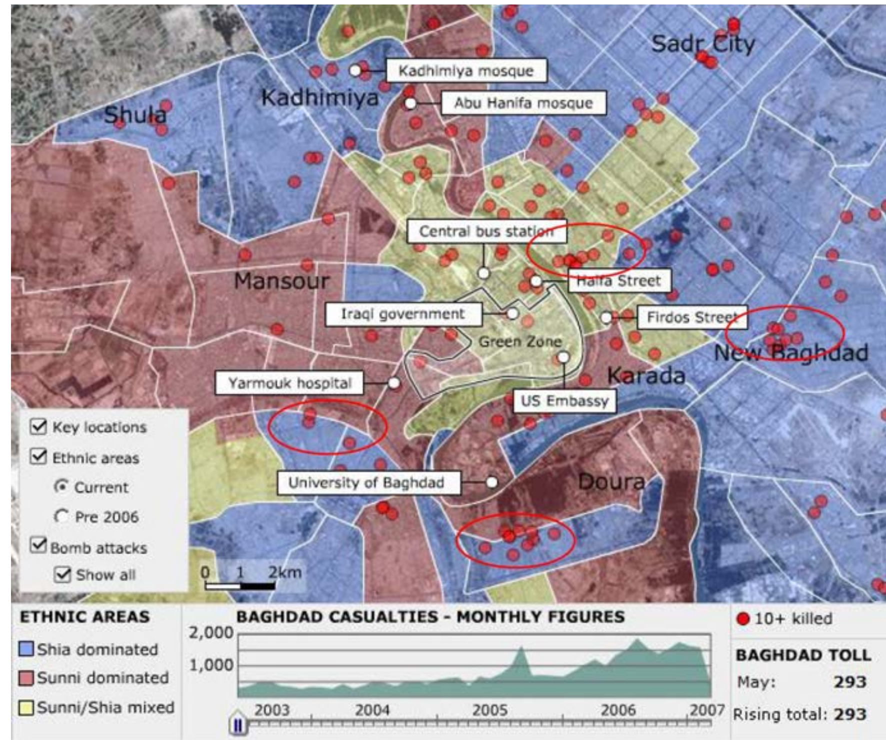
and others

Interrelation of Spatial Interaction, Conflict, and Migration

Source: BBC



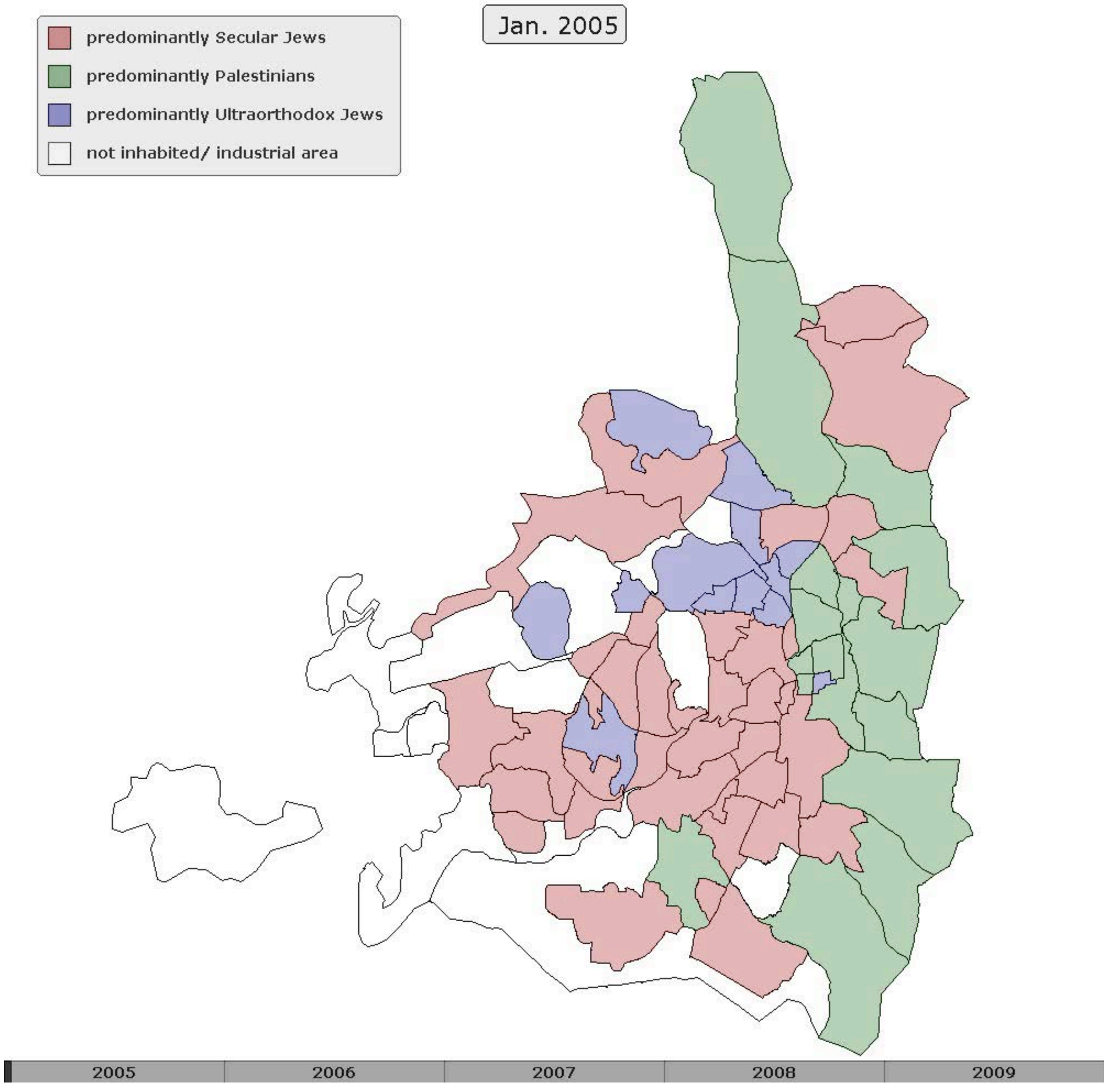
Ethnic areas and bomb attacks before 2006



