ETH zürich

Risks and Crises in Complex Coupled Systems

Dirk Helbing,

with Lubos Buzna, Karsten Peters, further team members from TU Dresden and ETH Zurich, and external collaborators

Content

- Damage of Crises
- Role of Complexity
- Energy Systems
- Causality Networks
- Modeling Cascade Spreading
- Dynamic Instability
- Confronting Disasters
- Computational Social Science and Big Data
- Summary and Conclusions

Some Video Lectures of Interest

- Globally networked risks and how to respond http://www.youtube.com/watch?v=89lsg4CfhXE
- Globally networked risks, logistics, and some insights from biology http://www.youtube.com/watch?v=hGlW7Tnhdv8

Damage due to Crises, and the Role of Complexity

Challenges to Address

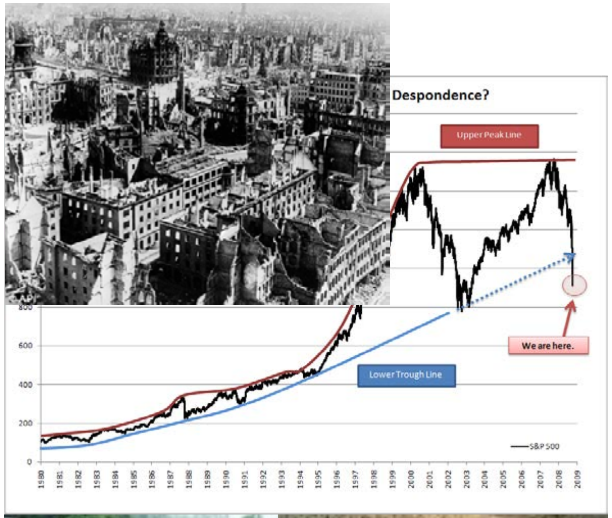
- Social and economic systems are rapidly changing, are in a transformation process, not in equilibrium
- Scientists need to be put in a better position to address the increasing number of socio-economic problems

As president of New York's Columbia University, Lee C. Bollinger formulated the issue as follows: "The forces affecting societies around the world ... are powerful and novel. The spread of global market systems ... are ... reshaping our world ..., raising profound questions. These questions call for the kinds of analyses and understandings that academic institutions are uniquely capable of providing. Too many policy failures are fundamentally failures of knowledge."

- We must close the gap between existing socio-economic problems and solutions, and get into a position to come up with solutions before a problem occurs
- The goal is to support politicians and business people in addressing practical problems

Socio-Economic Systems Imply Major Risks

- Conflicts: World War I (more than 15,000,000 victims); World War II (60,000,000 fatalities; cost of 1,000,000,000,000 1944 US$; destruction of 1710 cities, 70,000 villages, 31,850 industrial establishments, 40,000 miles of railroad; 40,000 hospitals 84,000 schools); Vietnam, Korea, former Yugoslavia, Afghanistan, Irak, Darfur…
- Financial and Economic Crises: estimated loss of 4-20 Trillion US$
- Climate Change will cause natural disasters conflicts for water, food, land; migration; social and political instability (estimated reduction of world gross domestic product by 0.6 12 Trillion US$ per year)
- Epidemics: Spanish Flu (20-40 Mio. Deaths), SARS (ca. 800 victims, 100 Billion US$ losses)

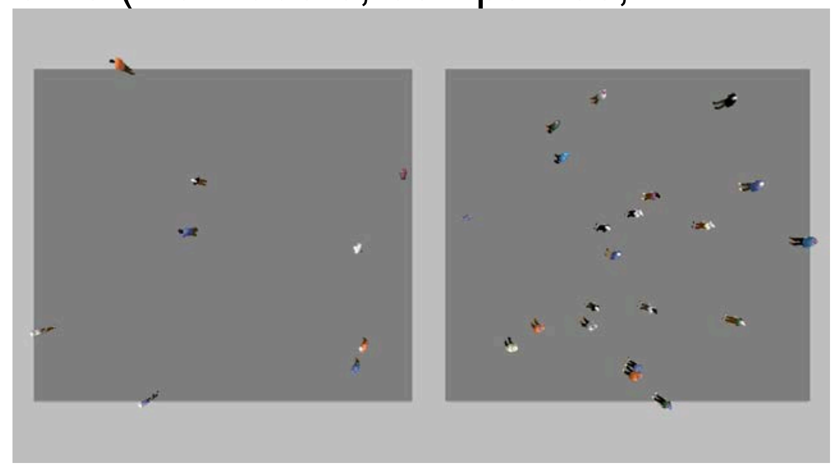


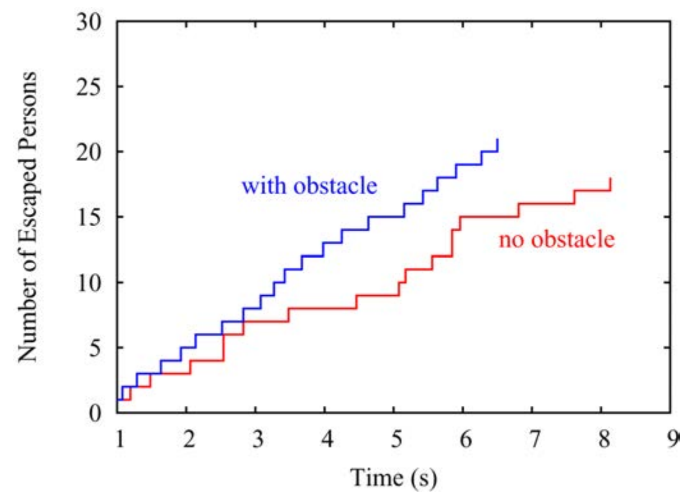
Socio-Economic Systems Imply Major Risks

- Examples: Turbulent fluids; traffic flows; large supply chains; social, political, economic and ecological systems; financial markets; group dynamics and crowd behavior

Complex Systems: A Daunting Class of Problems

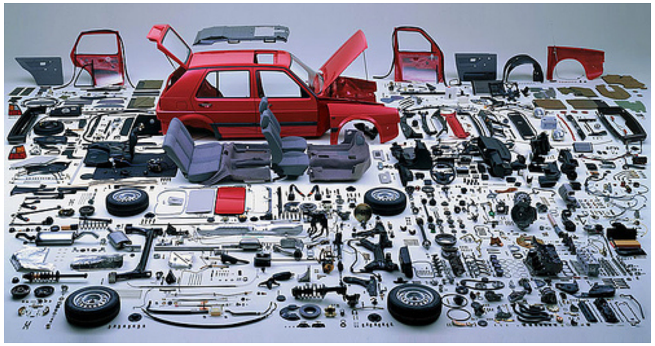
- Large number of interacting system elements (individuals, companies, countries, cars…)
- Non-linear or network interactions
- Rich system behavior
- Dynamic rather than static
- Probabilistic rather than deterministic
- Surprising, often paradoxical system behavior (e.g. slower-is-faster effects)
- Hardly predictable
- Seemingly uncontrollable
- Challenge our common way of thinking
- Almost everywhere around us
- Currently a nightmare for decision-makers



