CCSS
COPING WITH CRISES
IN COMPLEX SOCIO-ECONOMIC SYSTEMS
A Competence Center of ETH Zurich

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

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

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ETH Foundation Zürich

Practical challenges

- Social and economic systems are rapidly changing, are in a *transformation process*, not in equilibrium
- Science is not well enough prepared to address the *increasing number of socio-economic problems*
- How to *close the gap* between existing socio-economic problems and solutions, and how to come up with solutions *before* a problem occurs?
- How can social scientists better support politicians and business people in addressing practical problems?
- Traditional publication procedures are too slow, give too little freedom for new concepts, ideas, and methods

Fundamental theoretical challenges

- Lack of realistic, powerful, consistent theories
- The vast body of literature is for socio-economic systems in a stationary or equilibrium state. Existing dynamical theories are not advanced enough to address many of today's problems
- Insufficient consideration of space-dependence, non-linearity, stochasticity, etc. leads to models that do not reflect reality well
- Assuming *homo economicus* (a strictly profit maximizing behavior with infinite memory and computational capabilities) has lead to an economic theory that often fails to reproduce observations
- How to get the data required to develop better theories?

What makes theory construction difficult

- The situation is less desperate than social scientists tend to believe, but more difficult than natural scientists usually think
- Some challenges for the construction of theories 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.
- Furthermore, heterogeneity (due to individuality, social difference and specialization), and the fact that the observer participates and modifies social reality, imply additional difficulties.

Empirical challenges

- Lack of close relationship between theory construction and empirical and experimental work
- How to get access to data (e.g. consumer behavior data) for science?
- How to extract laws of social behavior from data, e.g. from social networking platforms (Web2.0)? Data-driven approach is missing
- How to obtain the data required for systematic theory construction (data of individual behavior in dependence of social context in the course of time)?
- How to take into account privacy concerns?
- Confidentiality of crises and disaster management studies and of commercially applicable results obstructs scientific progress

Challenges of interdisciplinary collaboration

- Weak interdisciplinary networking, few interdisciplinary projects
- Lack of appropriate funding and project review procedures
- No commonly agreed standards, what is “good“ social science and what is not
- Social science education in computer science, mathematical modeling, and complexity science missing
- Fewer career opportunities
- Lack of interdisciplinary high-impact journals

Our goals

- Better, *quantitative understanding* of complex socio-economic systems
- Inclusion and study of *systemic risks*
- *Assessment of alternative scenarios*, provision of advise
- *Fusion of approaches* from the science of complex systems, statistical physics, and network science with traditional approaches in the social sciences
- *Innovation at the interface* between the social and natural sciences and engineering

Example: Critical phenomena, bifurcations...

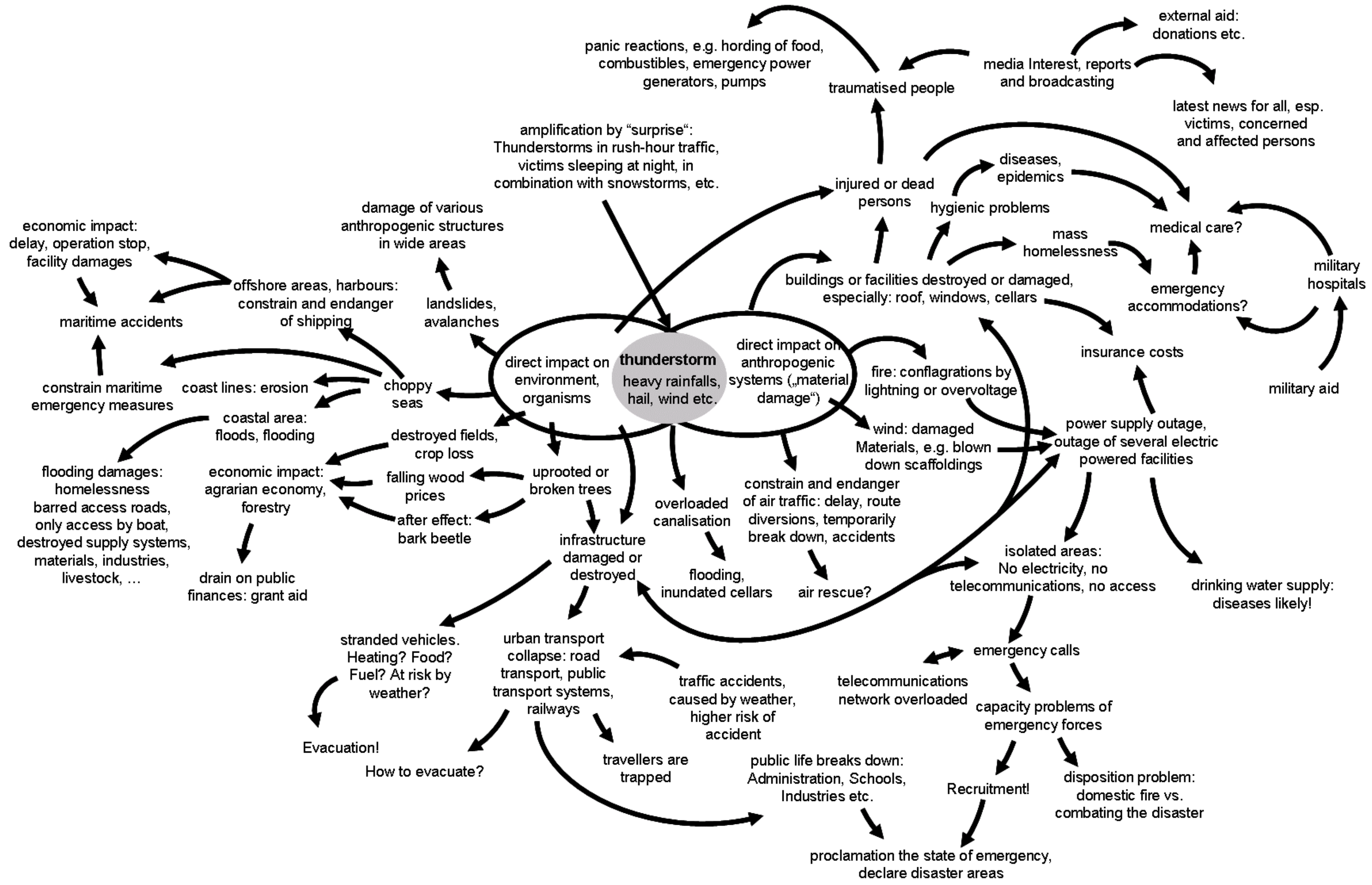
- Natural sciences have gained a good understanding of *non-equilibrium and critical phenomena*. Often characterized by *fat-tail*/power law rather than normal *distributions*, i.e. *extreme events* are more frequent than expected

- Examples are *stock markets, wars and conflicts, cascading failures related with disasters, traffic jams in urban environments, turbulence during crowd disasters* ("panic stampedes")

- Supplementary concepts: Bifurcations, non-linear dynamics...

Cascading effects

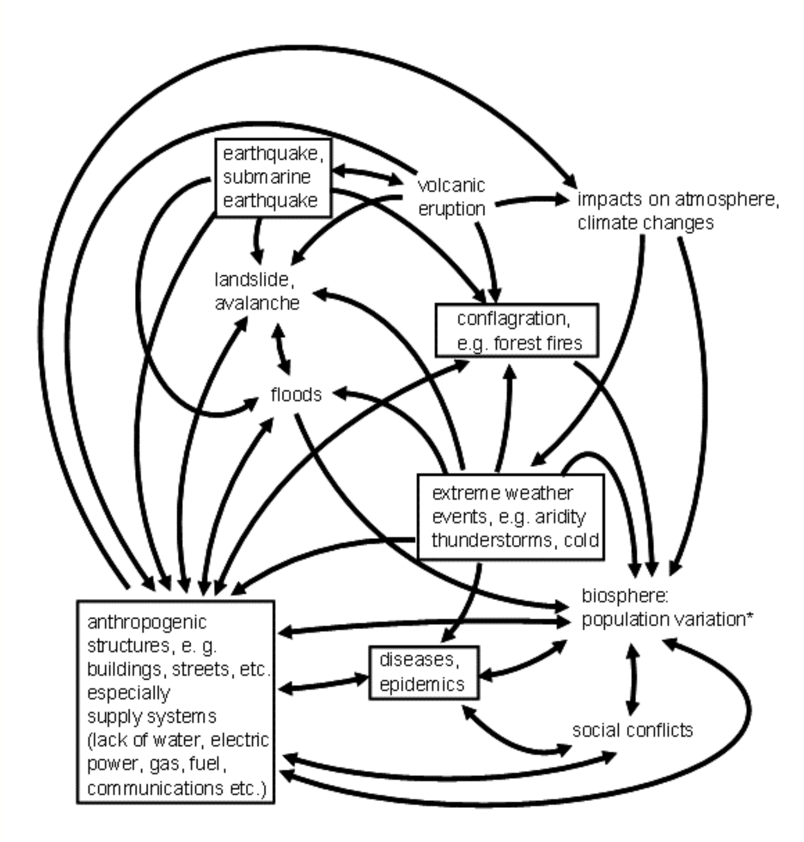
Causality network for thunderstorms



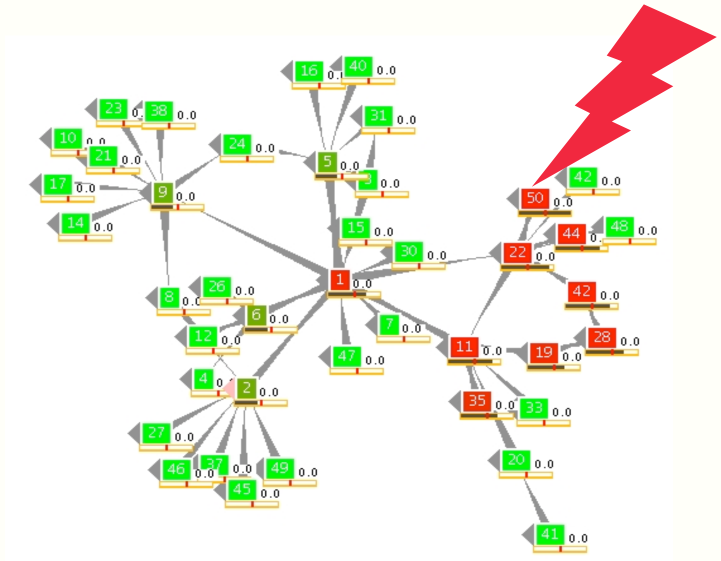
Modeling and simulation of disaster spreading

Every sector in a network consists of special elements, which can be damaged or destroyed by a causing event. We analyze all involved sectors (agriculture, mining, ..., households) and their interactions.

Disasters cause disasters



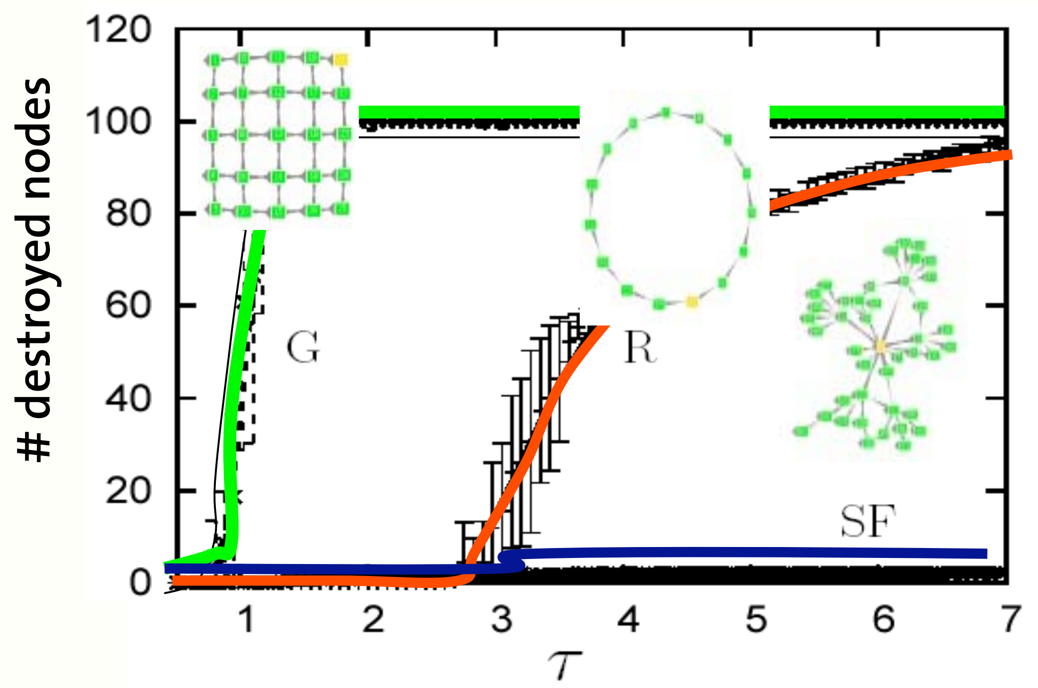
Mathematical model



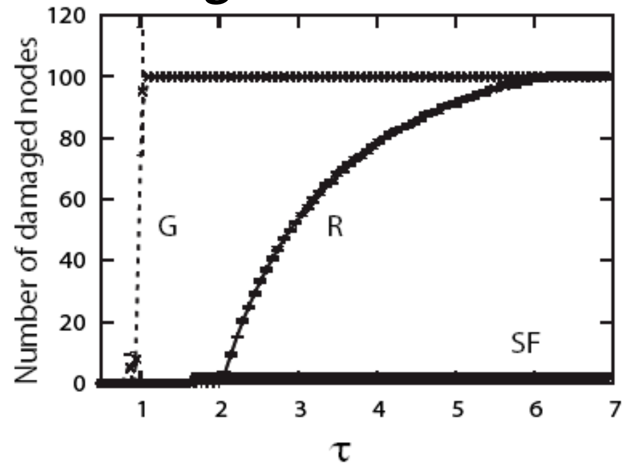
$$\frac{dx_i}{dt} = -\frac{x_i}{\tau} + \Theta\left(\sum_{j\neq i} \frac{M_{ij}x_j(t-t_{ij})}{f(O_i)} e^{-\beta t_{ij}/\tau}\right) + \xi_i(t)$$

Network-dependence of spreading dynamics

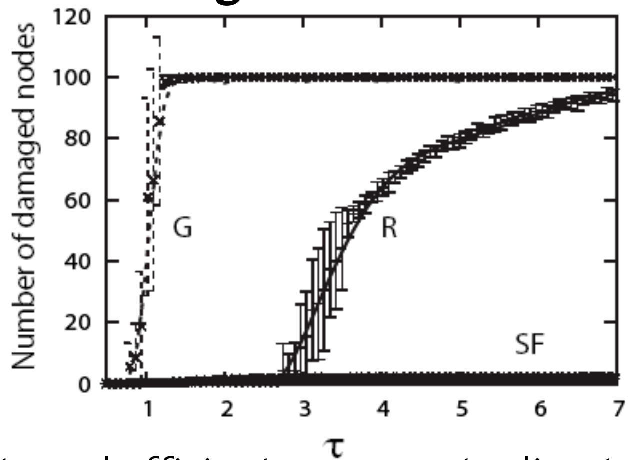
Example: 100 nodes, average state after t=300



Homogeneous network



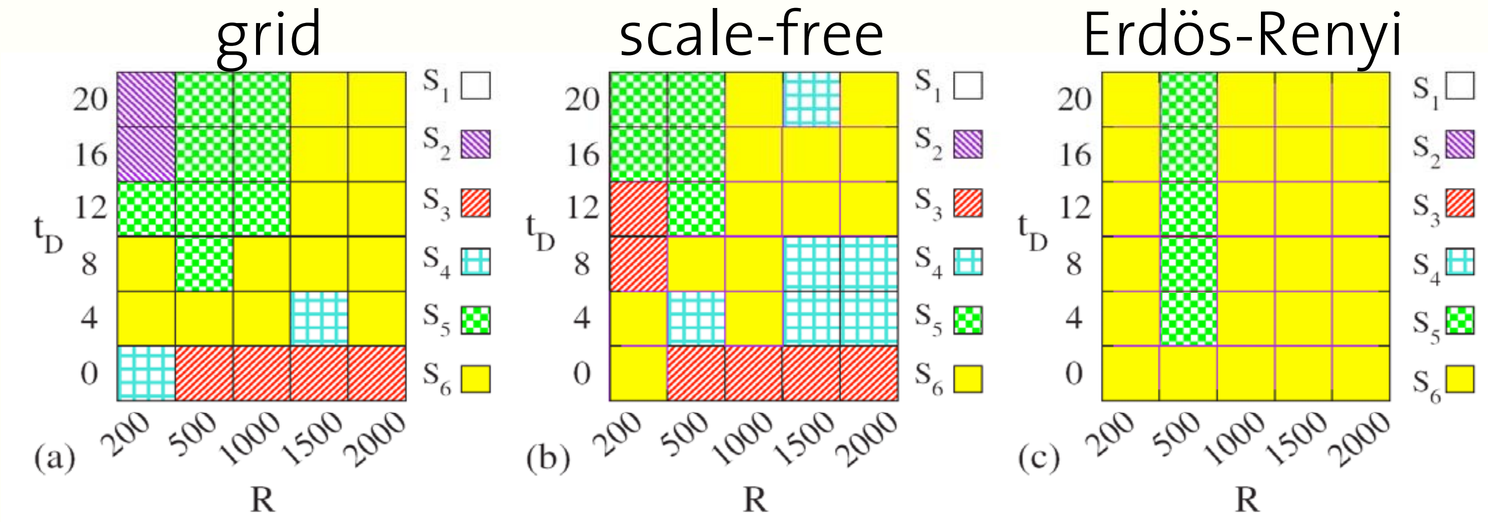
Heterogeneous network



➡ We find a topology-dependent „velocity“ of failure propagation.
Spreading in scale-free networks is slow.