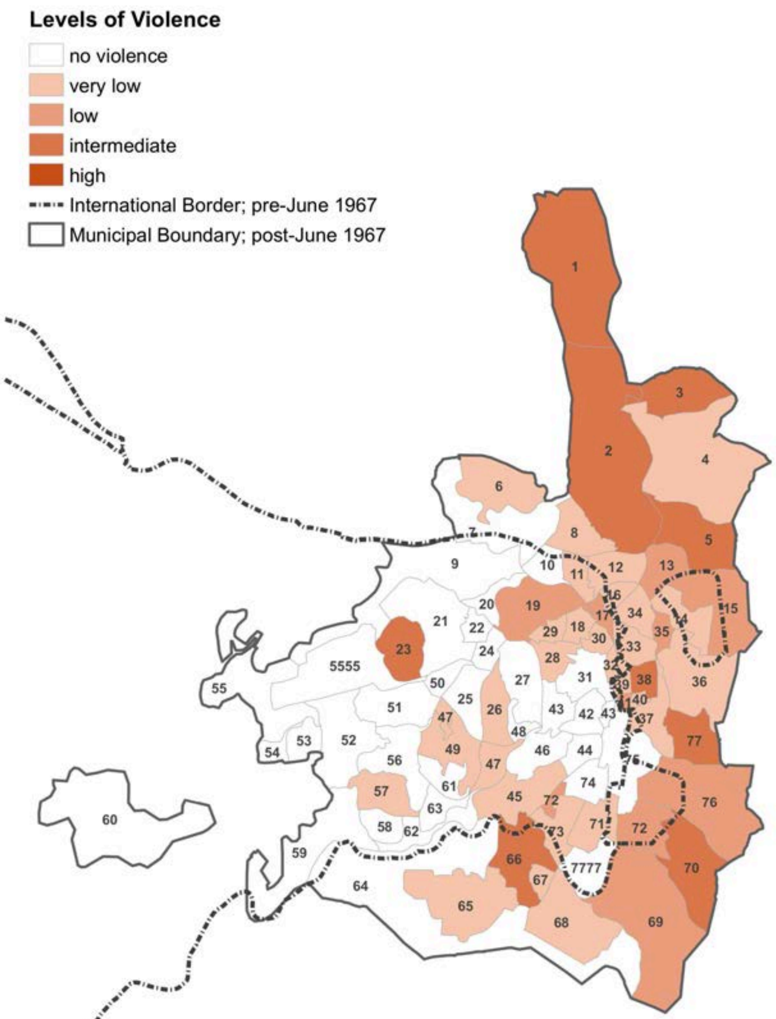
Ethnic areas and bomb attacks after 2006