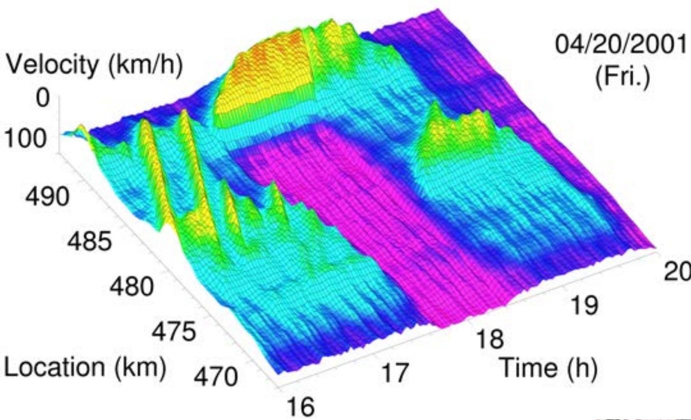


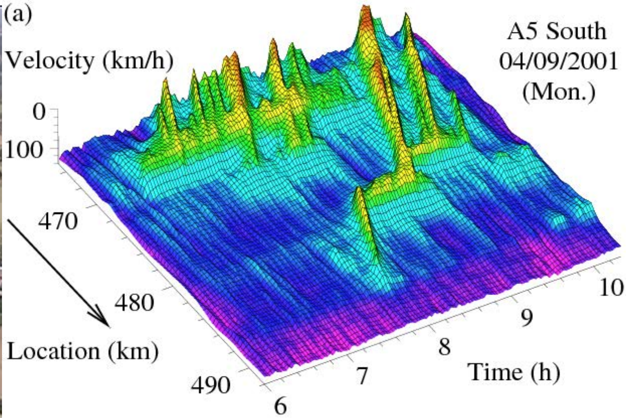
Complicated vs. Complex Systems

- Example: A car is a complicated system



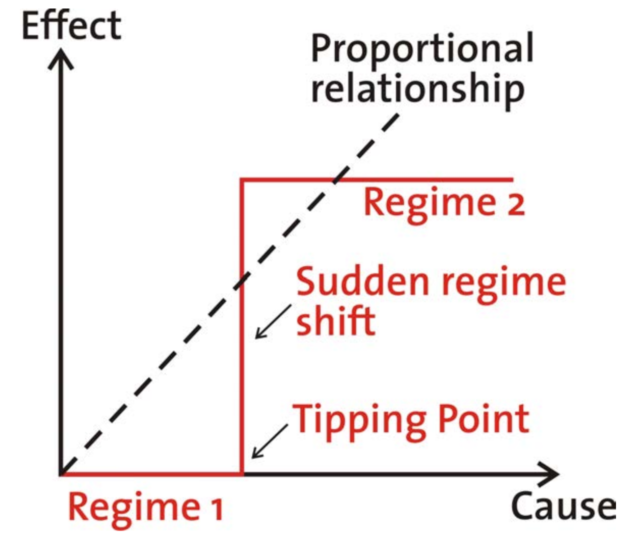
- Example: Traffic flows, involving the interaction of many cars, constitute a complex system
- Phantom traffic jams, many different kinds of congestion patterns

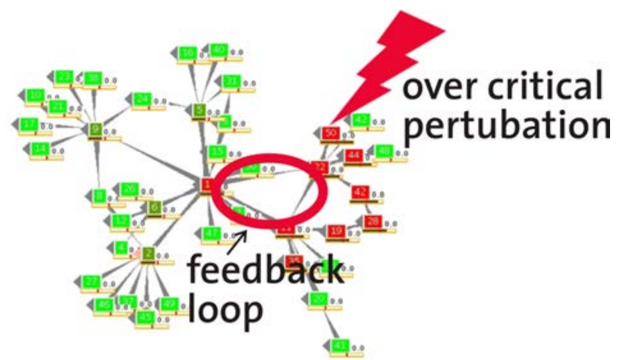




Non-Linear Interactions

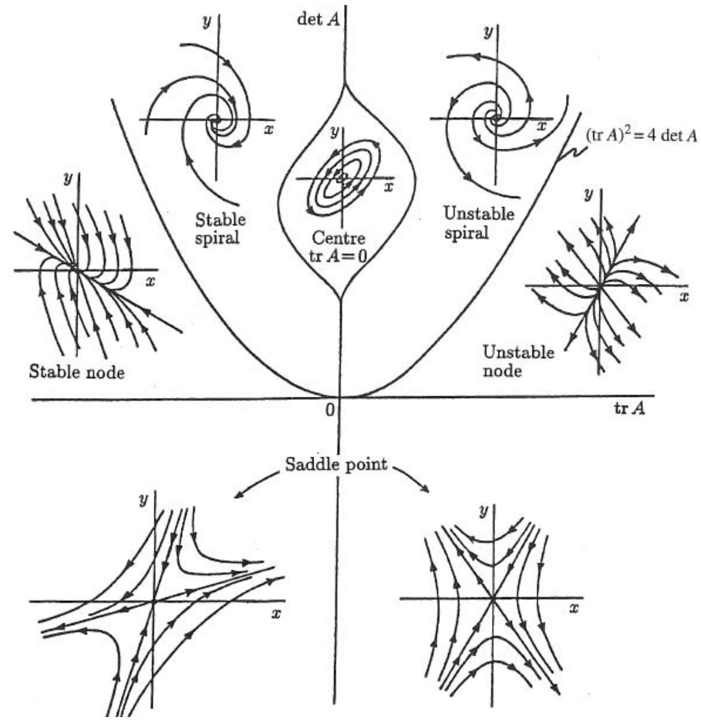
- Elements mutually adapt to each other
- They are influenced by their environment, but at the same time, they influence their environment
- Causes and effects not proportional to each other
- Unresponsive system or regime shifts
- Example: Sudden public opinion changes (pro vs. anti-war mood; public smoking ban; Swiss banking secrecy; car sales, etc.)
- Network interactions are ubiquitous
  - Feedback loops, circuli vitiosi
  - Cascade spreading
  - Unwanted side effects (example: tabacco tax caused smuggle and criminal activity)



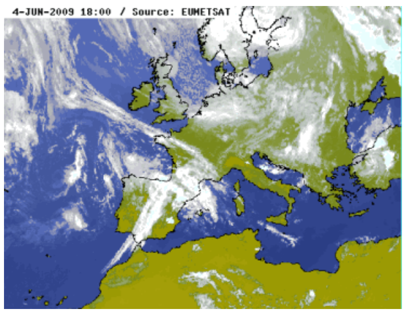


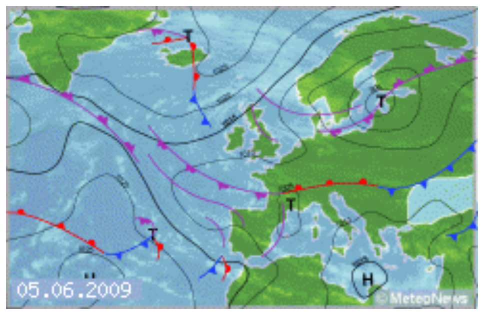
Limits of Predictability

Source: J. D. Murray

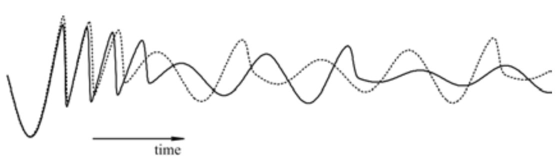


- Large number of non-linearly interacting system components leads to complex dynamics



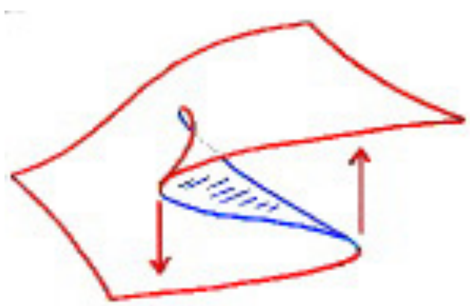


- Example: Weather forecast
- Chaotic dynamics/butterfly effect/ sensitivity: Small initial differences can cause very different behavior
- Self-fulfilling or self-destroying prophecy effects in socio-economic systems