K. Peters, L. Buzna, D. Helbing: Modelling of cascading effects and efficient response to disaster spreading in complex networks, *International Journal of Critical Infrastructures* **4**, 46-62 (2008).

Most efficient disaster response strategies



There is no unique optimal response strategy:

1. Strategies based on the network structure are most suitable for scale-free networks.
2. Strategies based on the damage information are more appropriate for regular networks such as grids.
3. Dependence on delay time t_D for Erdös-Rényi and small-world networks (short t_D => damage-based strategies) (large t_D => network structure-based strategies)

The potential of joining forces

- We can *bring together Natural Sciences and Engineering with Sociology and Economics*
- We *share interests*, tools and concepts, work on *complementary subjects*
- Opportunity at ETHZ is unique, any support will have multiple impact due to network effects, feedback cycles, ...
- ETH Zurich could trigger a new trend Europe- and world-wide
- *Early interaction with engineers* to design better, socially favorable technologies, or anticipate problems of new technologies
- Anticipation of potential socio-economic crises resulting from technological and other changes

Instruments to make a difference

- Commonly supervised PhD projects
- *PhD Course Program* on Complex Systems (start with a PhD and postdoc seminar)
- Invitation of *visiting scientists*
- International attraction of the best *PhDs and postdocs*
- International *Workshops*, with Think Tanks and Tutorials
- *Observatory of crises*, data repository, provision of computer codes
- Information portal, *LivingScience*, and *QScience publication platform*
- *ETH Zurich happens to have a critical mass of people* to initiate a change

Some common projects to start with

- ## Crises in markets

  Why do markets crash? Can we design markets such that bubbles and crashes do not happen? Under which conditions does the global network of firms and banks either stabilize markets or imply a higher risk of the global spread of local crisis? In the presence of increasing globalization, financial engineering innovations, and disintermediation due to the Internet, are the financial and credit markets becoming more stable or unstable?

- ## Crises in societal infrastructures

  What does congestion spreading have in common with cascading disaster spreading? How can one characterize the breakdown dynamics of traffic flows in urban networks? Why does the traffic situation vary largely from one day to another? How vulnerable is the critical infrastructure "transportation network"? How does the sensitivity of traffic flows to local perturbations (such as accidents) depend on the network topology? What is the interplay between topology and dynamics?

- ## Conflict-generated crises

  Why do wars and other conflicts break out and why do they persist? Are there specific causal mechanisms driving conflicts of different types, such as interstate and civil wars? What political institutions are likely to reduce conflict? What can be done to predict conflict outbreaks?

Kay Axhausen

- Professor of Transport Planning (Institute for Transport Planning and Systems of the Department of Civil, Environmental and Geomatic Engineering)
- Before: Chair of the International Association of Travel Behaviour Research (IATBR) until December 2005, Leopold-Franzens Universität, Innsbruck, Imperial College London and the University of Oxford.
- Earned PhD in Civil Engineering at the University of Karlsruhe and an MSc from the University of Wisconsin - Madison

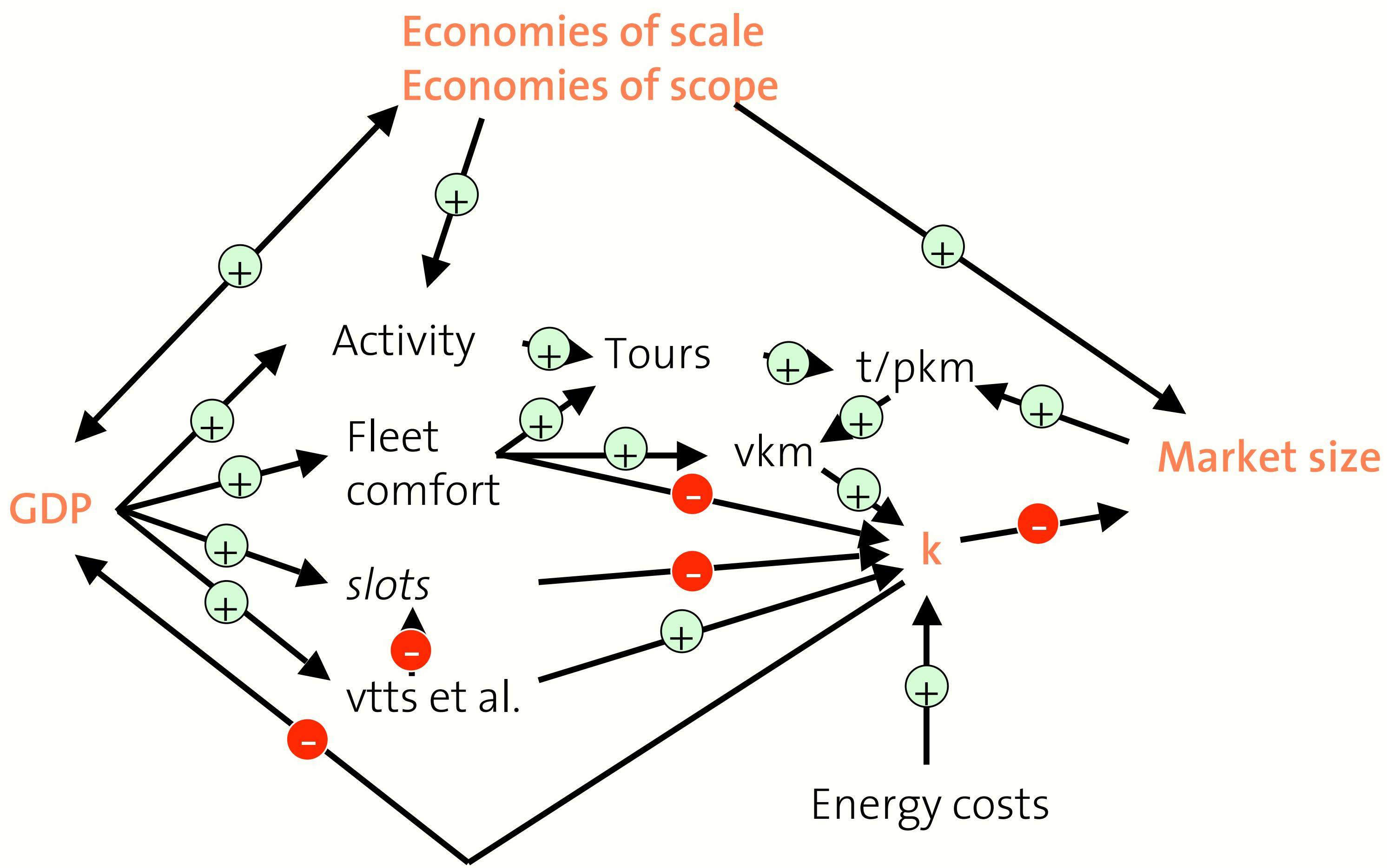
- **Research interest:** Measurement and modeling of travel behavior, microsimulation of daily travel behavior, valuation of travel time and its components, long-term mobility choices and the response of the land-use system to those choices, supported by analyses of human activity spaces and their dependence on the traveller's personal social network

Transport Systems and Daily Life

Kay Axhausen

Transport Planning and Systems (IVT)

The subsystem: A conceptual model



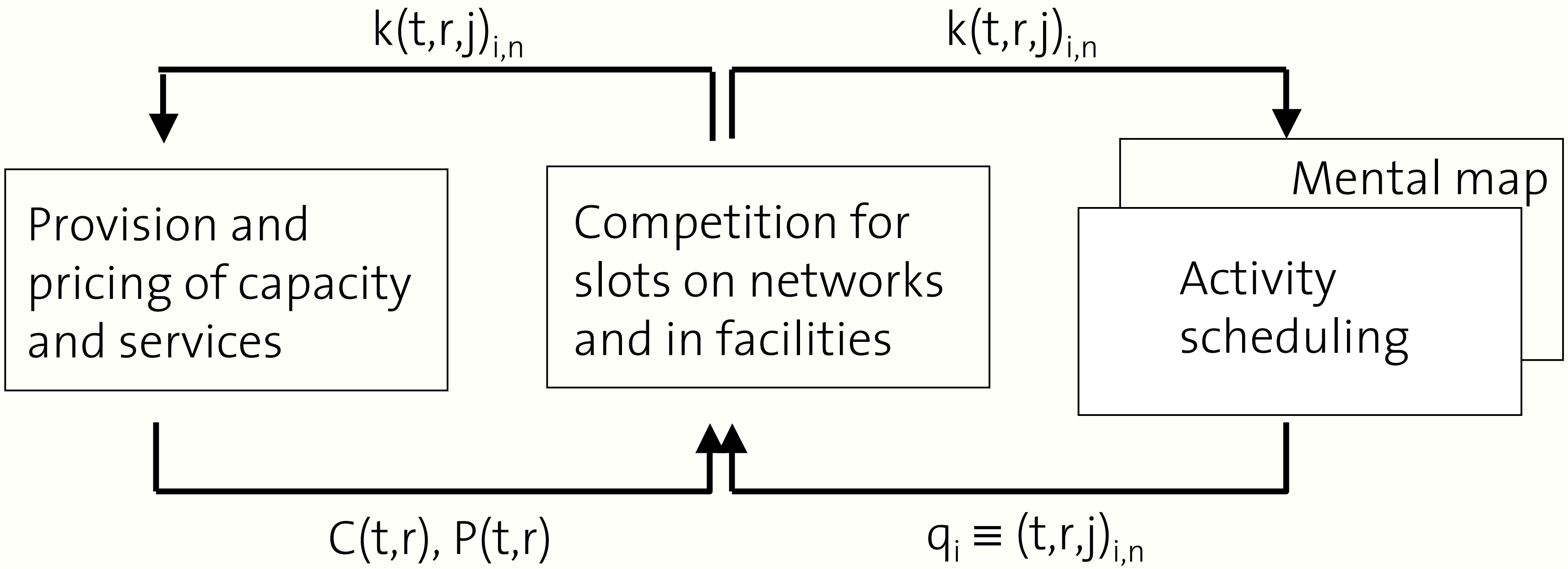
+ Elasticity > 0
– Elasticity < 0

Slots: possibilities to move goods or people
For a given infrastructure and commercial and private fleet

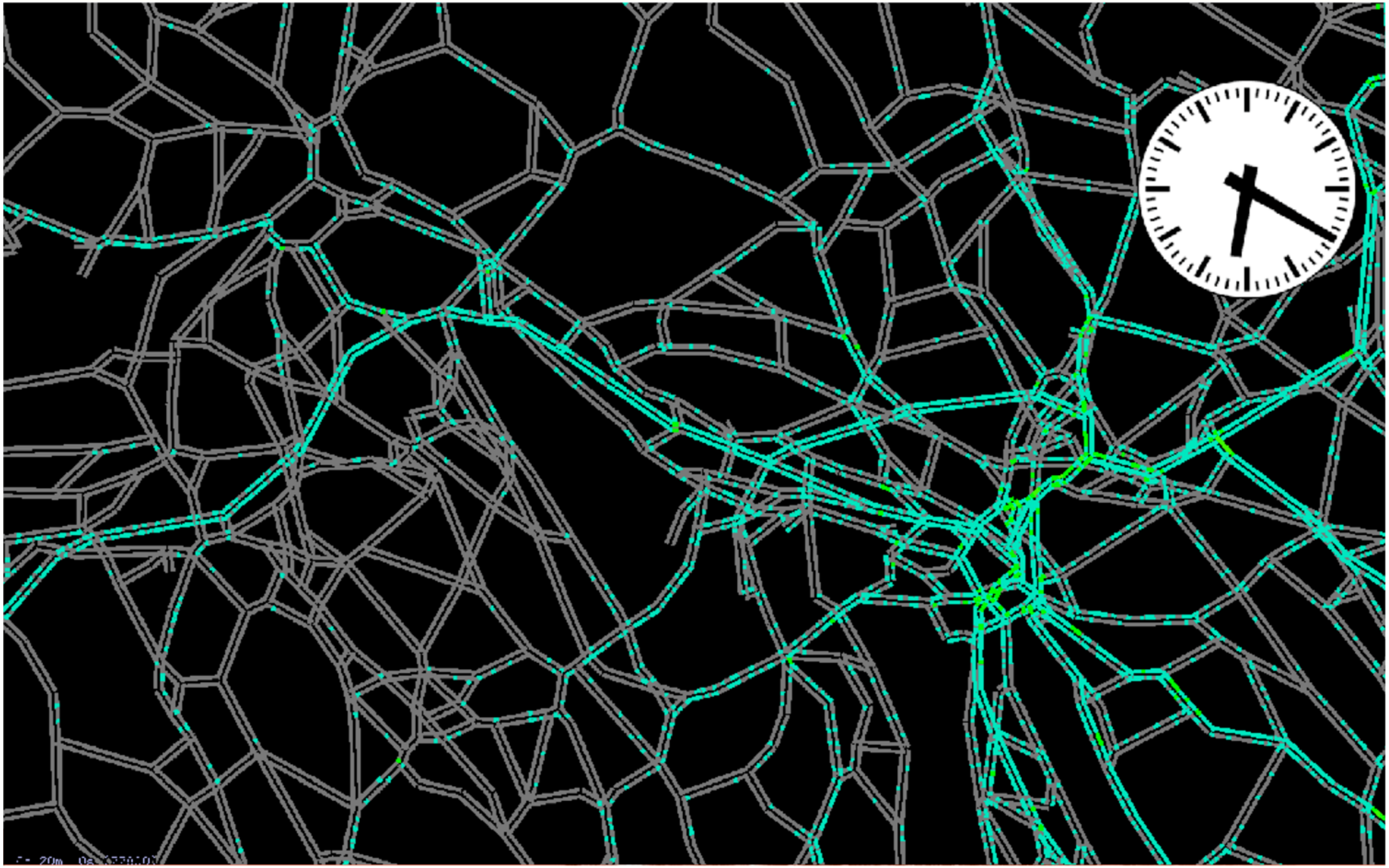
Degrees of freedom

	System	Person
Long term	slots	Home/work location
	Regulation	Car ownership
		Social networks
Medium term	Services offered	Season tickets
	Prices	
	Awareness	
Short term	Operation	**Daily schedule**