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

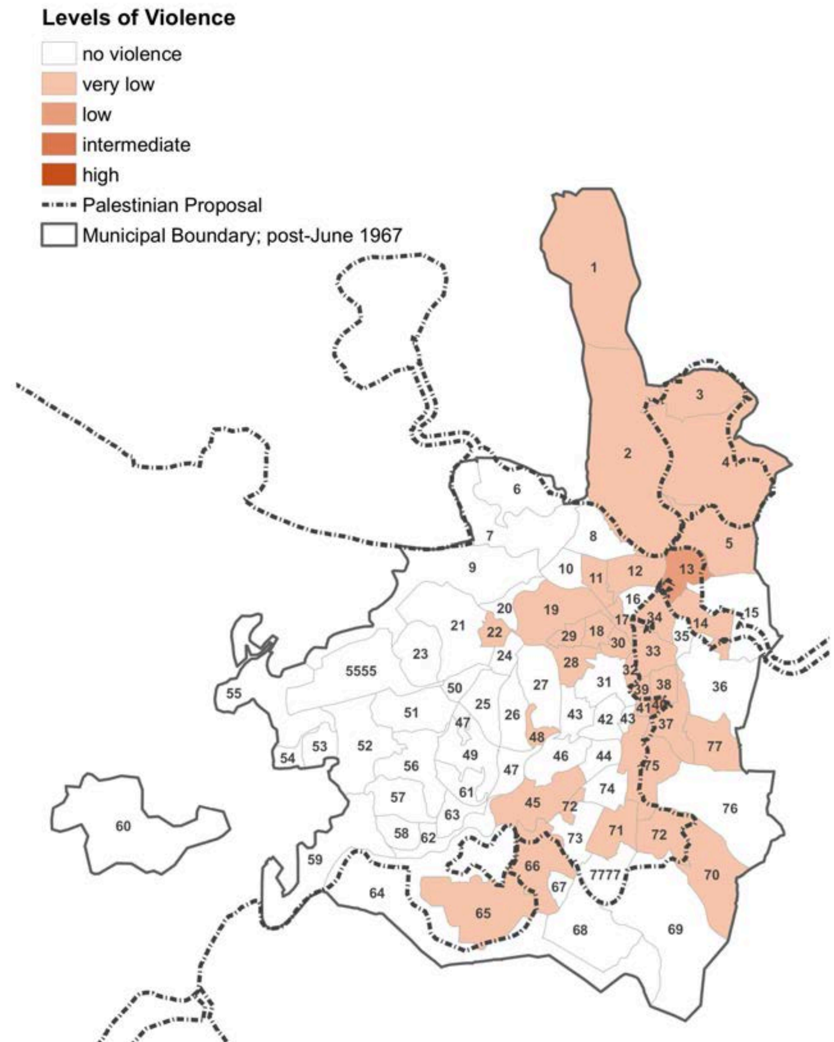
Conflict in the Middle East



Conflict in the Middle East: Possible Future Scenarios



‘Business as Usual’