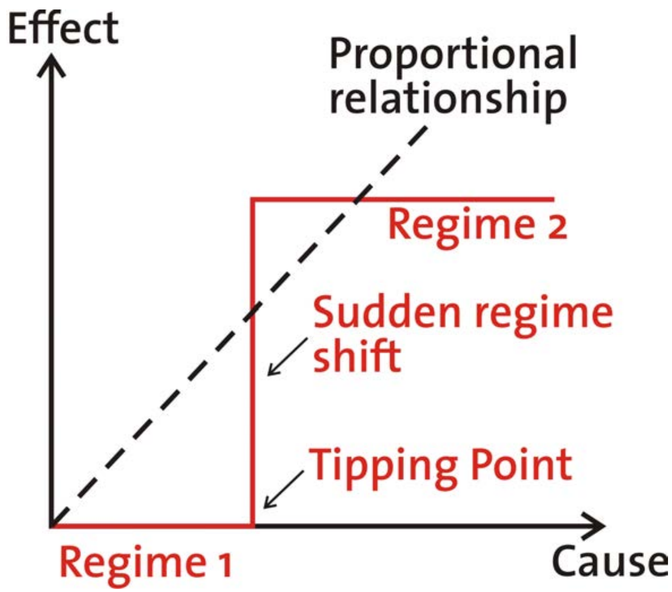


Limits of Control

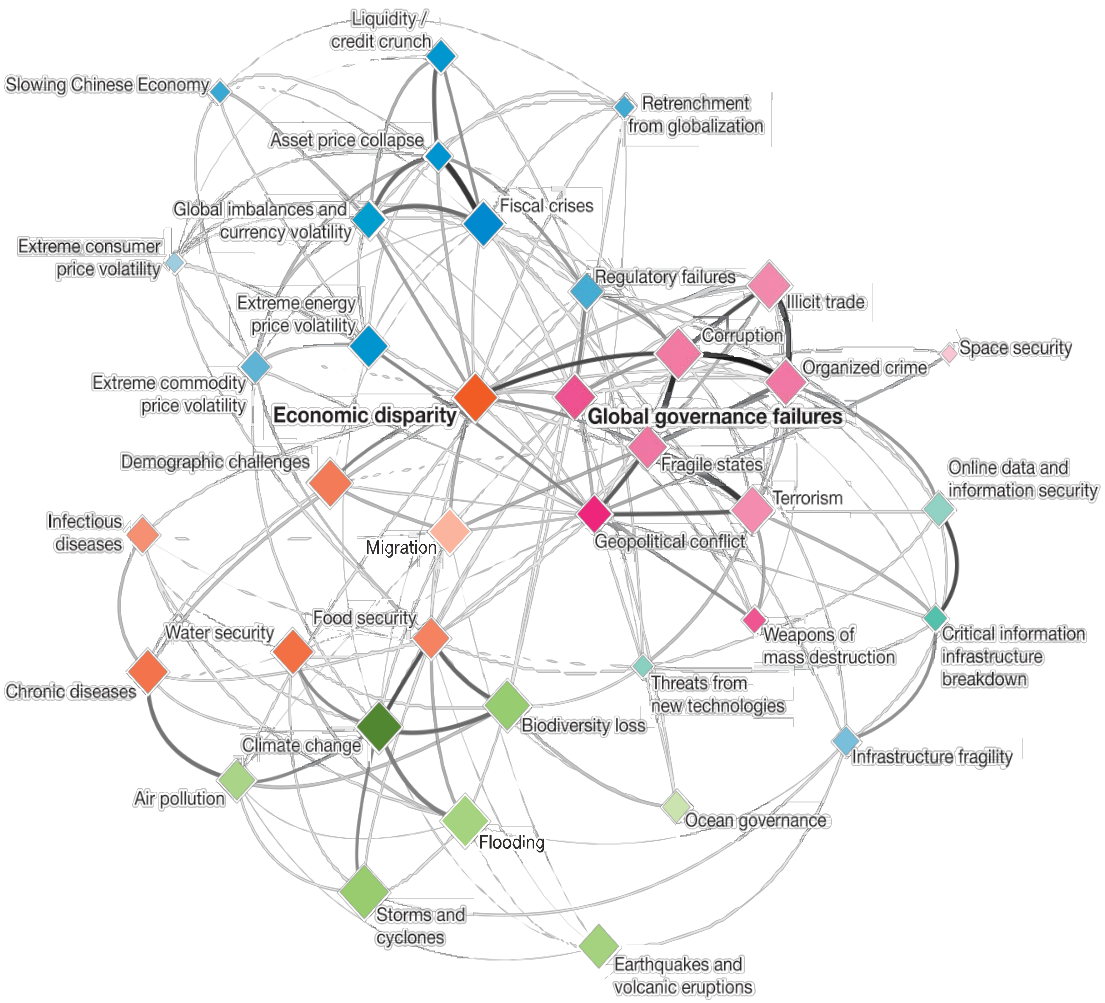
- Big changes may have small, no, adverse or unexpected effects
- Principle of Le Chatelier: A system tends to counteract external control attempts
- Irreducible randomness: A degree of uncertainty and perturbation that cannot be eliminated
- Delays may cause instabilities
- Regime shifts („phase transitions“, catastrophes): Sometimes small changes have a big impact



Cusp catastrophe“



Hyperconnected Systems

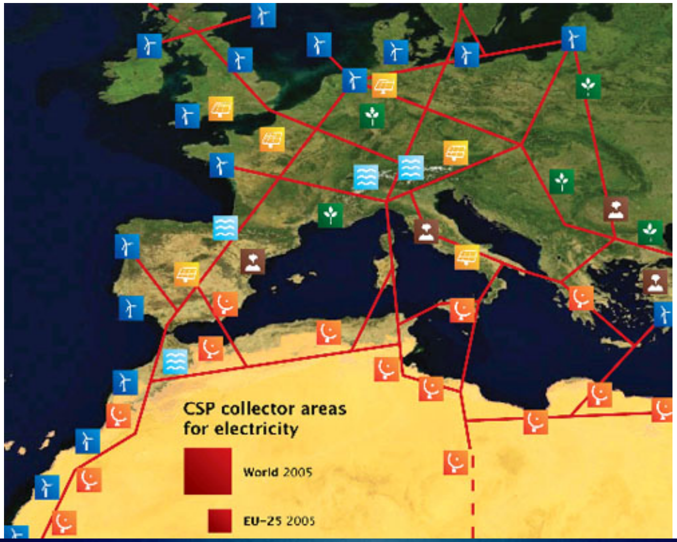


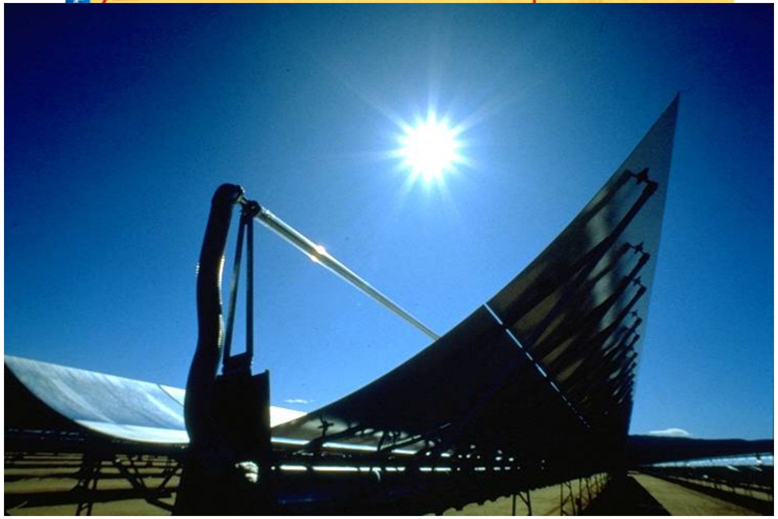
Great opportunities, but also systemic risks and too much complexity