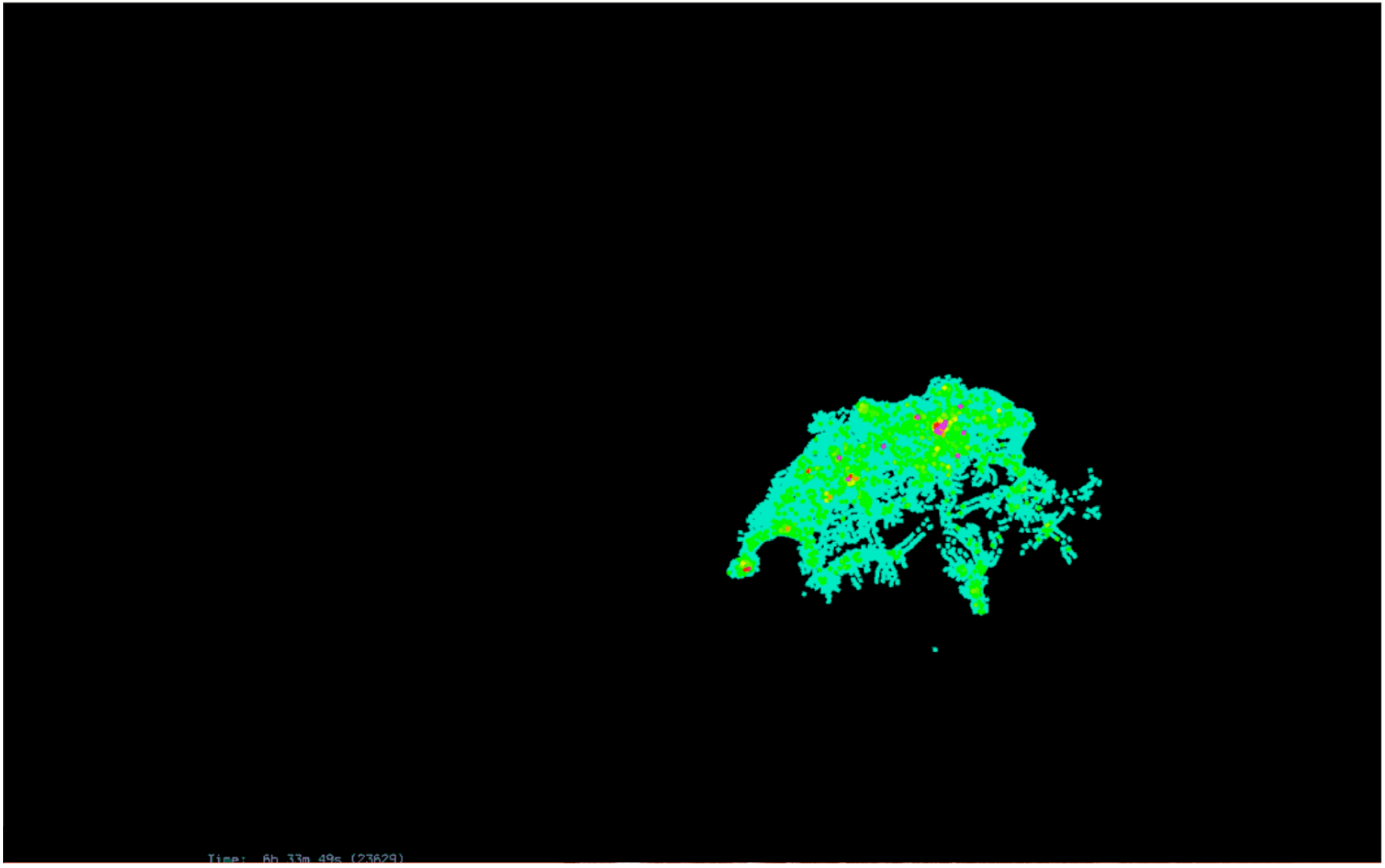
Modeling the transport/land use system



A peak hour



Zooming in



Didier Sornette

- Chair of Entrepreneurial Risks at the Department of Management, Technology, and Economics at ETH Zurich since March 2006.
- Member of the Swiss Finance Institute since 2007 and Adjunct Professor of Geophysics at IGPP and ESS at UCLA.
- Previously jointly a Professor of Geophysics at UCLA, Los Angeles California and a Research Director on the theory and prediction of complex systems at the National Center for Scientific Research in France
- Research Director in the X-RS R&D Company in Orsay, France (1988-1995), Scientific advisor of the Technical Director of Thomson-Marconi Sonar Company (now THALES) in Nice-Sophia Antipolis Technopolis, France (1984-1996) and consultant for numerous companies.
- **Research interests:** Prediction of crises and extreme events in complex systems (with applications to finance, economics, marketing, earthquakes, rupture, biology, medicine); Finance and economics: bubbles and crashes, large risks, theory of derivatives, portfolio optimization, trading strategies, insurance, macro-economics, agent-based models, market microstructures.

Crises in Markets

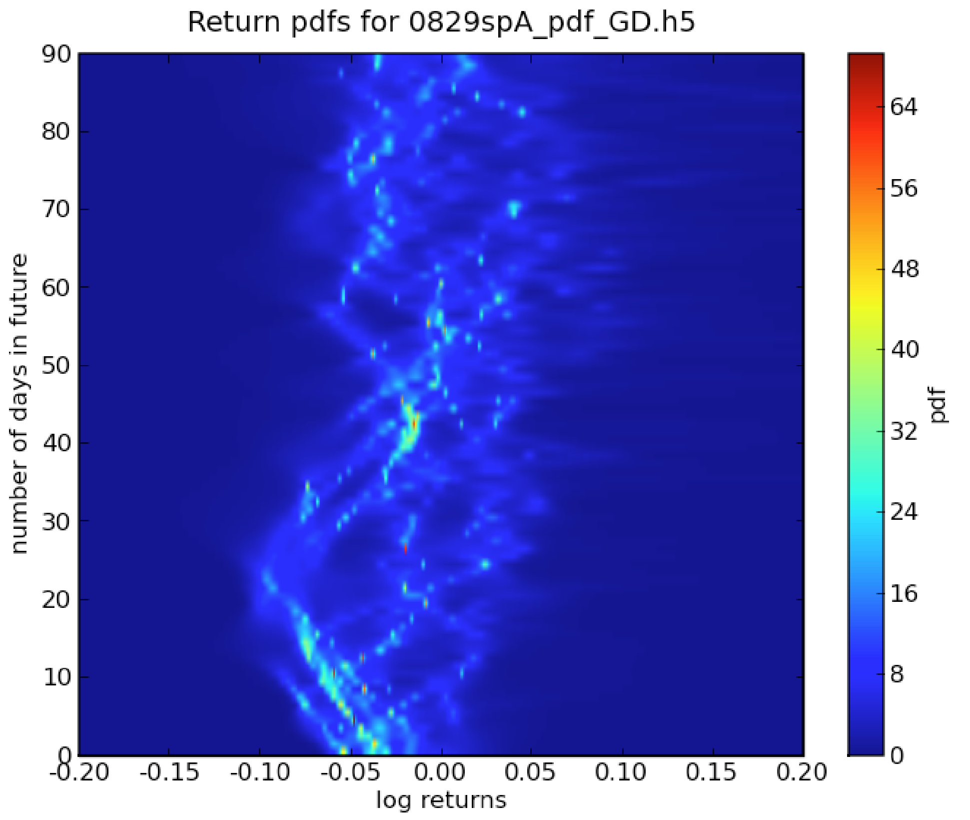
Didier Sornette

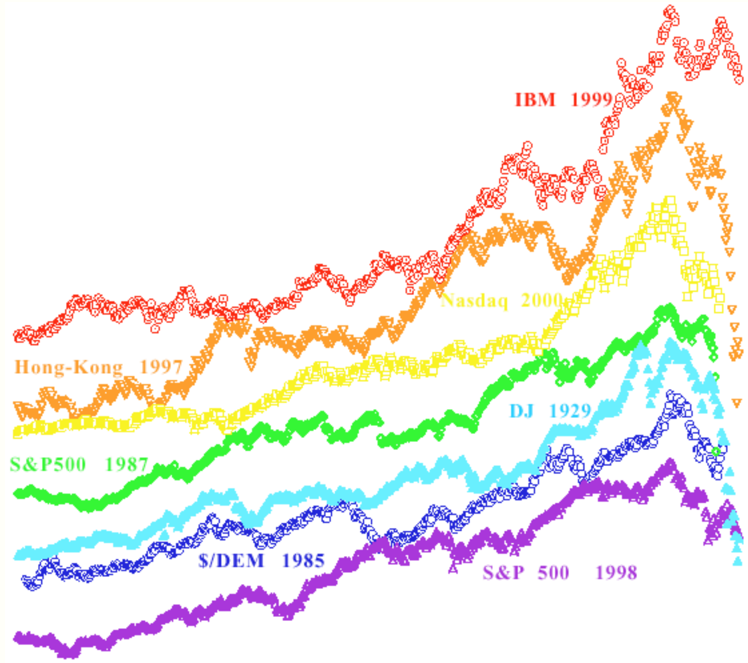
Chair of Entrepreneurial Risks

Crises in markets

- Models and analysis of bubbles
- Models of crises on networks, controlling systemic risk
- Agent-based models of cascading crises and network effect
- Precursors, prediction and validation

Financial crisis observatory



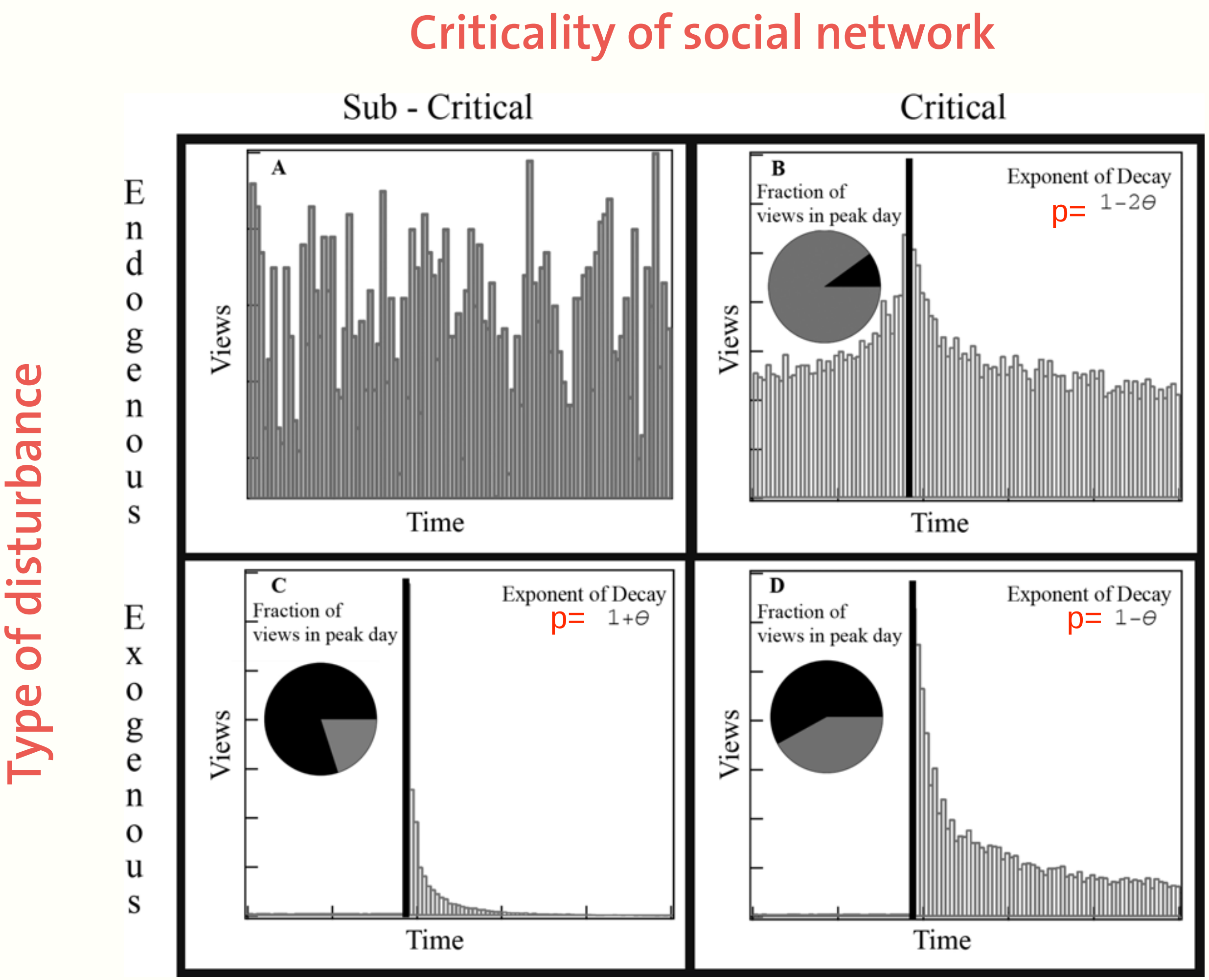


Predictions

Bubbles

(R. Woodard, W.-X. Zhou, W. Yan and D. Sornette, 2008)

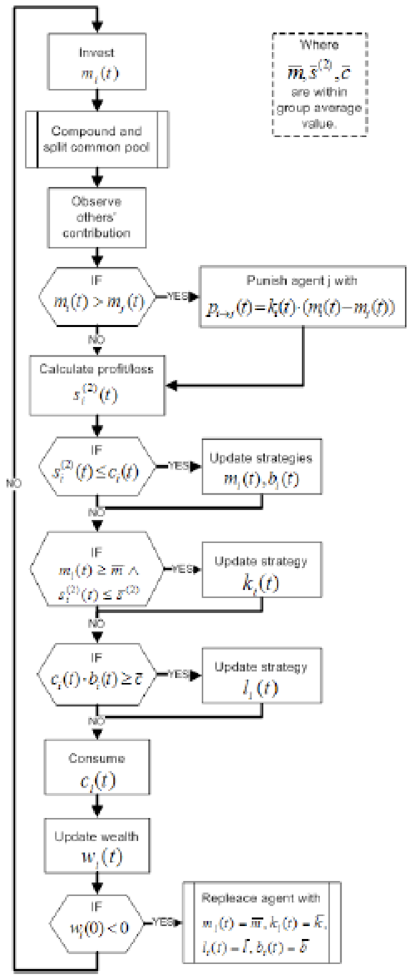
Dynamics and prediction of success



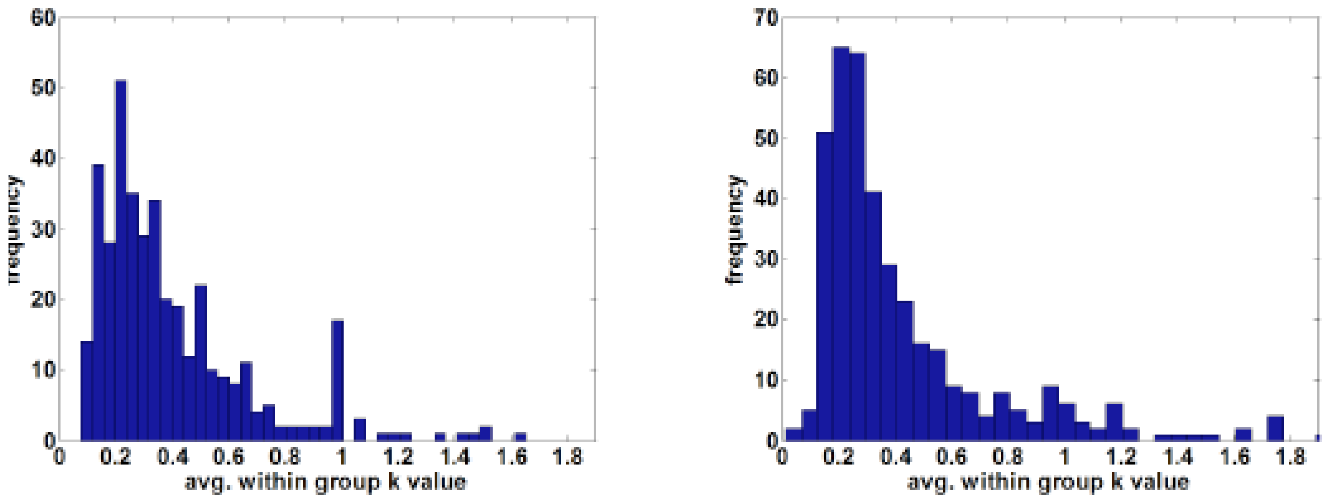
(R. Crane and D. Sornette, 2008)