Clinton Parameters

Understanding Social Dynamics by Analyzing Human Activity Data

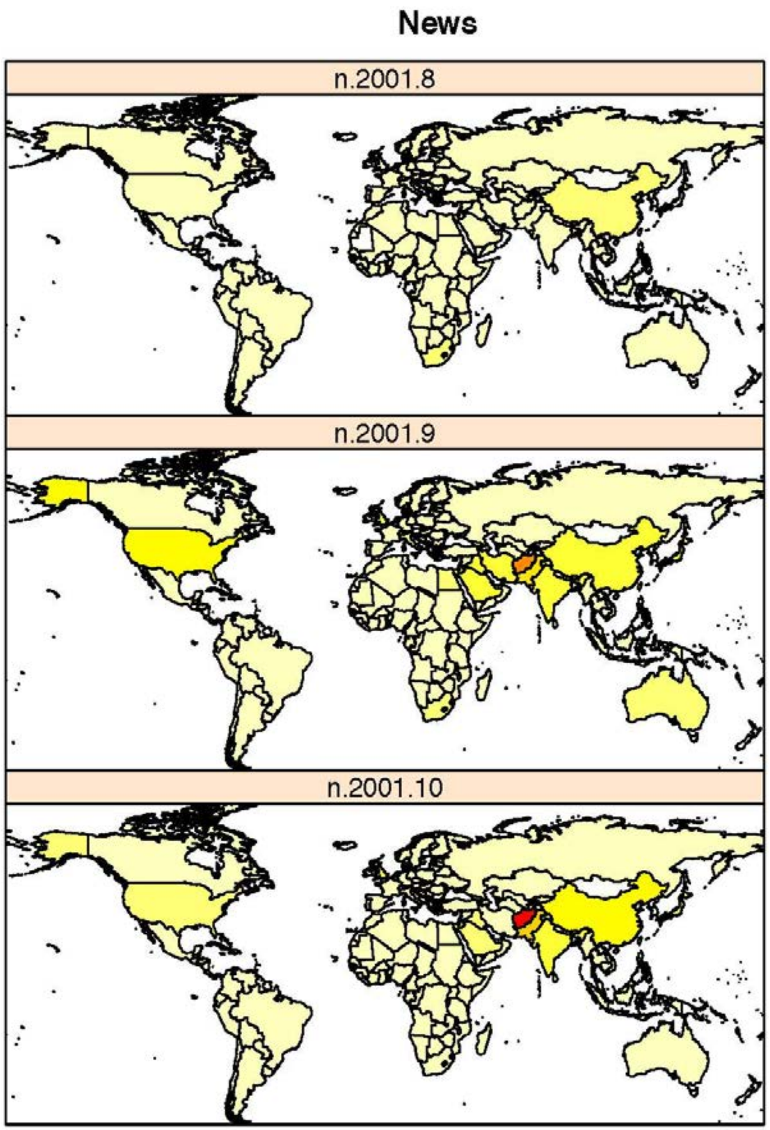
Dirk Helbing

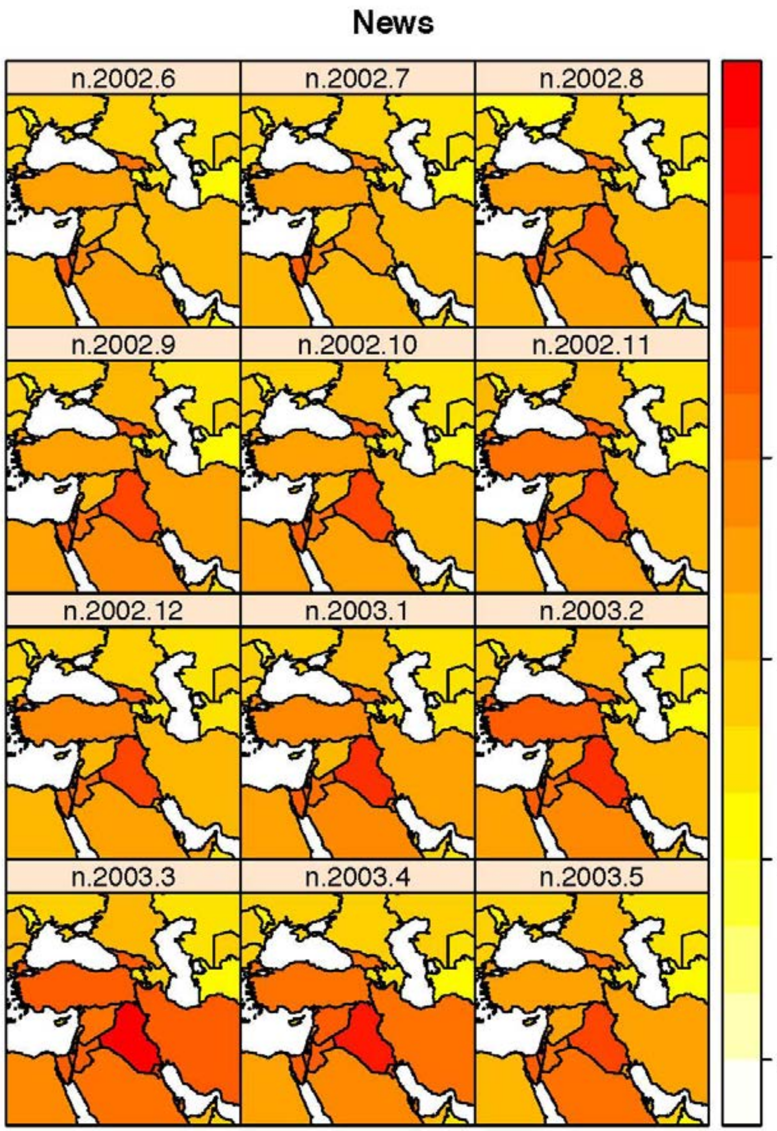