Source: World Economic Forum (WEF)

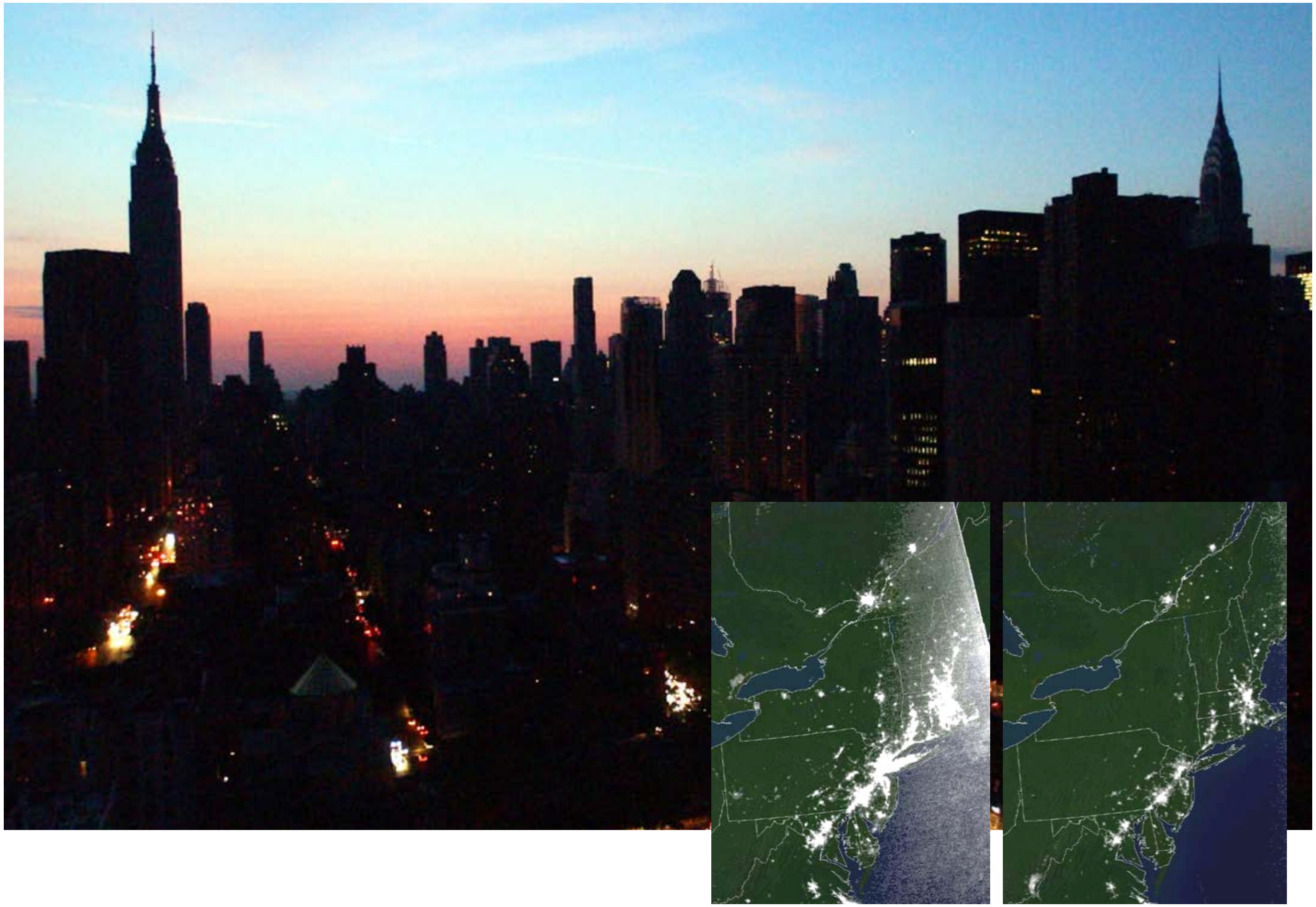
Energy Systems

Interdependencies in Energy Supply





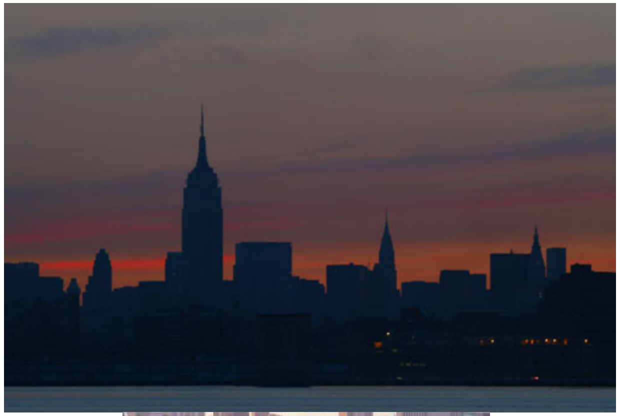
Failure of Electricity Networks



A power outage can affect society at large.

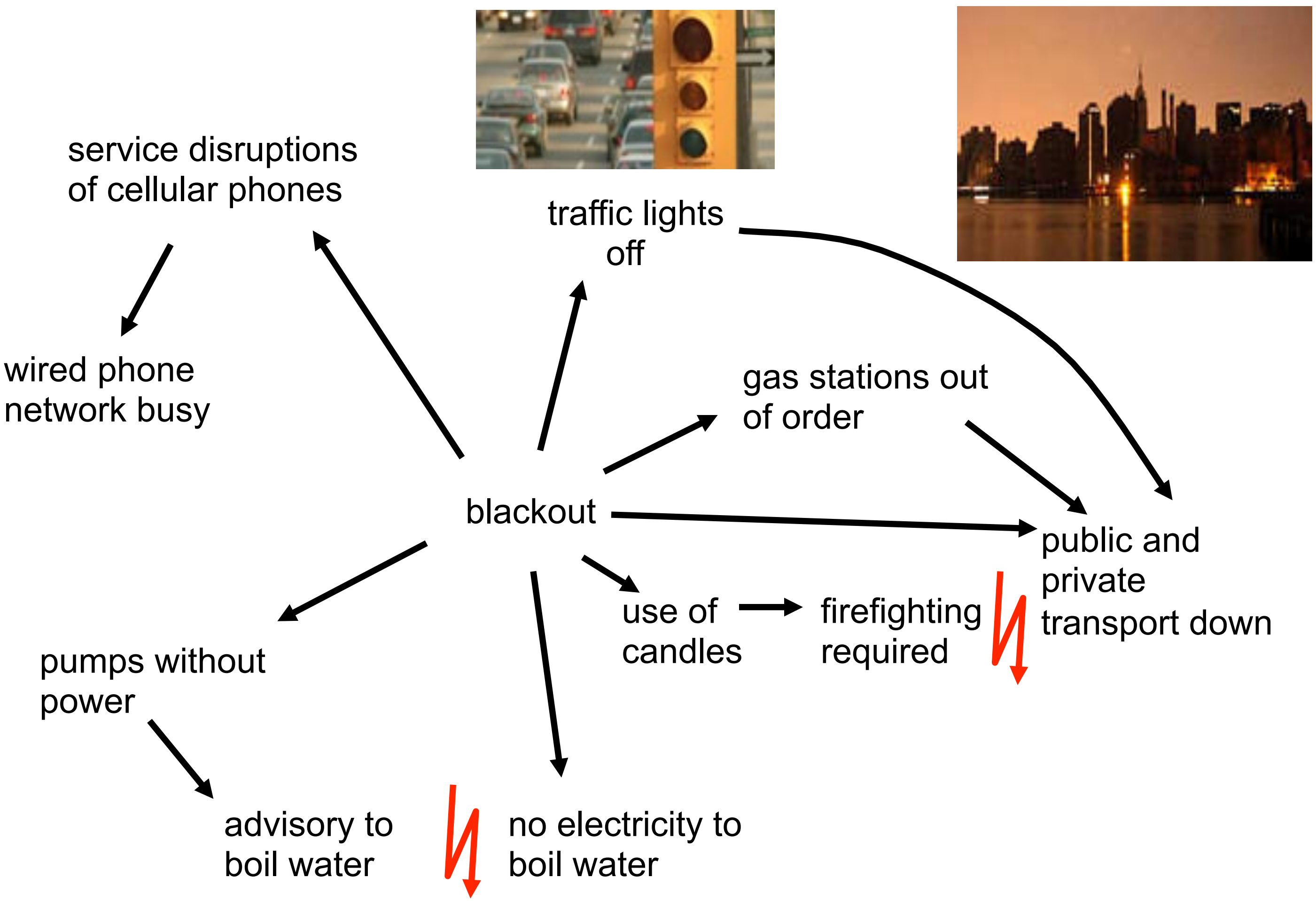
Blackouts and Cascading Effects in Electricity Networks