Human cooperation for sustainability

(why punishment is not the panacea)



Average propensity to punish in public good games



(a) empirical data (b) simulation

(M. Hetzer and D. Sornette, 2008)

Frank Schweitzer

- Professor for Systems Design at the Department of Management, Technology, and Economics at ETH Zurich since 2004. Associated member of the Department of Physics at the ETH Zurich (D-PHYS).
- Worked for different research institutions (Max-Planck Institute for the Physics of Complex Systems, Dresden, Fraunhofer Institute for Autonomous Intelligent Systems, Sankt Augustin) and universities (Humboldt University Berlin, Cornell University Ithaca NY, Emory University, Atlanta GA).
- Received first Ph.D. (Dr. rer. nat.) in theoretical physics and his second Ph.D. (Dr. phil.) in philosophy of science, further earned a habilitation/Venia Legendi in physics. Initiated and lead (2001-2005) the section of the German Physical Society (DPG) for the physics of socio-economic systems (AKSOE).
- **Research interests:** Applications of complex systems theory to the dynamics of social and economic organizations, including the development of formal concepts, quantitative modeling and computer simulations. Participating in European projects on "Measuring and Modelling Complex Networks Across Domains" and "Physics of Risk".

Systemic Risks in Financial Systems

Frank Schweitzer

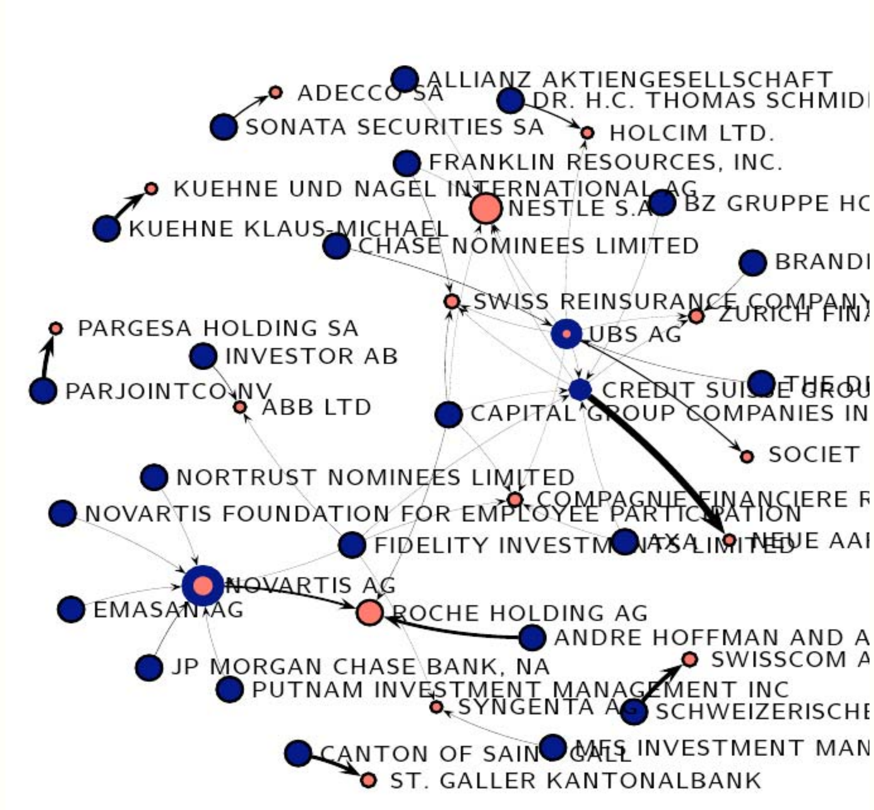
Chair of Systems Design

Problem

- Endogenous financial crises: *are not* well accounted for by *standard neoclassic economics.*
- Innovation of financial technologies: new sophisticated ways to diversify risk
- “Financial Institutions always find new ways to loose money”
- Debate about regulations to prevent crises

Approach

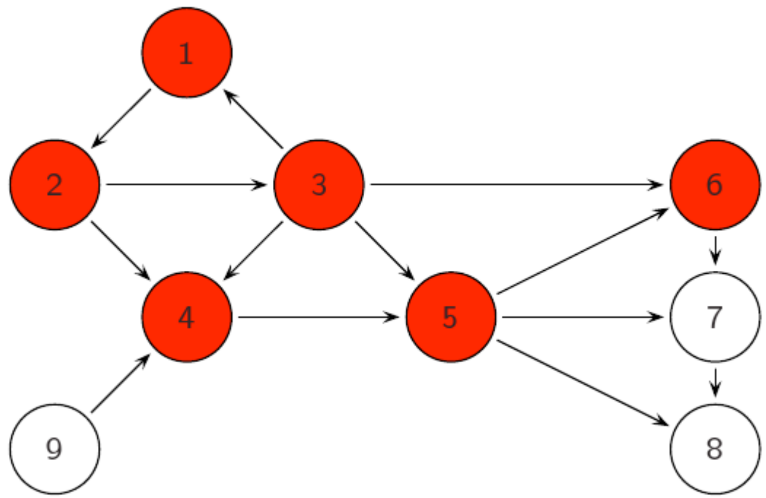
- The economy as a **network** of interdependent units
- Ties: *assets* and *liabilities*
- **Systemic Risk**: expected loss deriving from
  - **cascades** of many related failures
  - propagation of **financial distress**



Example: Ownership ties in the Swiss stock market

Financial contagion

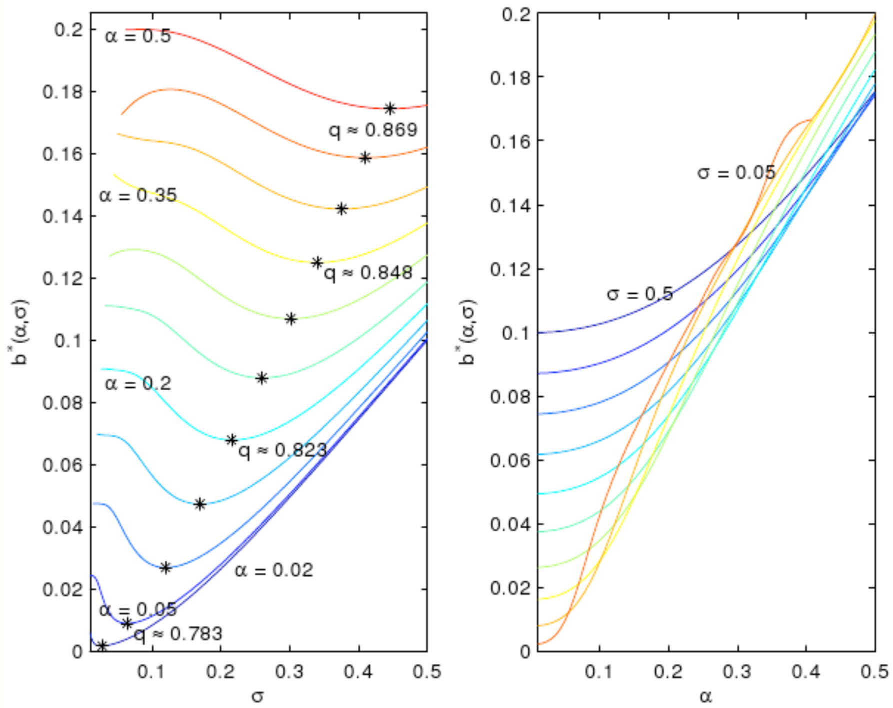
- Financial distress
  - propagates along dependency ties among firms/institutions (credit, supply, etc.)
  - Amplifies due to positive feedbacks (trend reinforcement)



L = liability ties
v = node value

Risk diversification

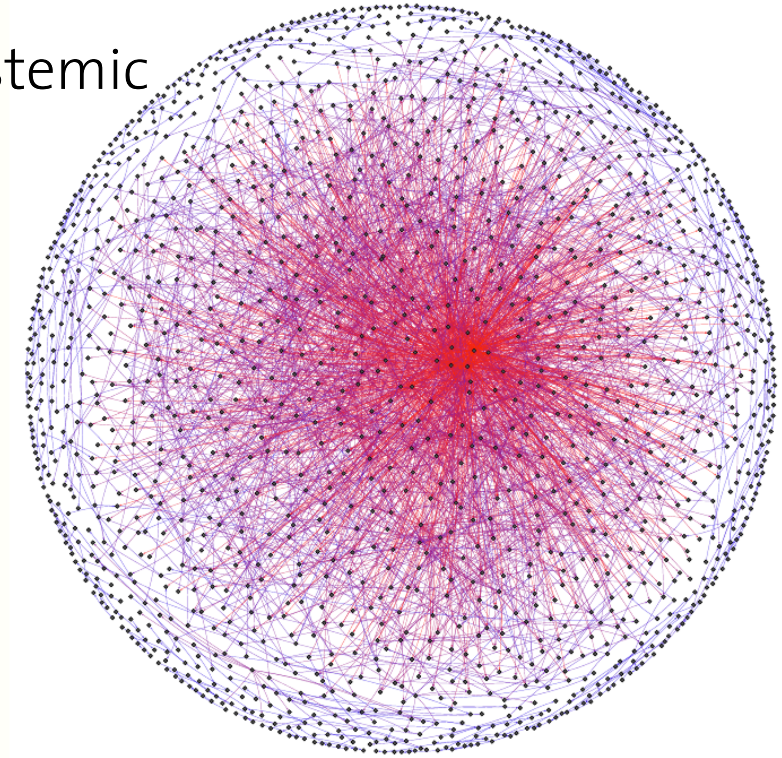
- Risk **diversification** is usually beneficial…
- …but in presence of **positive feedbacks** on financial distress can lead to **more severe** crises
- Theory of *networks* and *stochastic processes* helps us understanding why



Example of theoretical result: fraction of failures as function of control parameter

In a nutshell

- Further develop complex networks approach to systemic risk:
  - better understand
  - design of mitigation strategies



Hans Herrmann

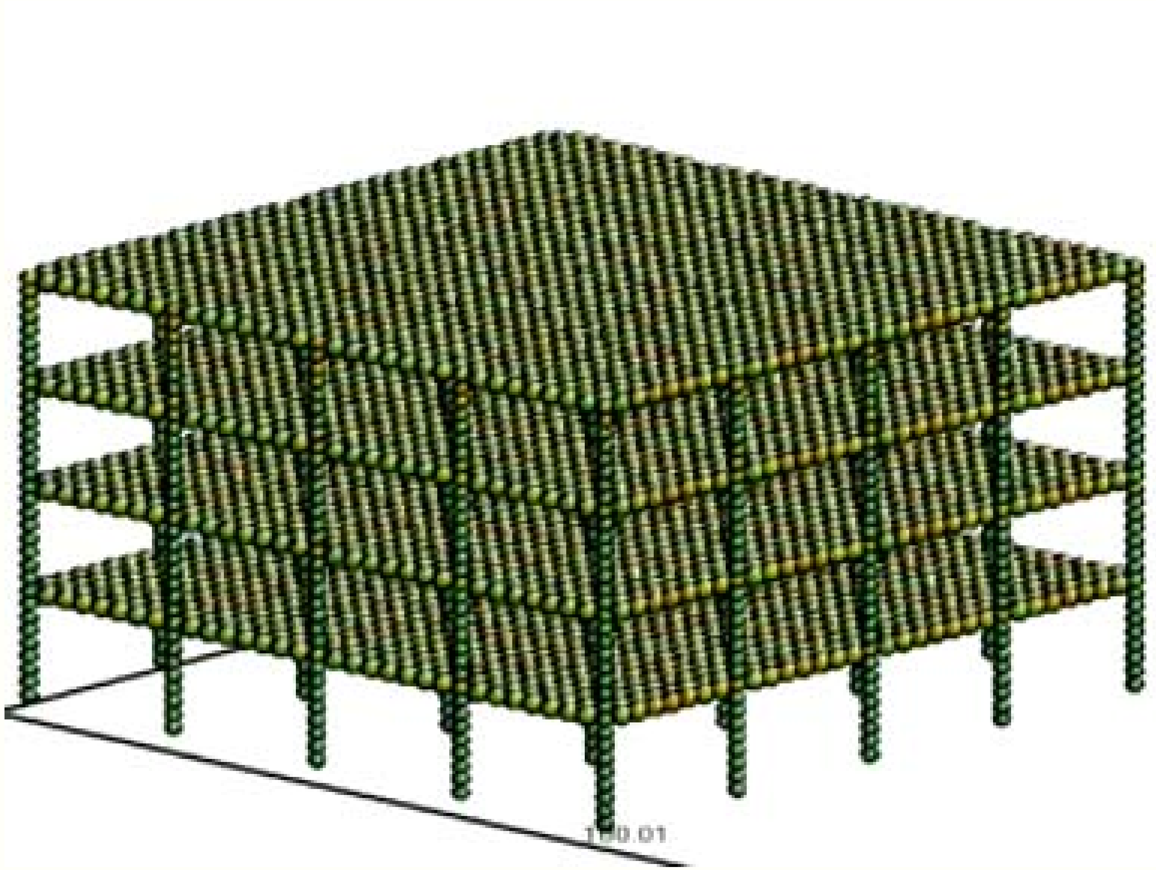
- Theoretical physicist and full professor at the Institute of Building Materials since April 2006.
- Studied physics in Göttingen and Cologne, PhD in 1981. Collaborator at the Service de Physique Théorique in Saclay. Became member of section 02 of the CNRS and is today Directeur de Recherche 1ère Cl. en mise à disponibilité.
- In 1990, head of the many-body group at HLRZ of KFA Jülich for four years. Then director of the PMMH of ESPCI, Paris for six years, also filled a chair. In 1996, named full professor and director of the Institute of Computer Physics at the University of Stuttgart. Guggenheim Fellow (1986), member of the Brazilian Academy of Science, Max-Planck prize recipient (2002) and won the 2005 Gentner-Kastler prize.
- **Research interests:** Construction of space-filling bearings and the establishment of equations of motion for dunes. Present research subjects include dense colloids, the formation of river deltas, quicksand, the failure of fibrous and polymeric composites and, in particular, complex social networks.