with Dirk Brockmann, Maximilian Schich,

Laszlo Barabasi, Bogdan State,

and others

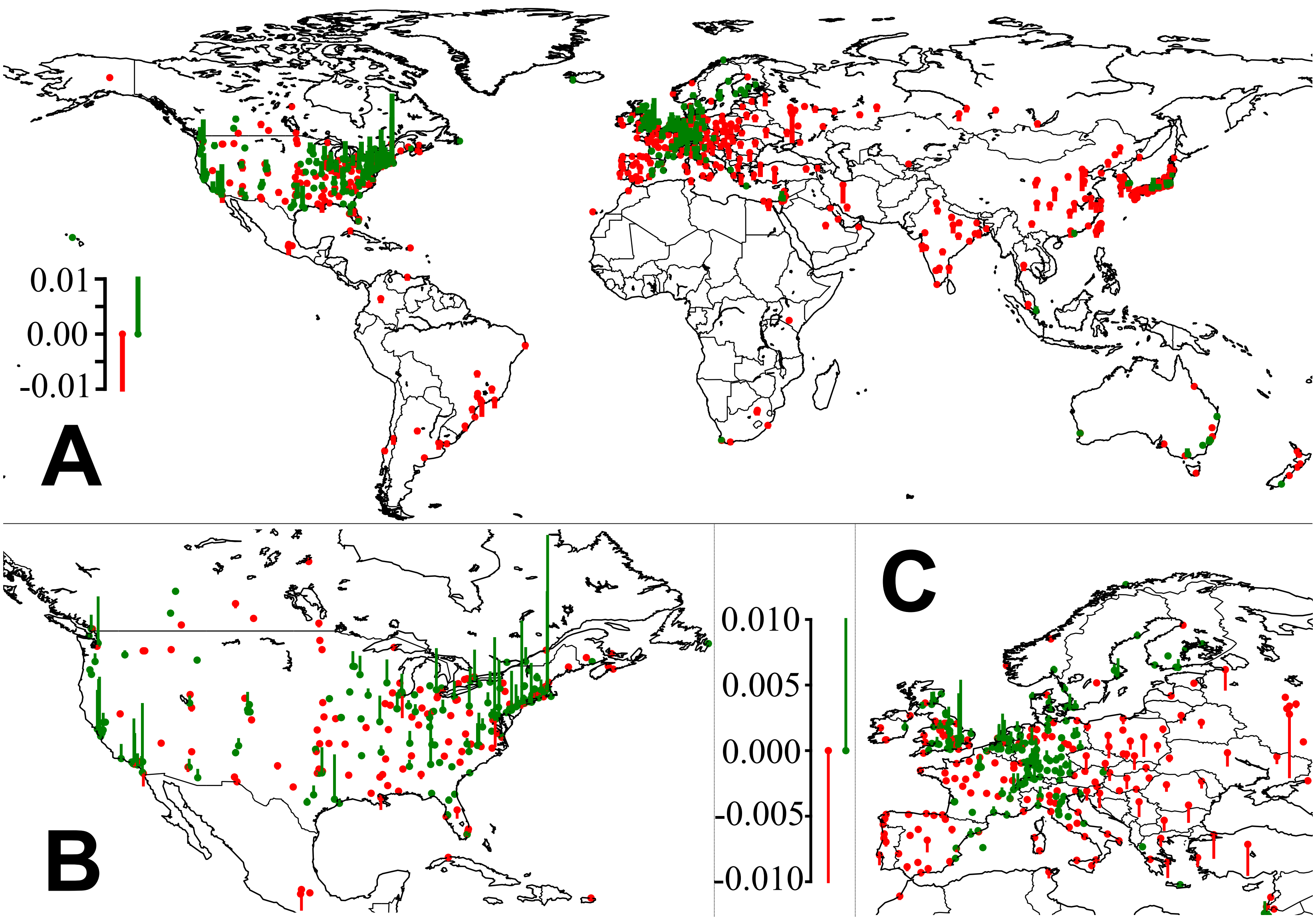
Measurement and Prediction of Conflict Probability