New York, August 14, 2003



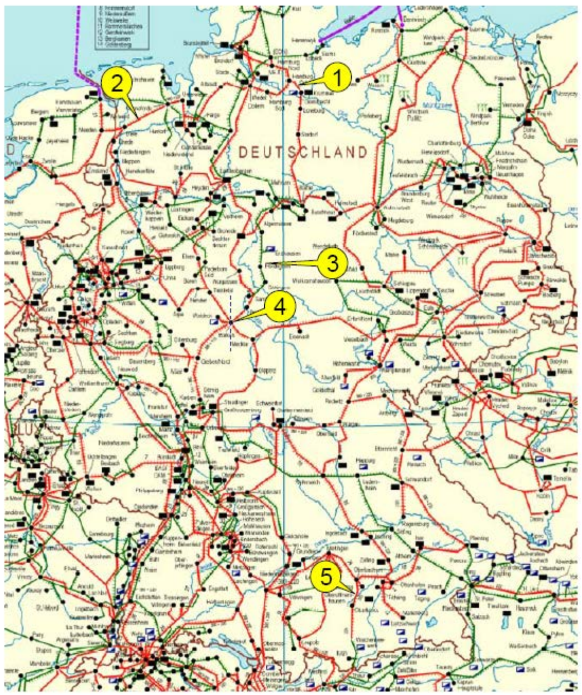
Rome, September 28, 2003

Causality Network for the Blackout in North America 2003 (Detail)



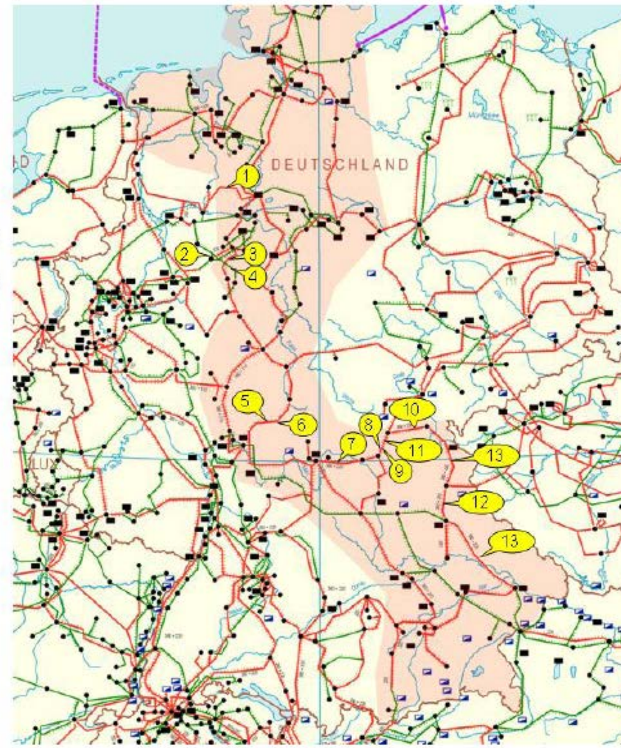
Blackouts and Cascading Effects in Electricity Networks

State of the power grid shortly before the incident



Sequence of events on November 4, 2006

Nr.	Zeit	kV	Leitung
1	22:10:13	380	Wehrendorf-Landesbergen
2	22:10:15	220	Bielefeld/Ost-Spexard
3	22:10:19	380	Bechterdissen-Elsen
4	22:10:22	220	Paderborn/Süd-Bechterdissen/Gütersloh
5	22:10:22	380	Dipperz-Großkrotzenburg 1
6	22:10:25	380	Großkrotzenburg-Dipperz 2
7	22:10:27	380	Oberhaid-Grafenrheinfeld
8	22:10:27	380	Redwitz-Raitersaich
9	22:10:27	380	Redwitz-Oberhaid
10	22:10:27	380	Redwitz-Etzenricht
11	22:10:27	220	Würgau-Redwitz
12	22:10:27	380	Etzenricht-Schwandorf
13	22:10:27	220	Mechlenreuth-Schwandorf
14	22:10:27	380	Schwandorf-Pleinting

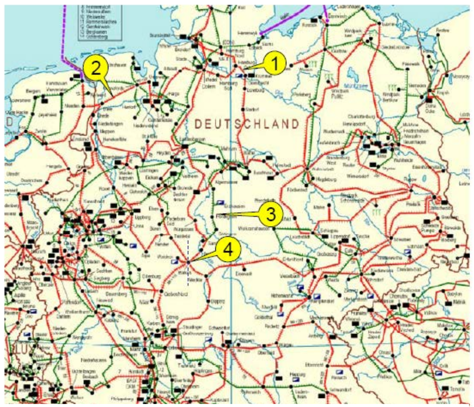


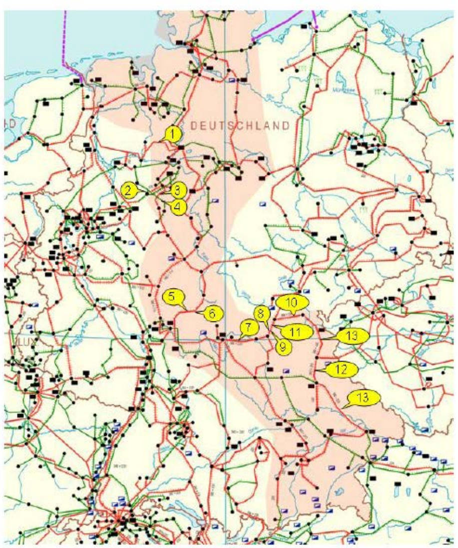
1,3,4,5 – lines switched off for construction work