Networks, Collapse and Self-Organization

Hans Herrmann

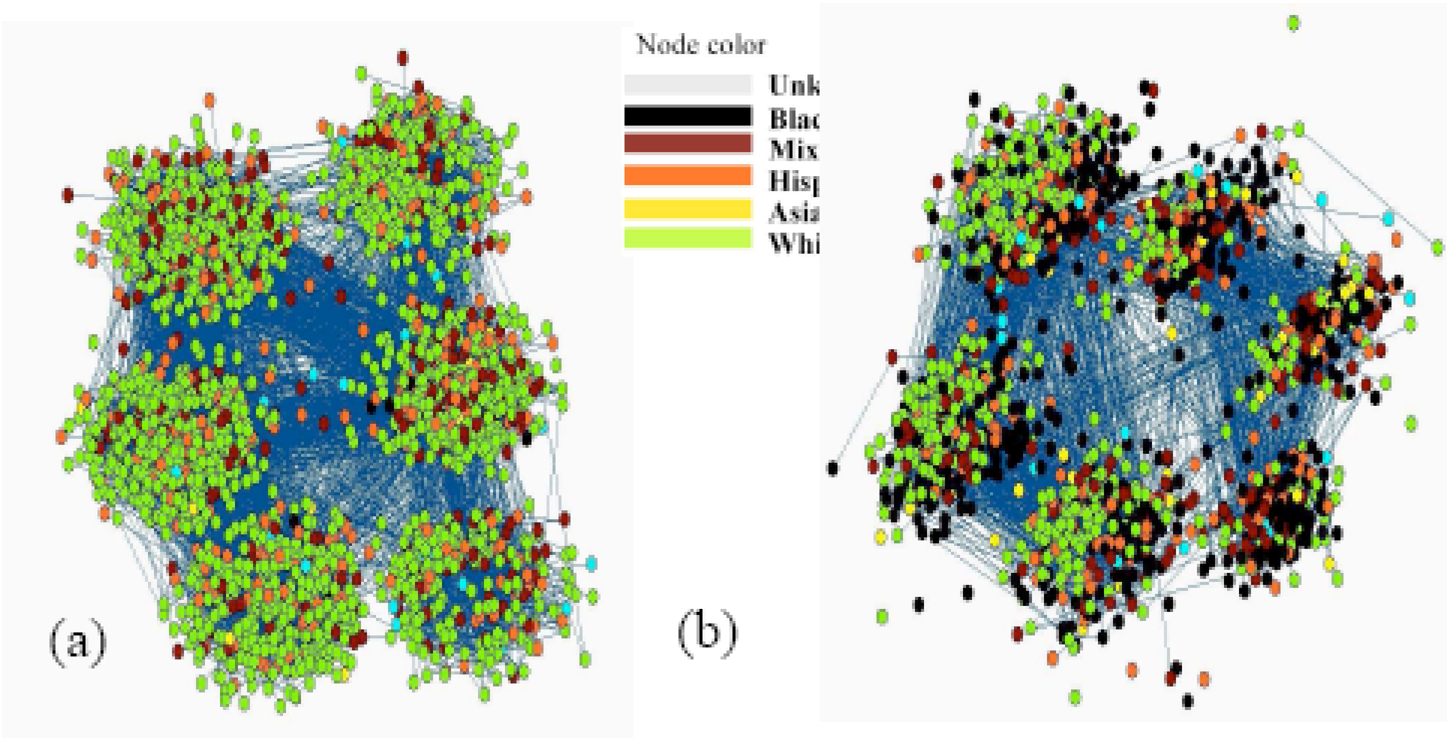
Computational Physics - IfB, DBAUG

Collapse of a building



Friendship networks in schools

Survey interviewing 90118 student from 84 schools in US



Visualization using „Pajec“

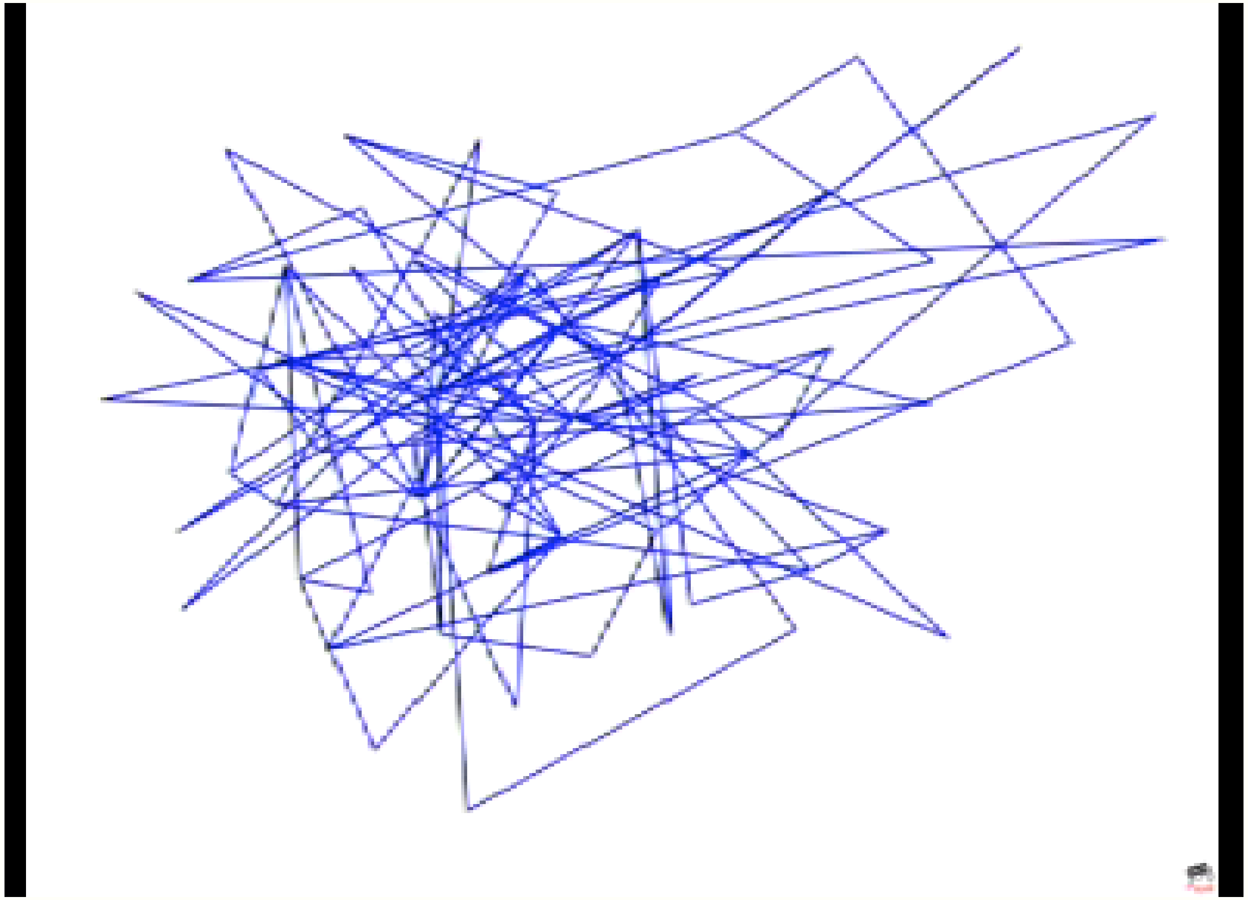
Other social networks

- WWW, Internet
- Collaborations (scientific, actors)
- Sexual contacts
- Criminal organizations
- Air flight connections
- Electrical power stations
- Logistics, assembly of products

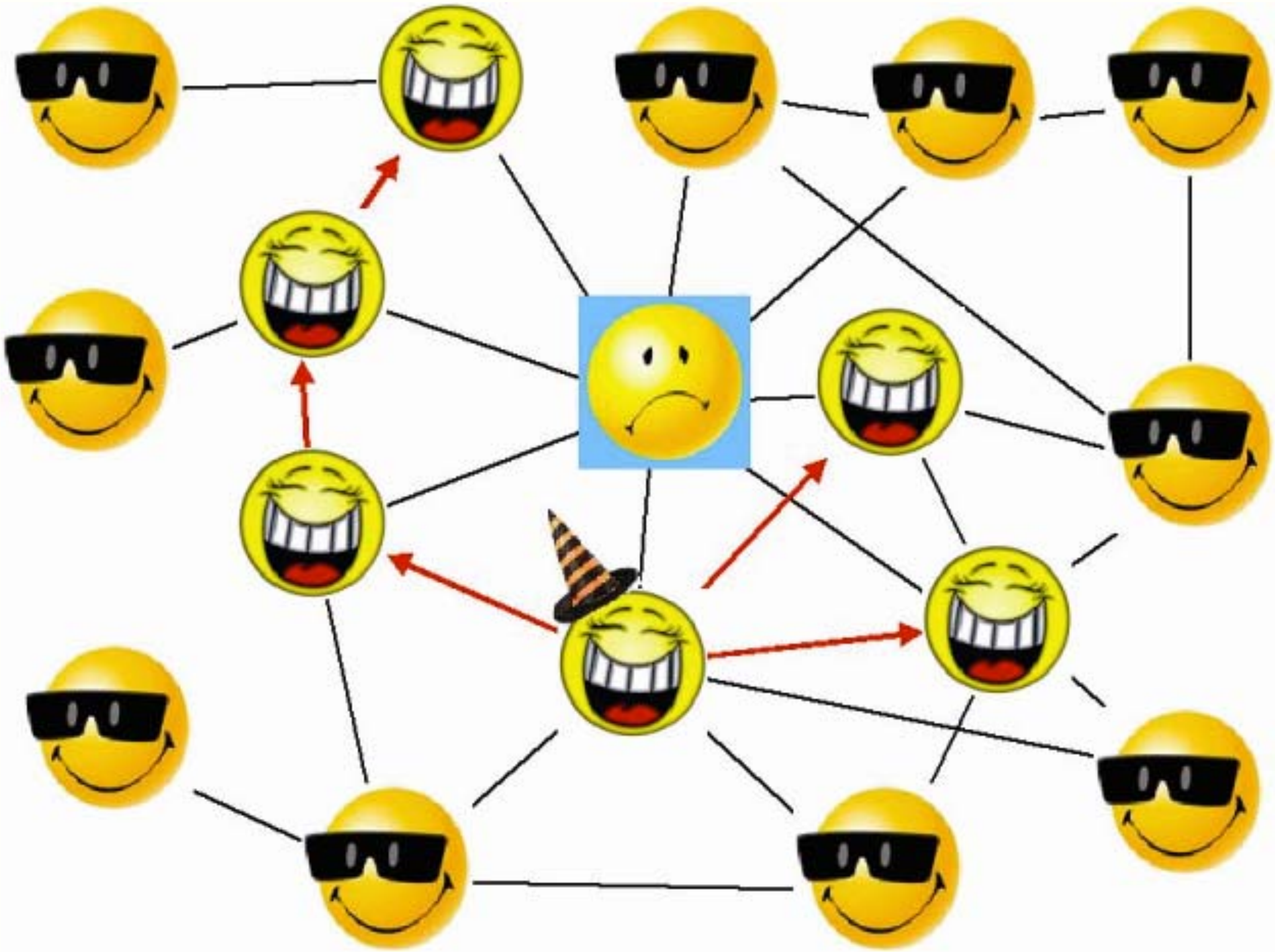
Optimization of networks against malicious attacks

- Why is it interesting?
  - We can retard a breakdown of the
    - Airline network in case of a strike
    - Internet in case of a hacker attack
- Malicious Attack
  - Attack the nodes with the highest connectivity
- Optimization Process
  - Rewire two edges randomly
  - Attack the network
  - If the robustness is improved, keep the network

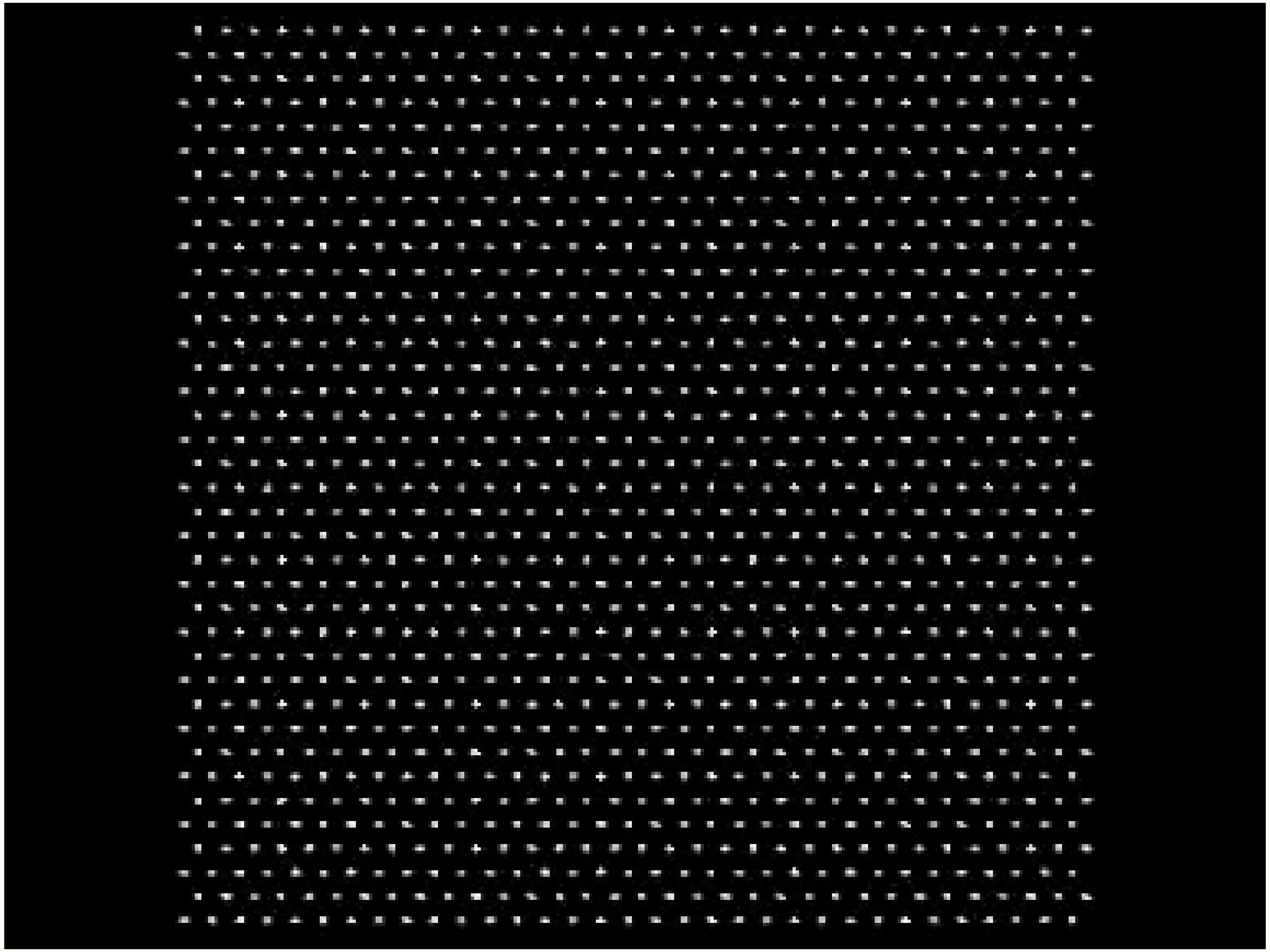
Optimizing networks



Gossip



Evolution of networks with life-times



Lars-Erik Cederman

- Chair of International Conflict Research at the Center of Comparative and International Studies at ETH Zurich since May 2003
- Previously Associate Frederick S. Danziger Associate Professor of Government at Harvard University, Assistant Professor of Political Science at University of California at Los Angeles and University Lecturer at Oxford University
- Graduated from Uppsala University with a M.Sci. in Engineering Physics (1983-1988), followed by a Diplôme d'Etudes Supérieurs at the Graduate Institute of International Studies, Geneva (1988-1990) and a PhD in Political Science at the University of Michigan, Ann Arbor (1990-1994)
- **Research interests** include the causes of civil and international wars in the context of macro-historical processes such as state formation, nationalism and democratization. To trace such transformations, he relies on agent-based modeling, geographic information systems, statistical and qualitative analysis