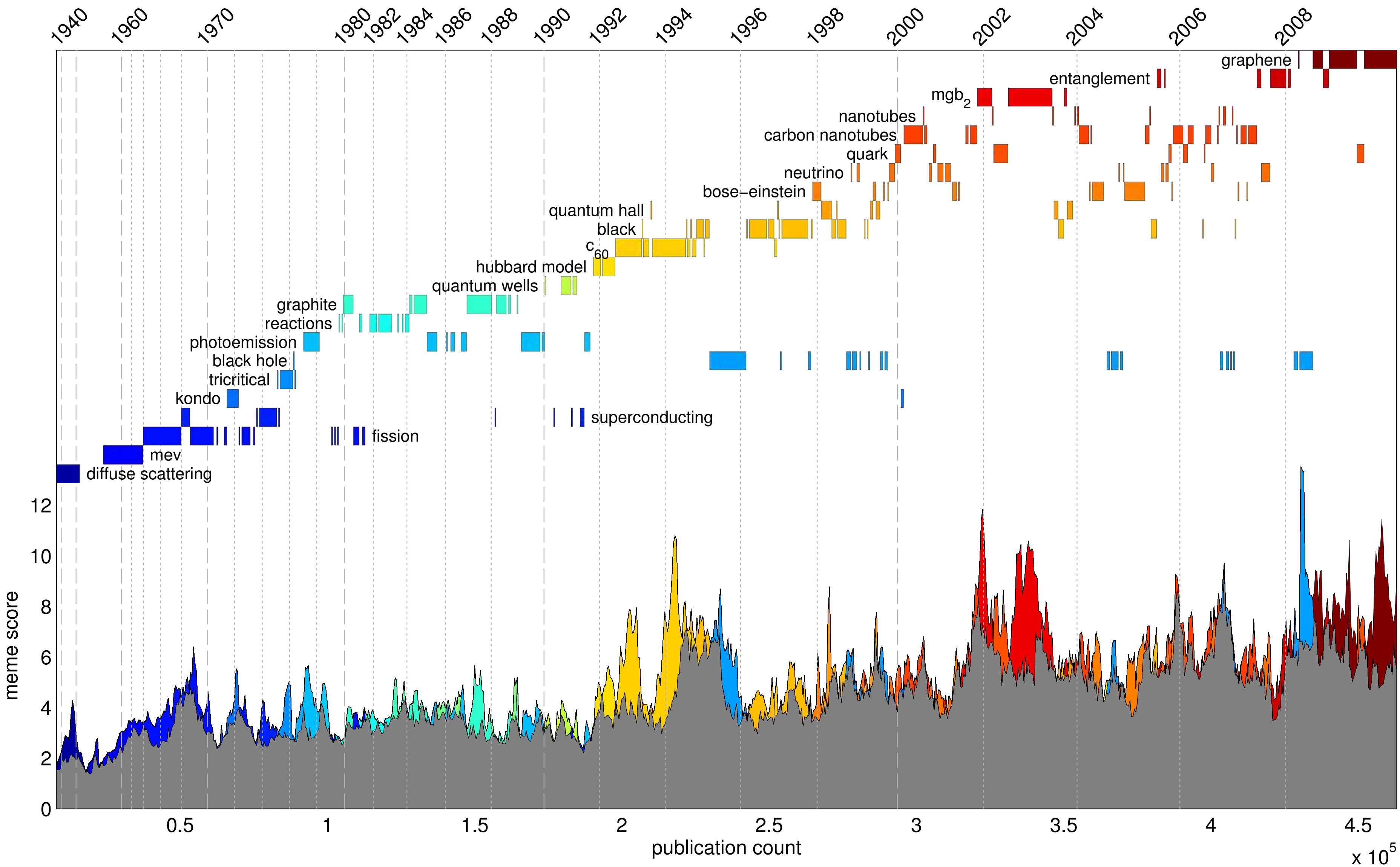


Joint work of Thomas Chadefaux and Dirk Helbing

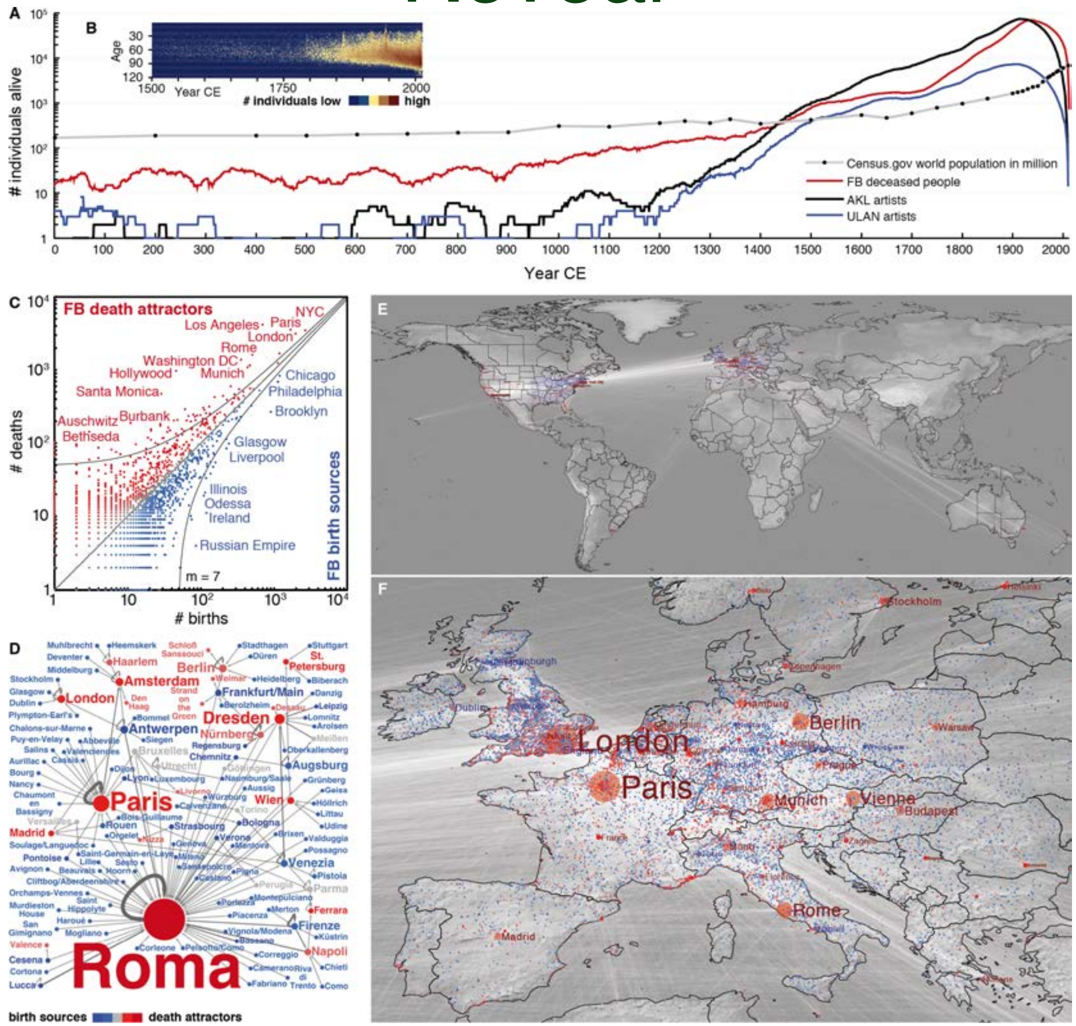
Global Knowledge Production and Consumption