2 – line switched off for the transfer of a ship by Meyer -Werft

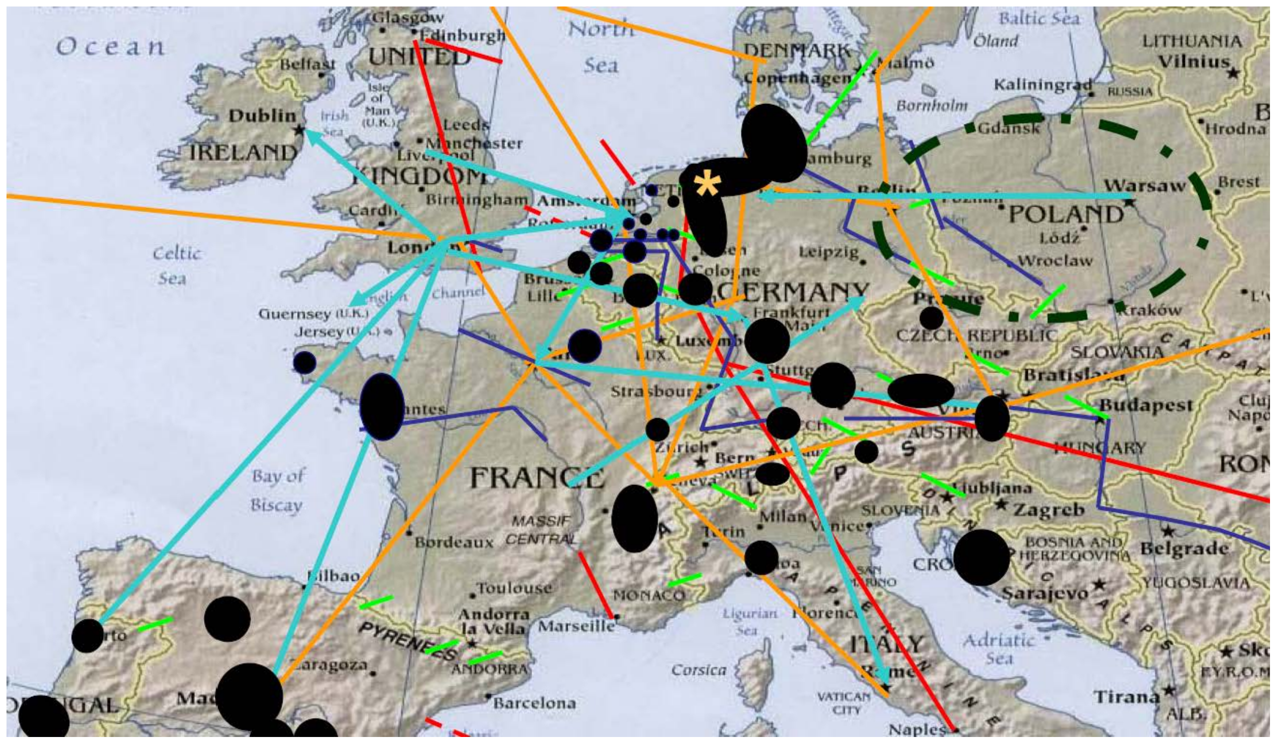
E.ON Netz's report on the system incident of November 4, 2006, E.ON Netz GmbH