Modeling Armed Conflict

Lars-Erik Cederman

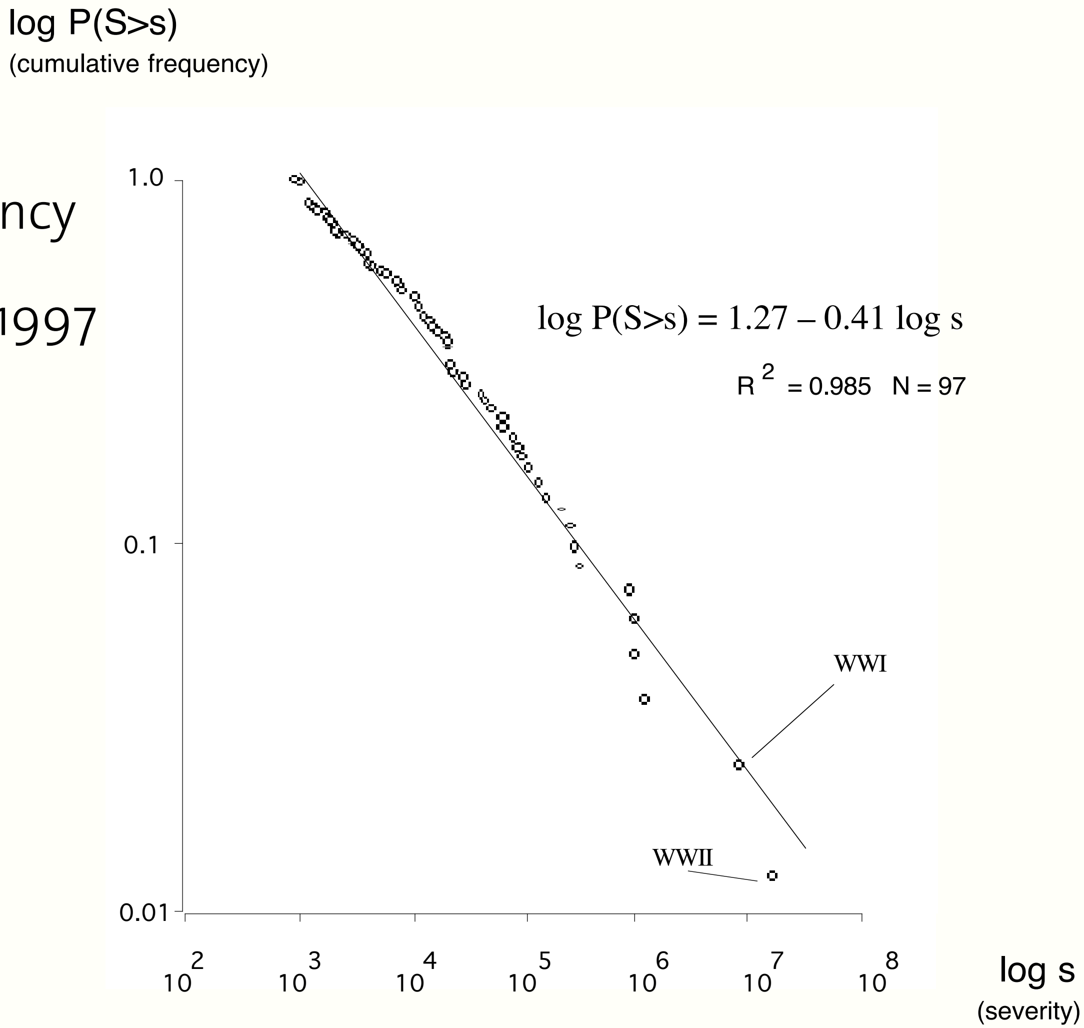
International Conflict Research (ICR)

Armed conflict continues to cause political crises

- Refugees fleeing the fighting in South Ossetia (AP Photo/Musa Sadulayev)

Viewing conflict as outcome of complex social systems

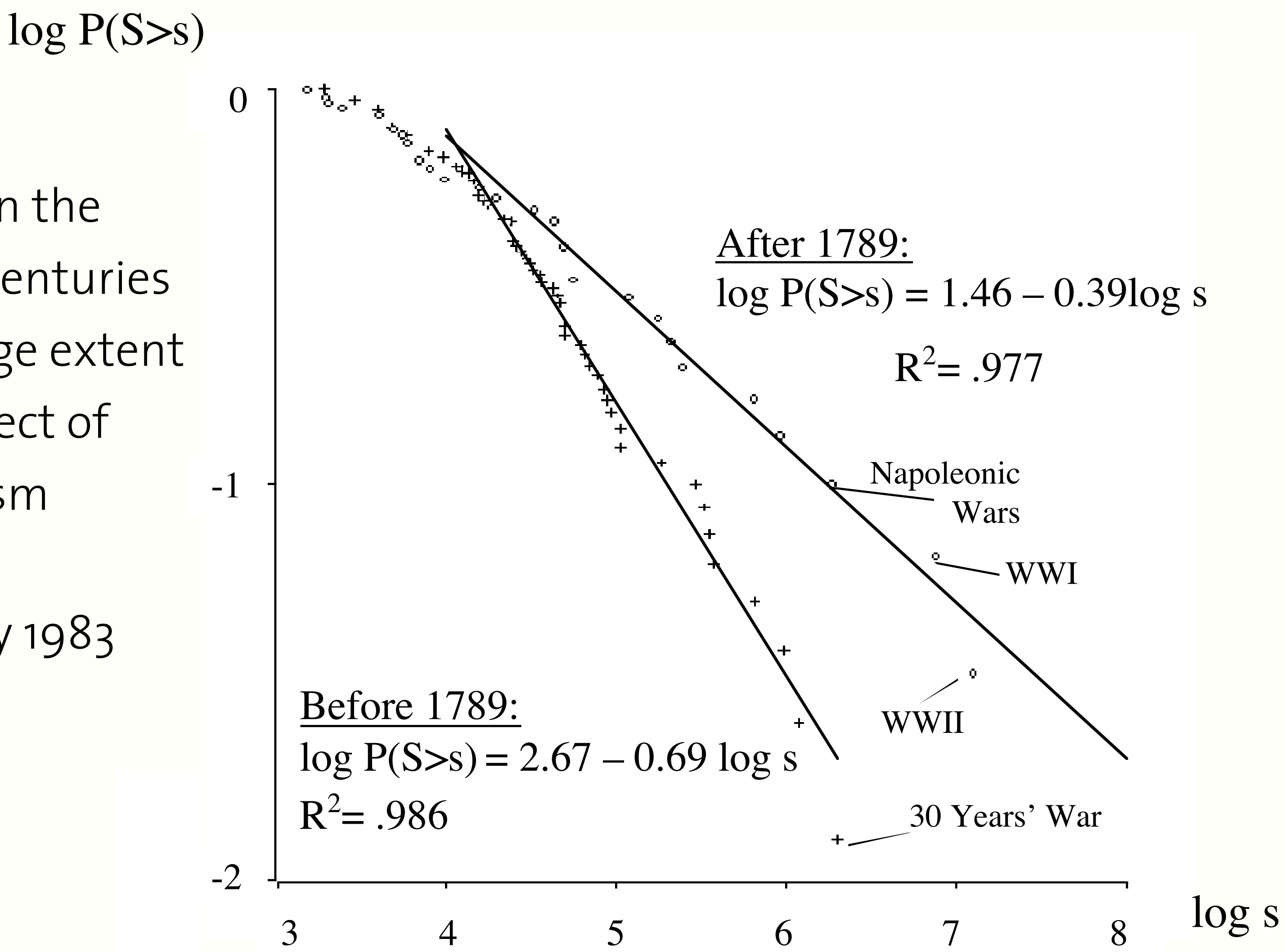
- Cumulative log-log frequency plot, interstate wars 1820-1997 (Cederman 2003)



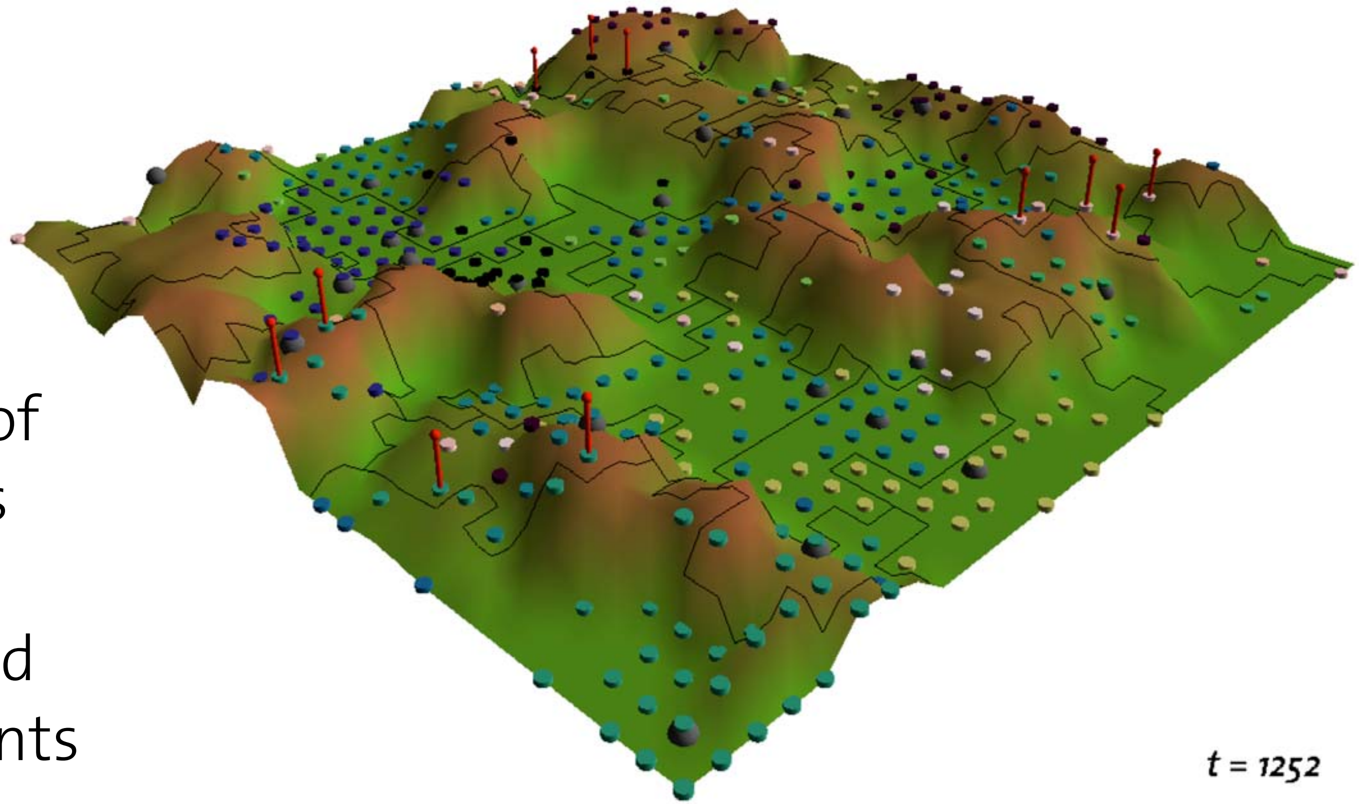
Studying changes in conflict distributions

- Warfare in the two last centuries is to a large extent a side-effect of nationalism

- Data: Levy 1983



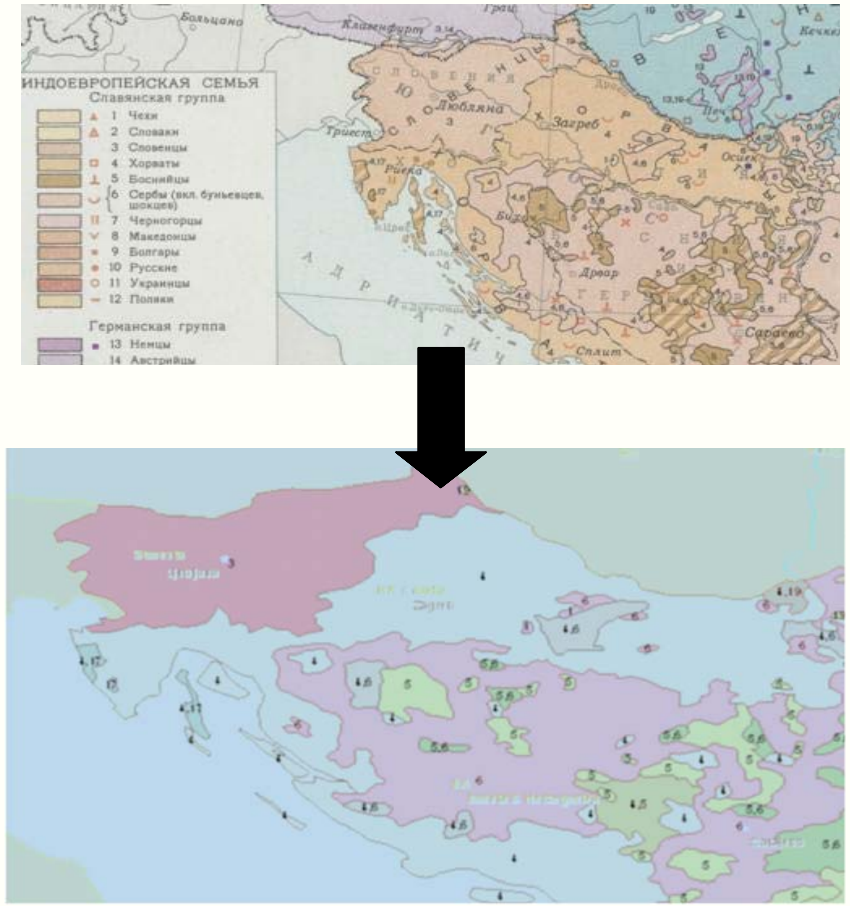
Computational models



- Reconstruction of macro processes within artificial worlds populated by software agents

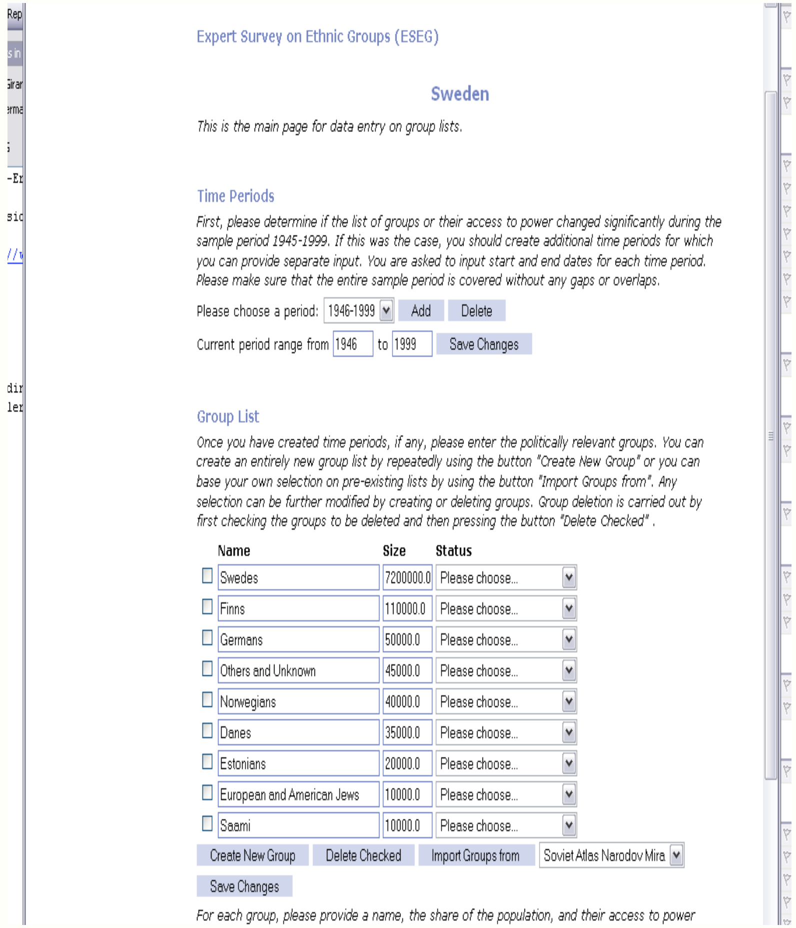
Data collection: Geographic Information Systems