Measuring Physics Memes

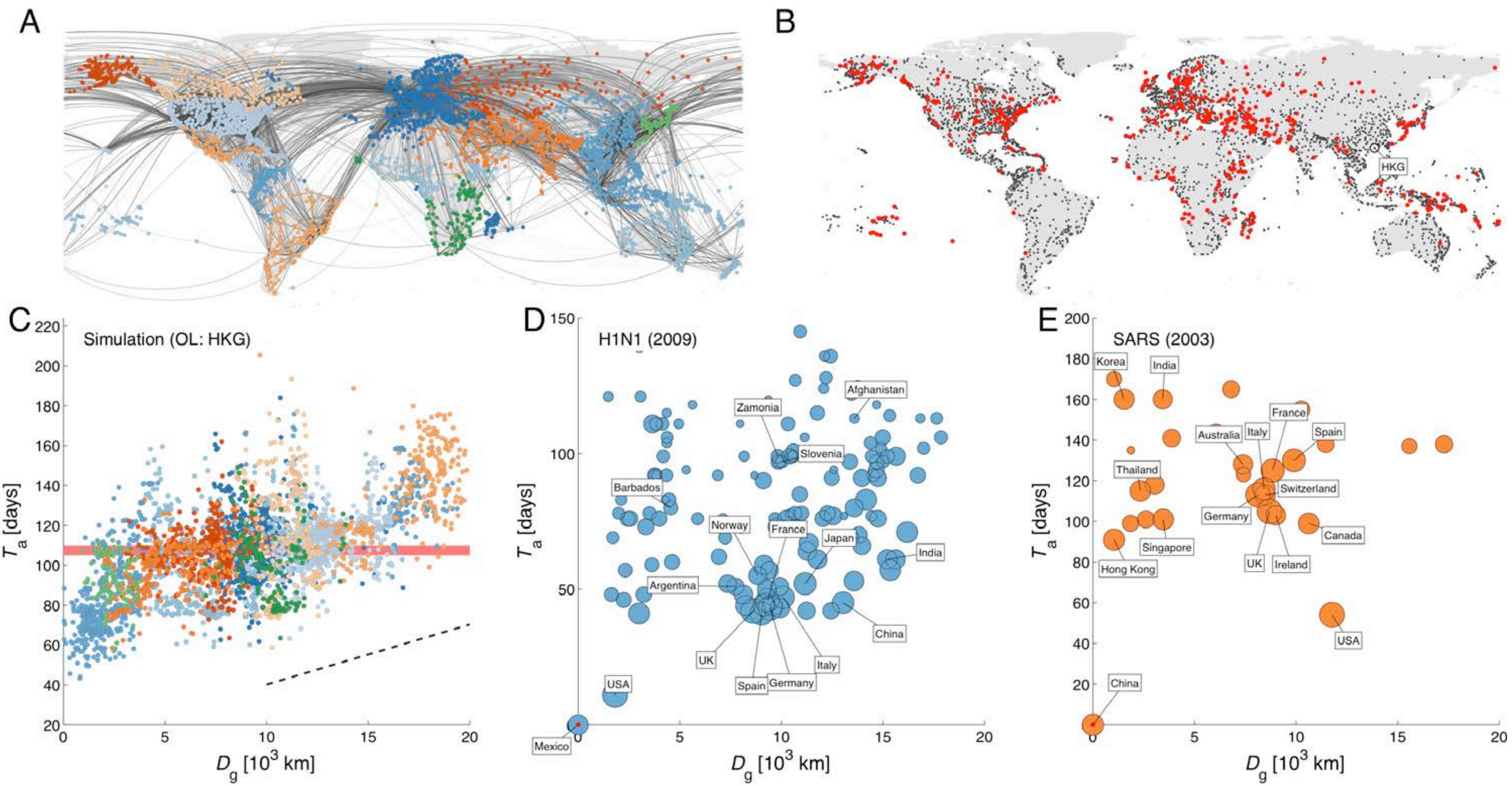


Cultural Science – What Birth and Death Data Reveal



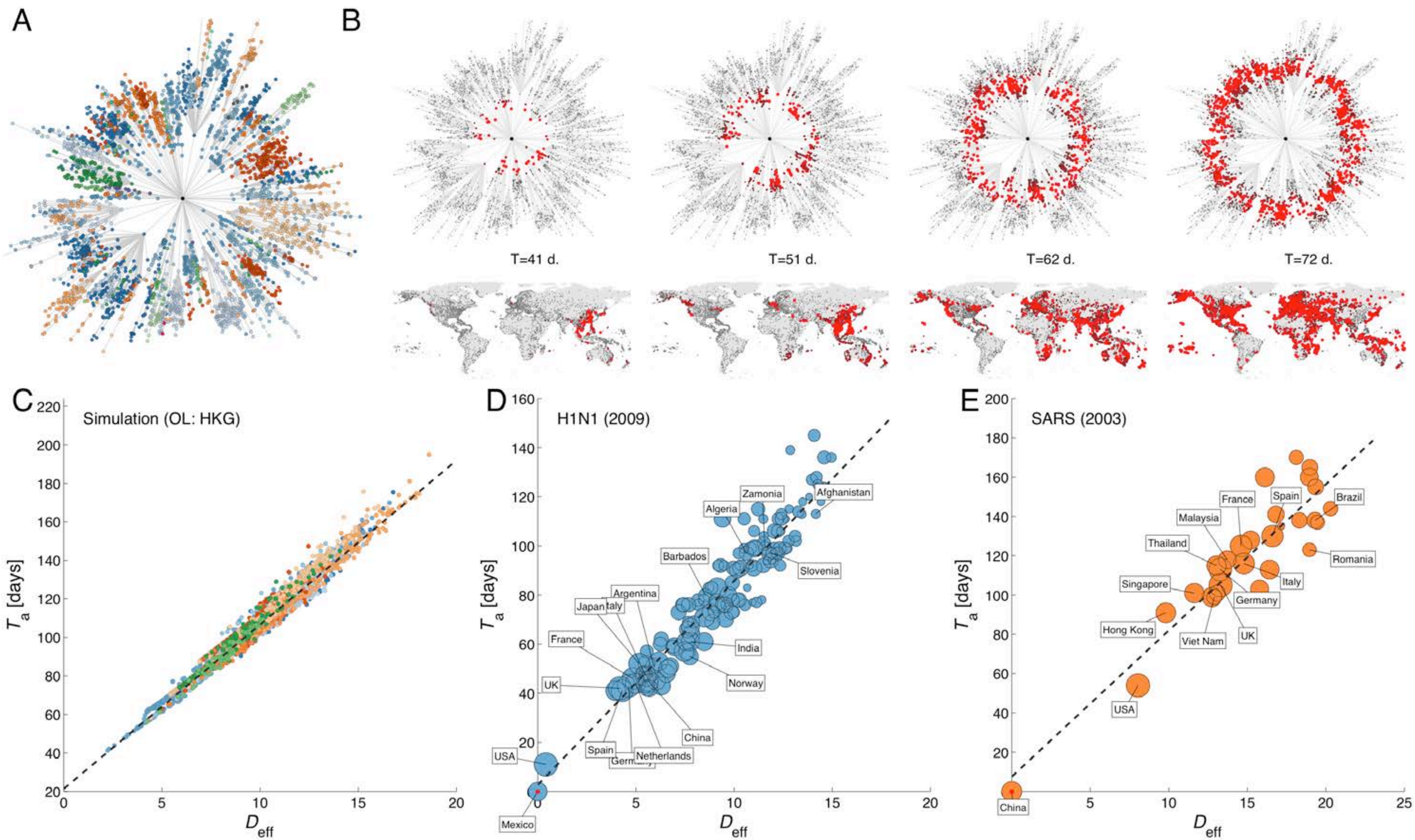
M. Schich, C. Song, Y.-Y. Ahn, A. Mirsky, M. Martino, A.L. Barabasi, DH, Science (2014)