Cascading Effects and Blackout in the European Electricity Networks





Failure in the continental European electricity grid on November 4, 2006

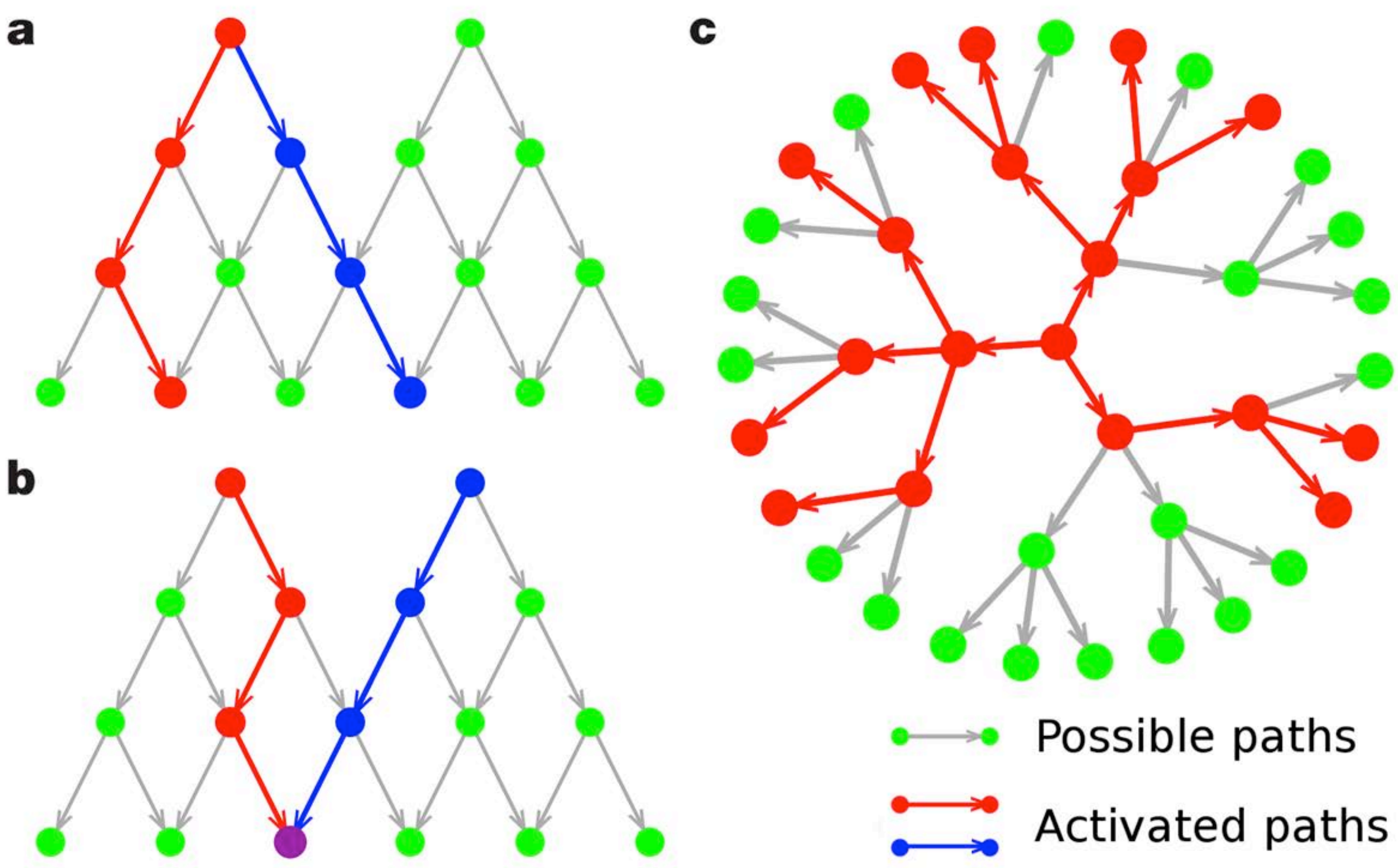


EU project IRRIIS: E. Liuf (2007) Critical Infrastructure protection, R&D view

Causality Networks

Illustration of a Cascading Failure

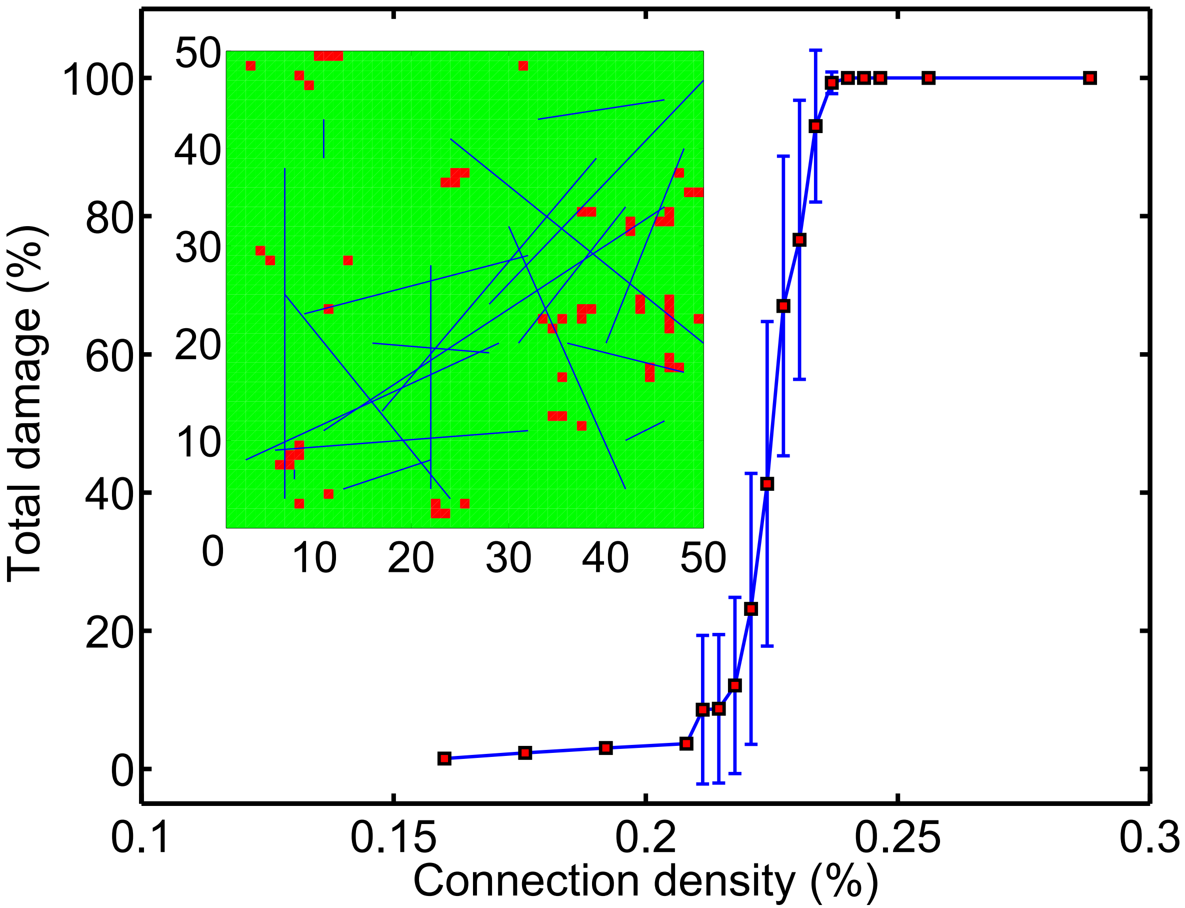
How the Combination of Risk and Complexity Creates Uncertainty



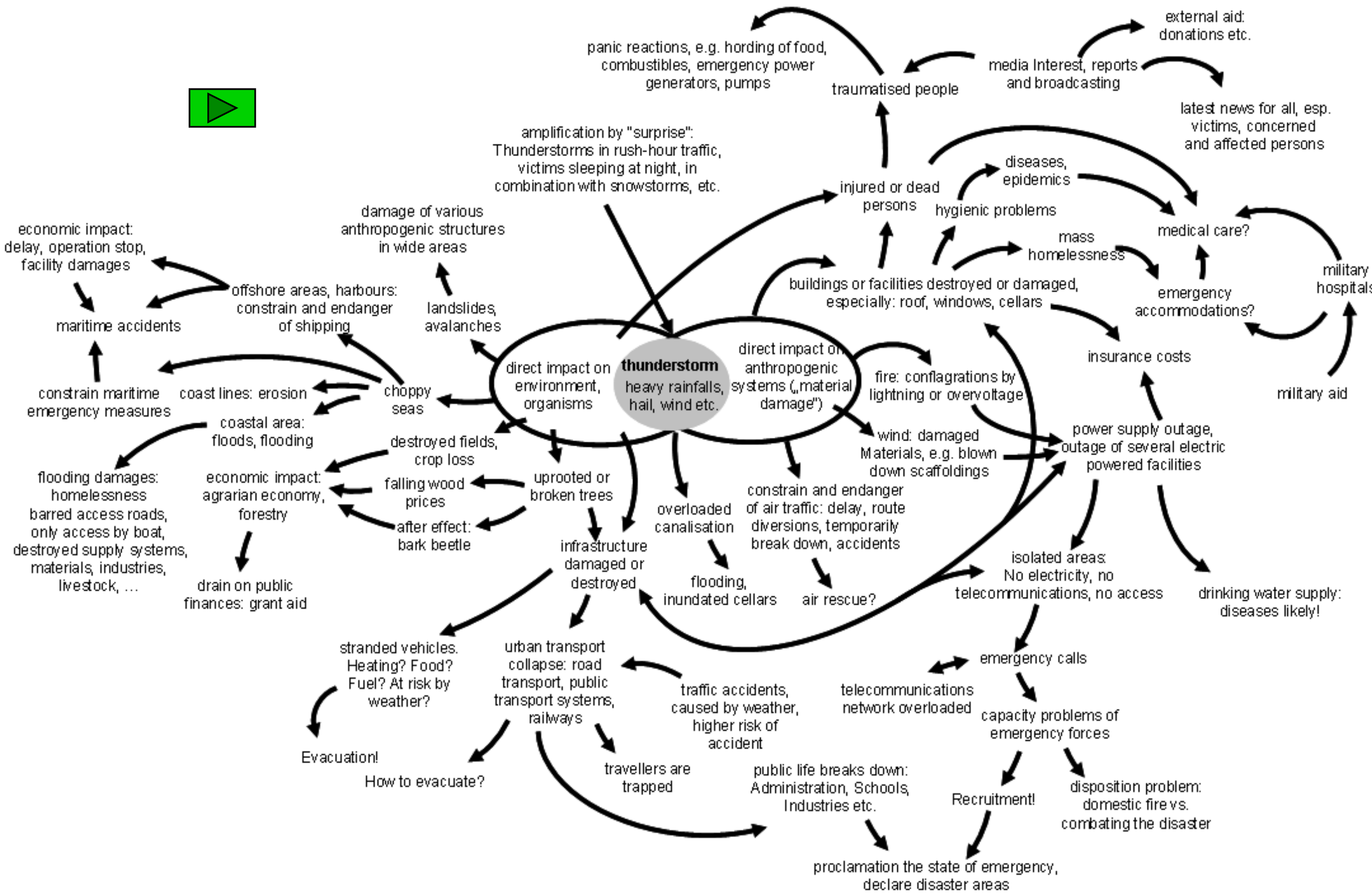
Cascading Effects During Financial Crises

Video by Frank Schweitzer et al.