- Geo-coding of ethnic groups around the world based on *Atlas Narodov Mira*
- Weidmann, Rød & Cederman 2008

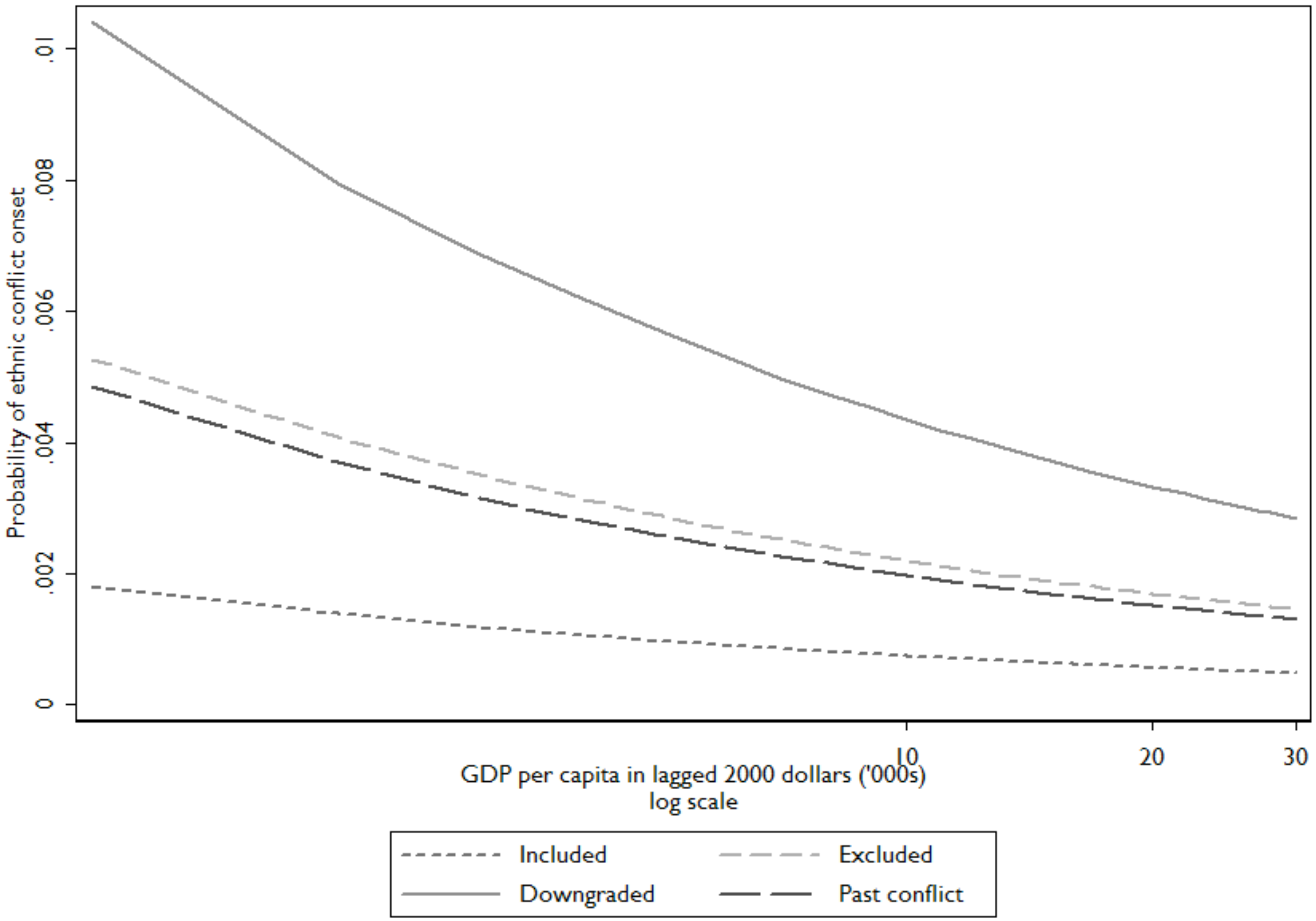


Data collection: Online expert surveys

- Ethnic Power Relations
- Political relevant groups' access to power around the world
- Collaboration with Wimmer & Min (UCLA)



The effect of GDP on conflict involving in-/excluded groups



Cederman, Wimmer & Min 2008

Dirk Helbing

- Since June 2007 Professor of Sociology, in particular of Modeling and Simulation. Before, full professor and managing director of the Institute for Transport & Economics at Dresden University of Technology since the year 2000.
- Studied physics and mathematics in Göttingen, master thesis dealt with nonlinear modeling and multi-agent simulation of observed self-organization phenomena in pedestrian crowds. Ph.D. at Stuttgart University on modeling social interaction processes.
- Habilitation on traffic dynamics and Heisenberg scholarship. Principal investigator in about 20 research projects sponsored by the DFG, EU, BMBF, and various industrial partners.
- **Research interests:** Behavioral models, decision and game theory; cascade failures in critical infrastructure networks, evacuation; optimization of transport systems; dynamics of supply networks and business cycles; vehicle and pedestrian traffic including panic; multi-agent simulation of socio-economic and biophysical systems; self-organization and pattern formation phenomena in space and time

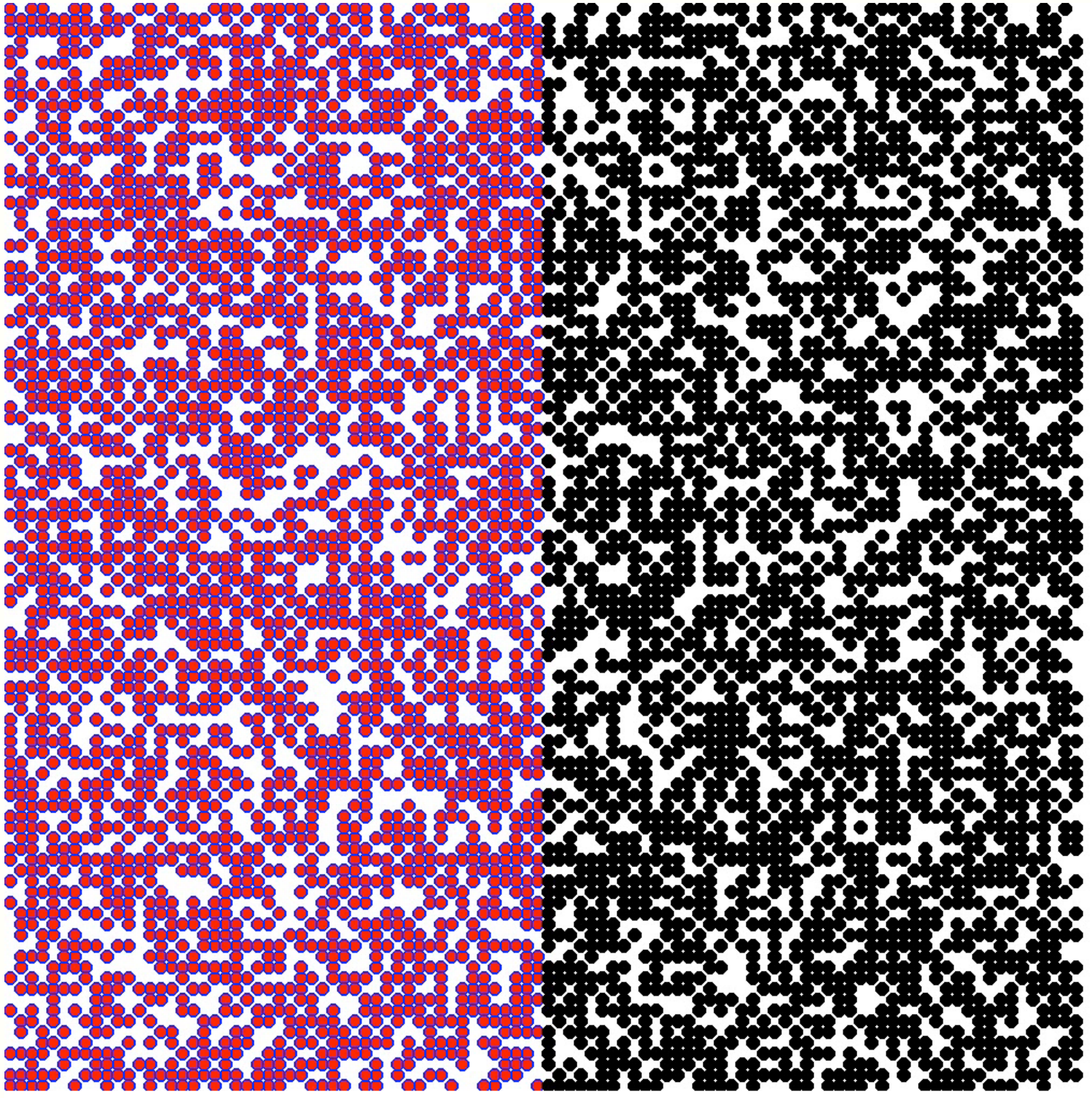
Outbreak and Breakdown of Cooperation

Dirk Helbing

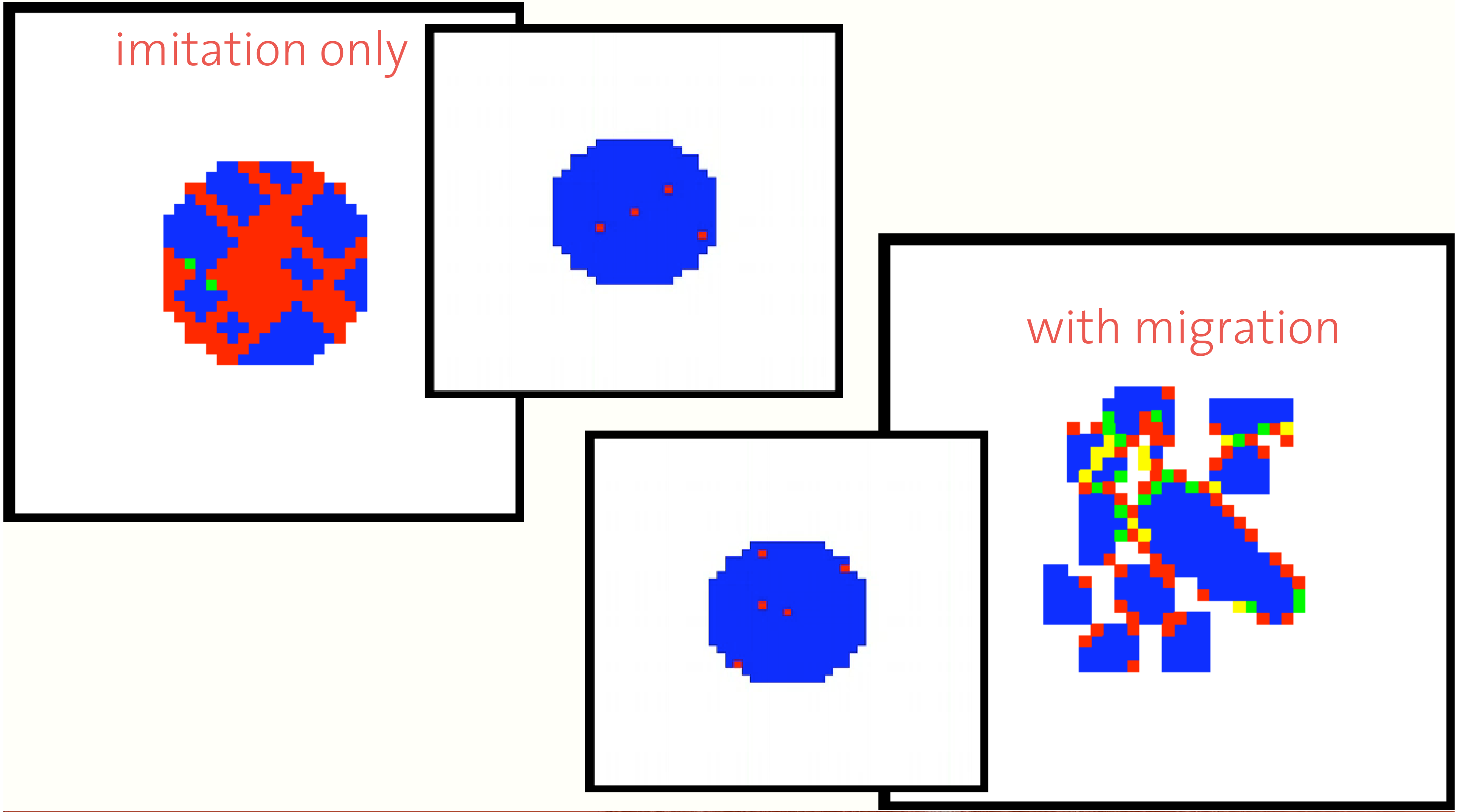
Chair of Sociology,

in particular of Modeling and Simulation

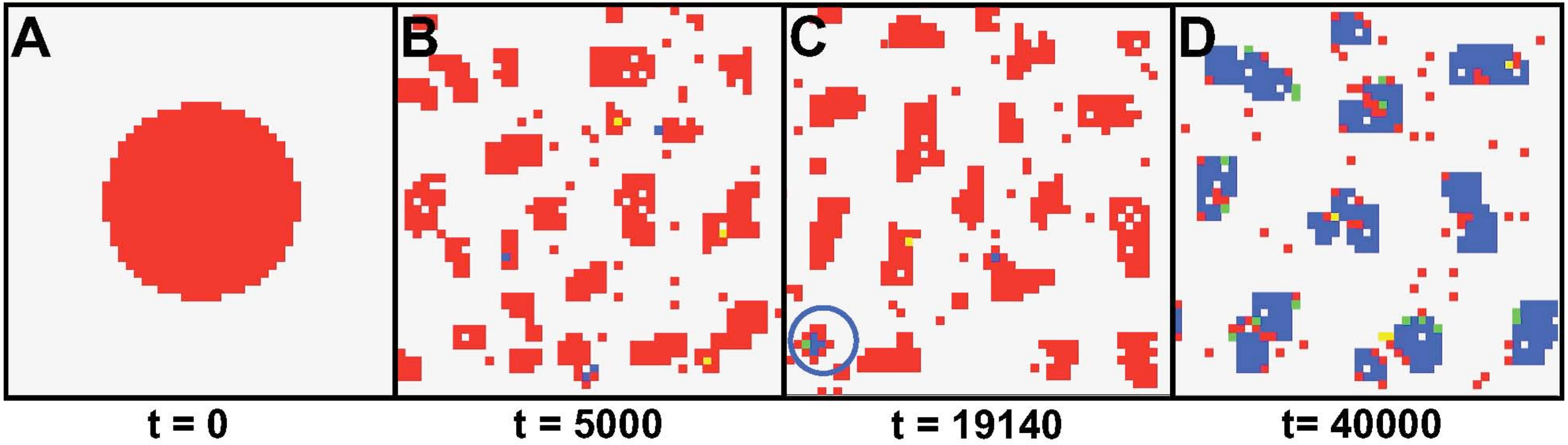
Simulation of social conflict: Preliminary results