Complexity of Epidemic Spreading



Dirk Brockmann and DH, Science (2013)

Predictability of Epidemic Spreading



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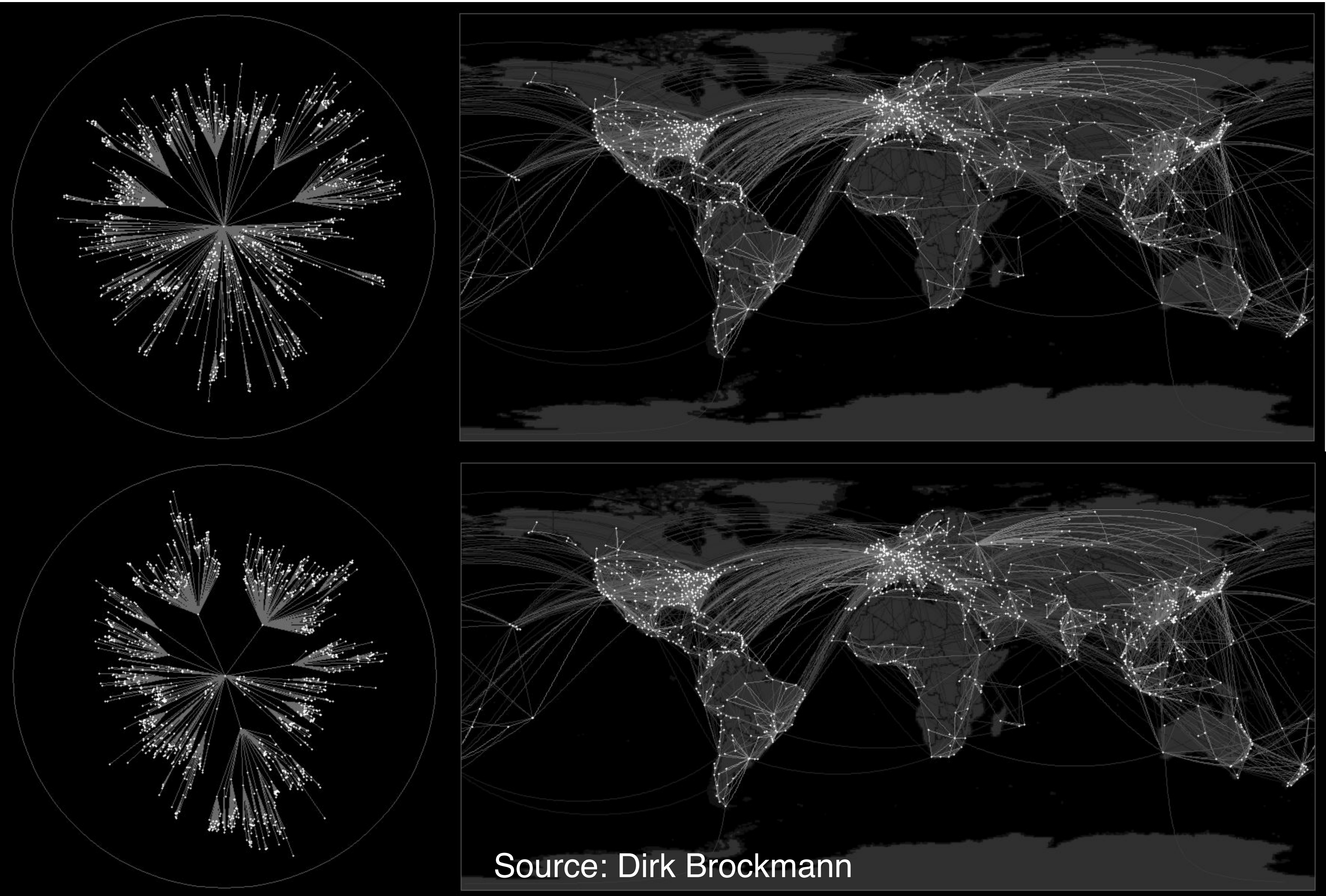
Epidemic Spreading



Source: Dirk Brockmann

Countering Pandemics

Dirk Helbing (ETH Zurich)

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