Invasion of a defector into a cluster of cooperators

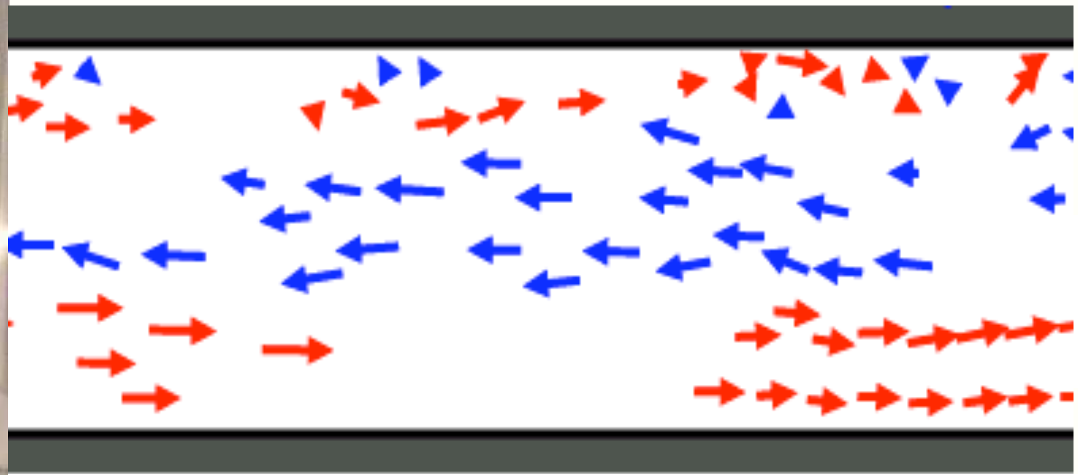


Different phases of the outbreak of cooperation



initial configuration	dispersal of defectors	birth of a super-critical cooperative cluster	spreading of cooperation

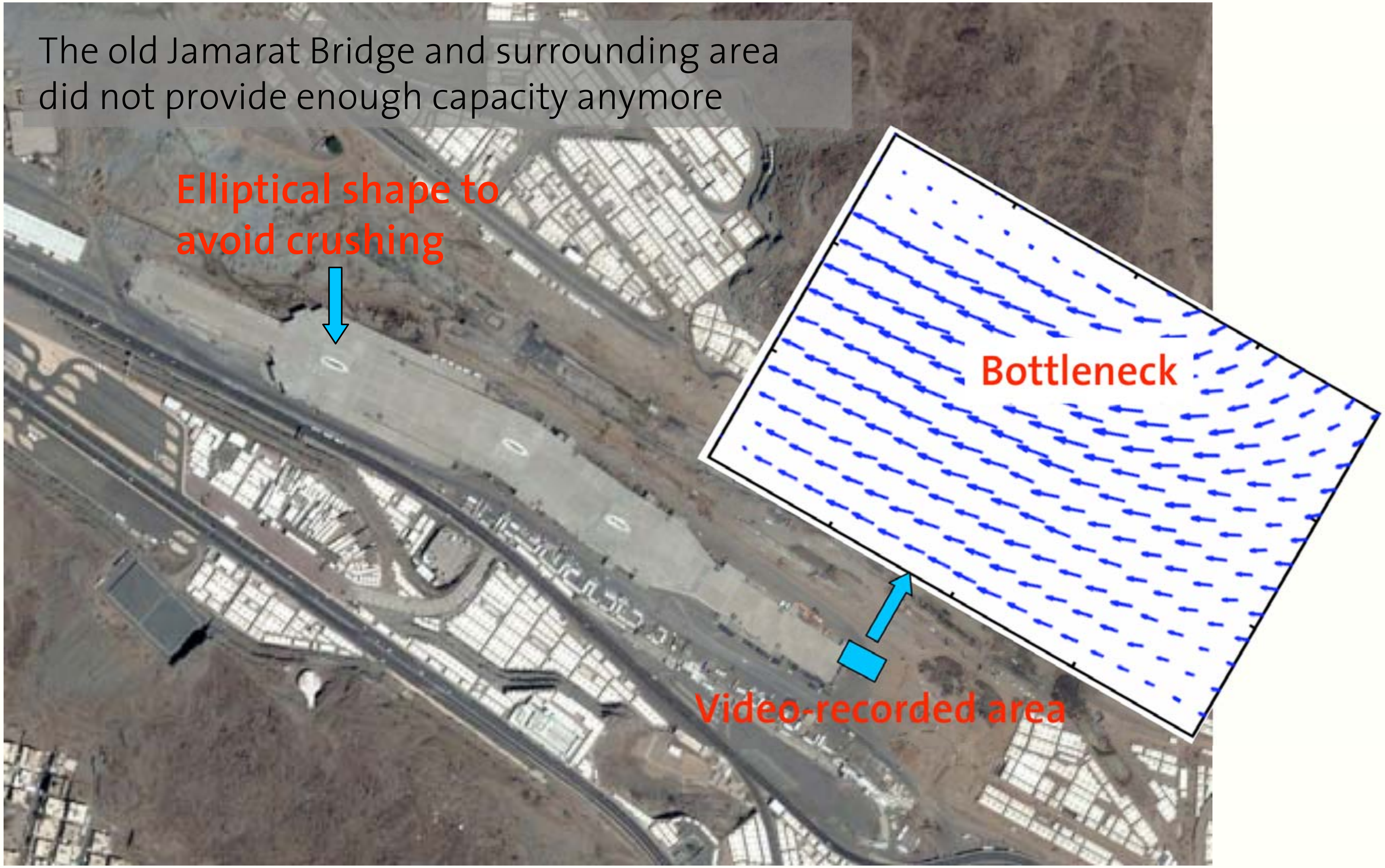
Emergent coordination in pedestrian counterflows



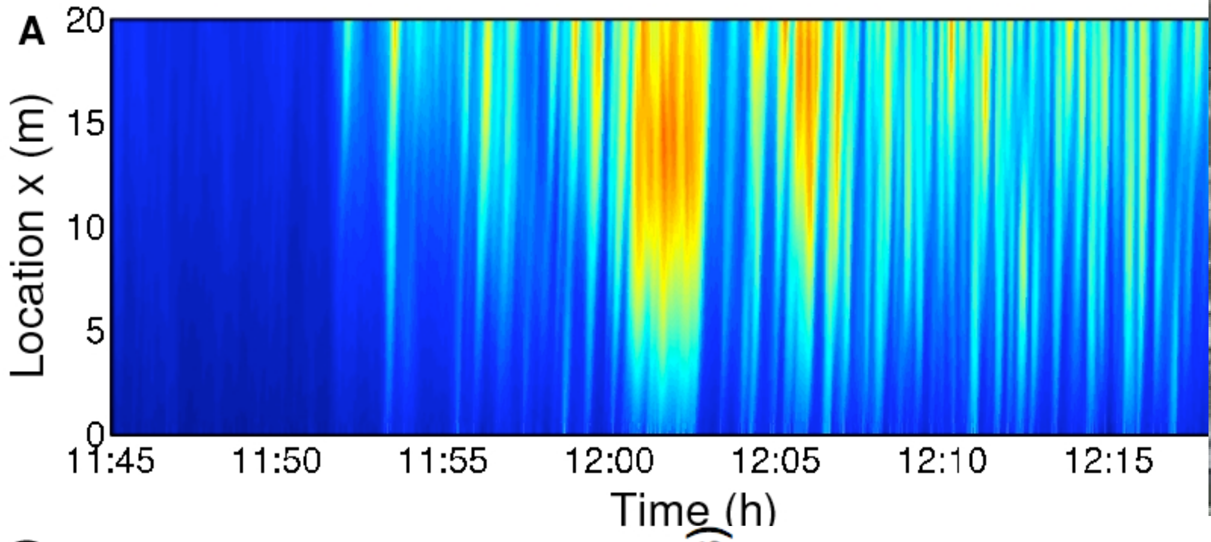
Based on individual interactions, lanes of uniform walking directions emerge in pedestrian crowds by self-organization. This constitutes a „macroscopic“ social structure. Nobody orchestrates this collective behavior, and most people are not even aware of it.

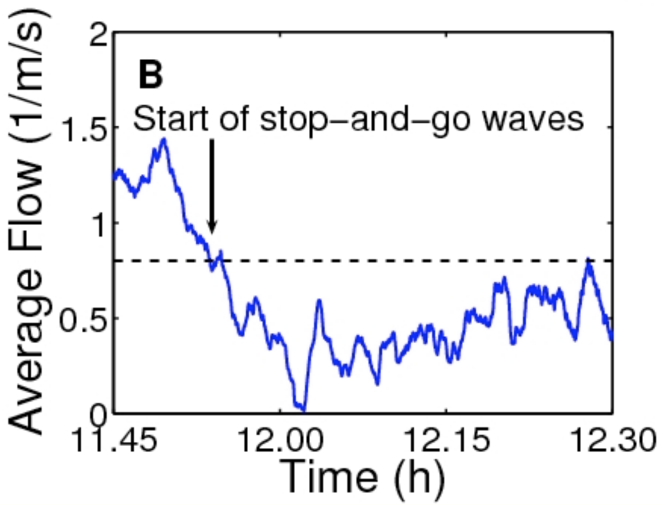
Breakdown of coordination and crowd disasters

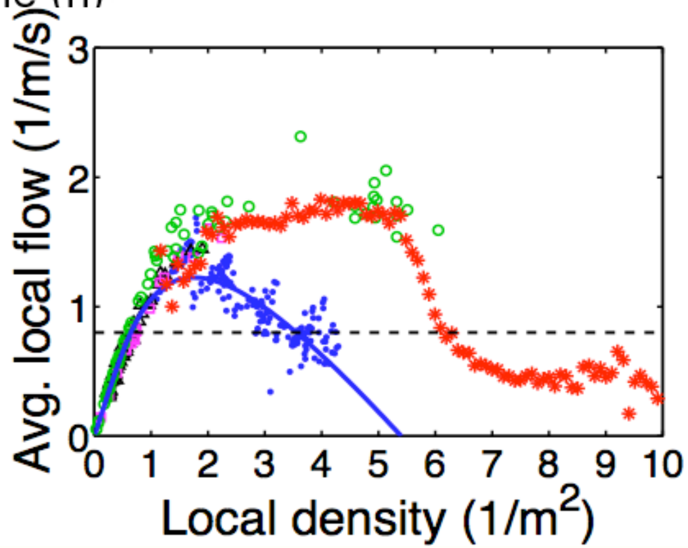
The Jamarat bridge (as of January 2006)

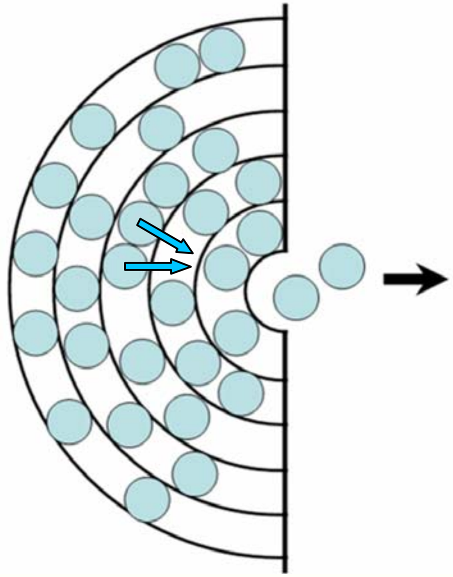


Transition from smooth to stop-and-go flow

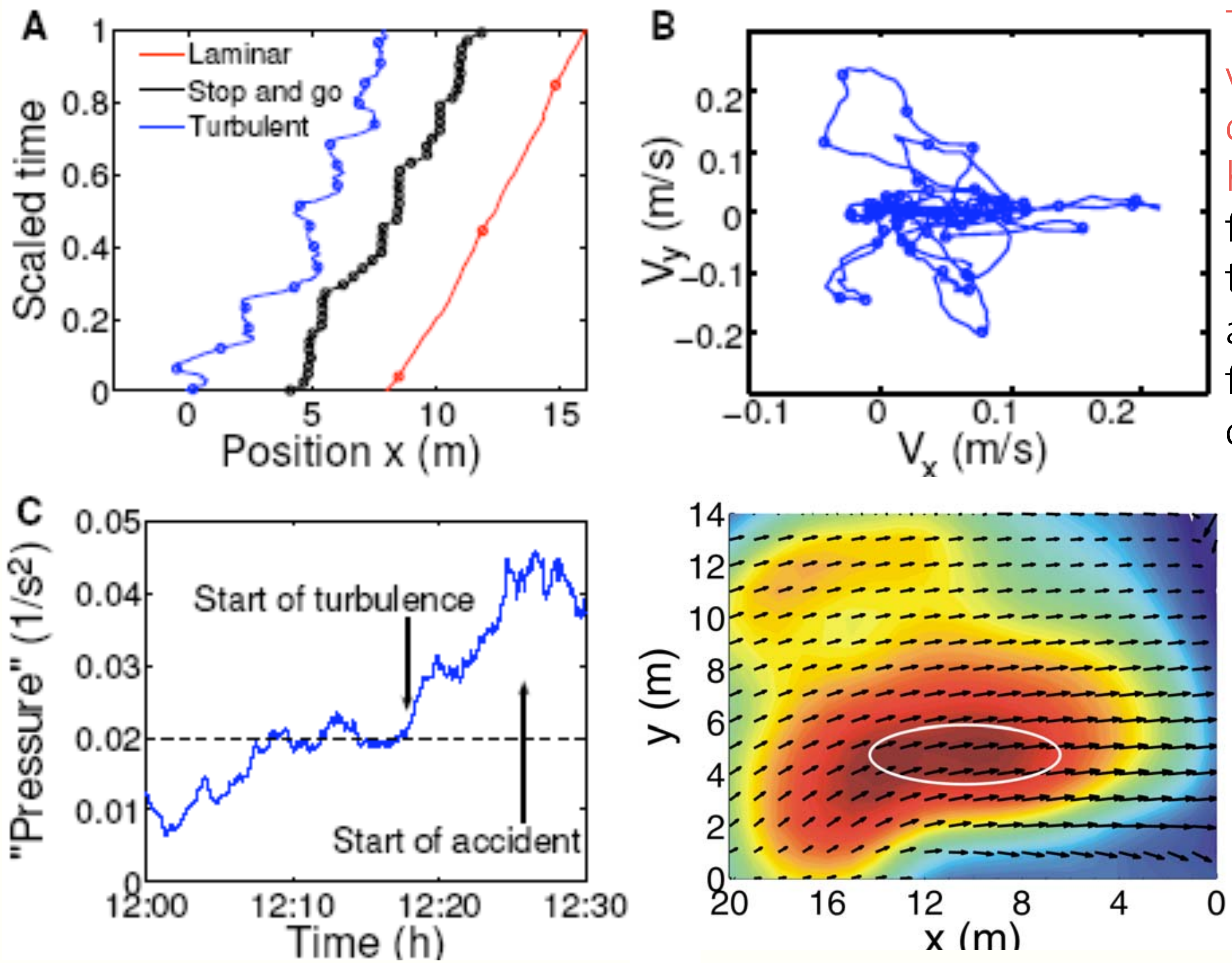








Transition to “crowd turbulence”



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 people try to gain space, particularly during “crowd panic”

The change in organization from 2006 to 2007

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

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