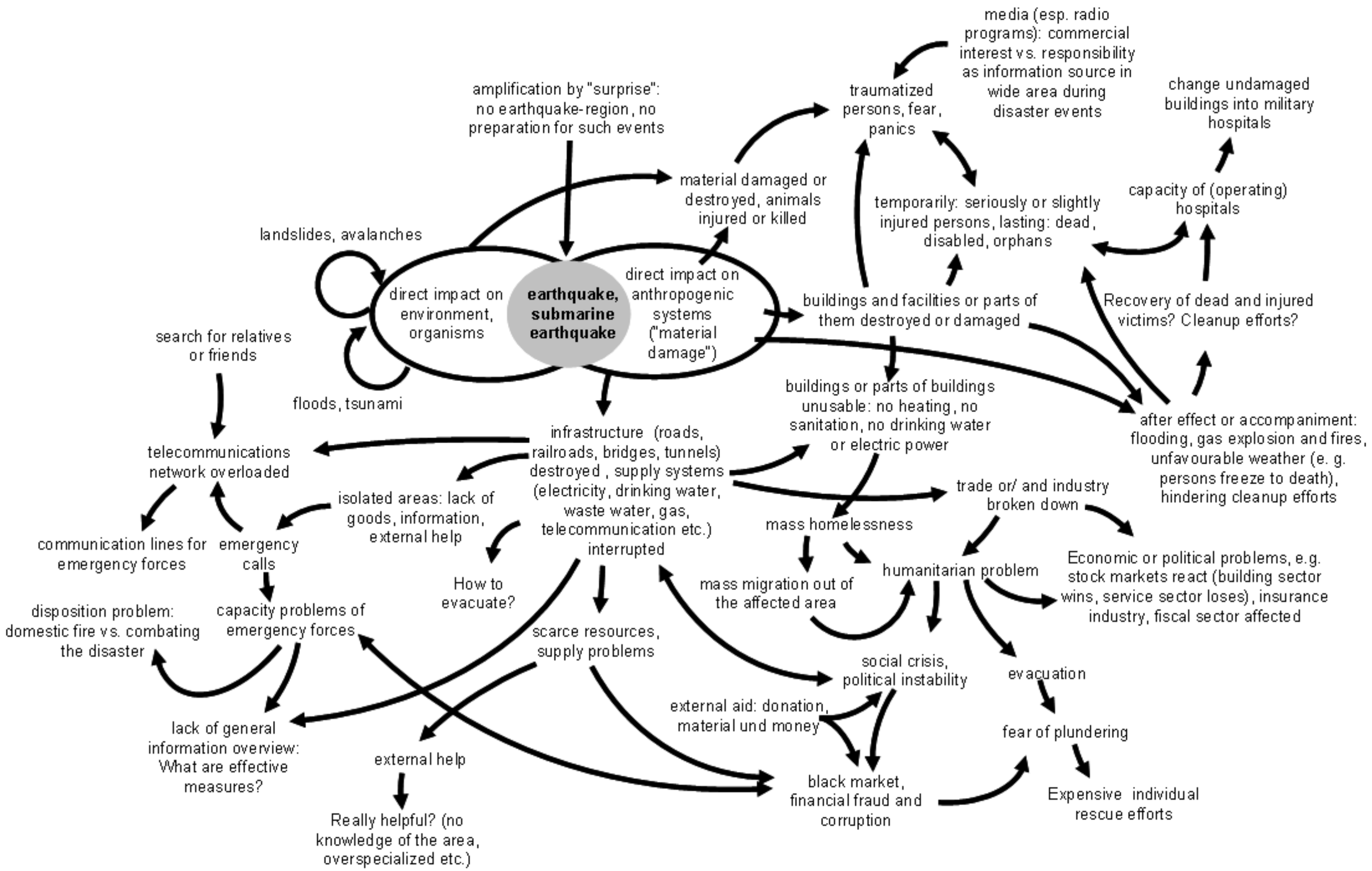
Explosive Epidemic Spreading with Budget-Constrained Recovery



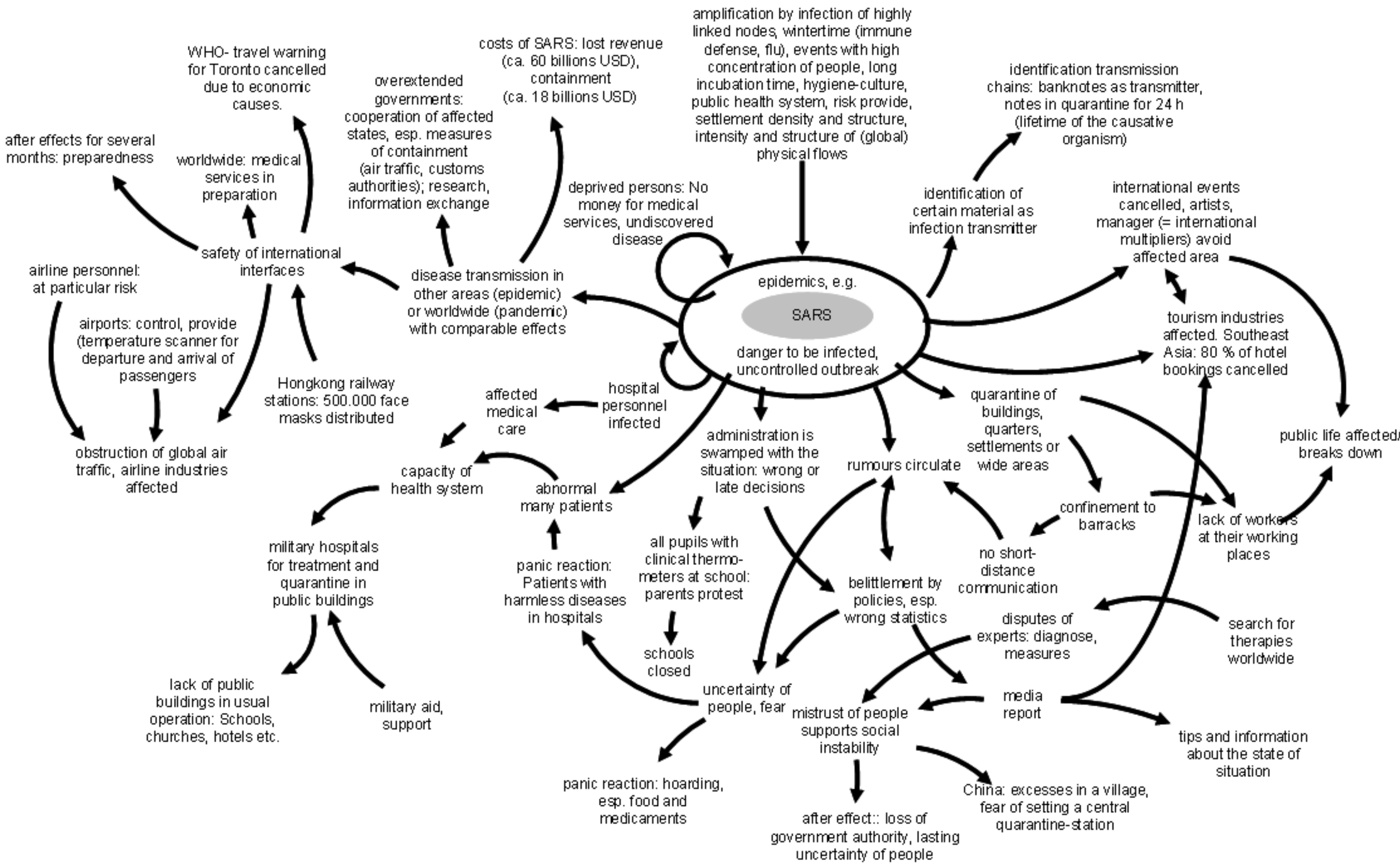
Causality Network for Thunderstorms



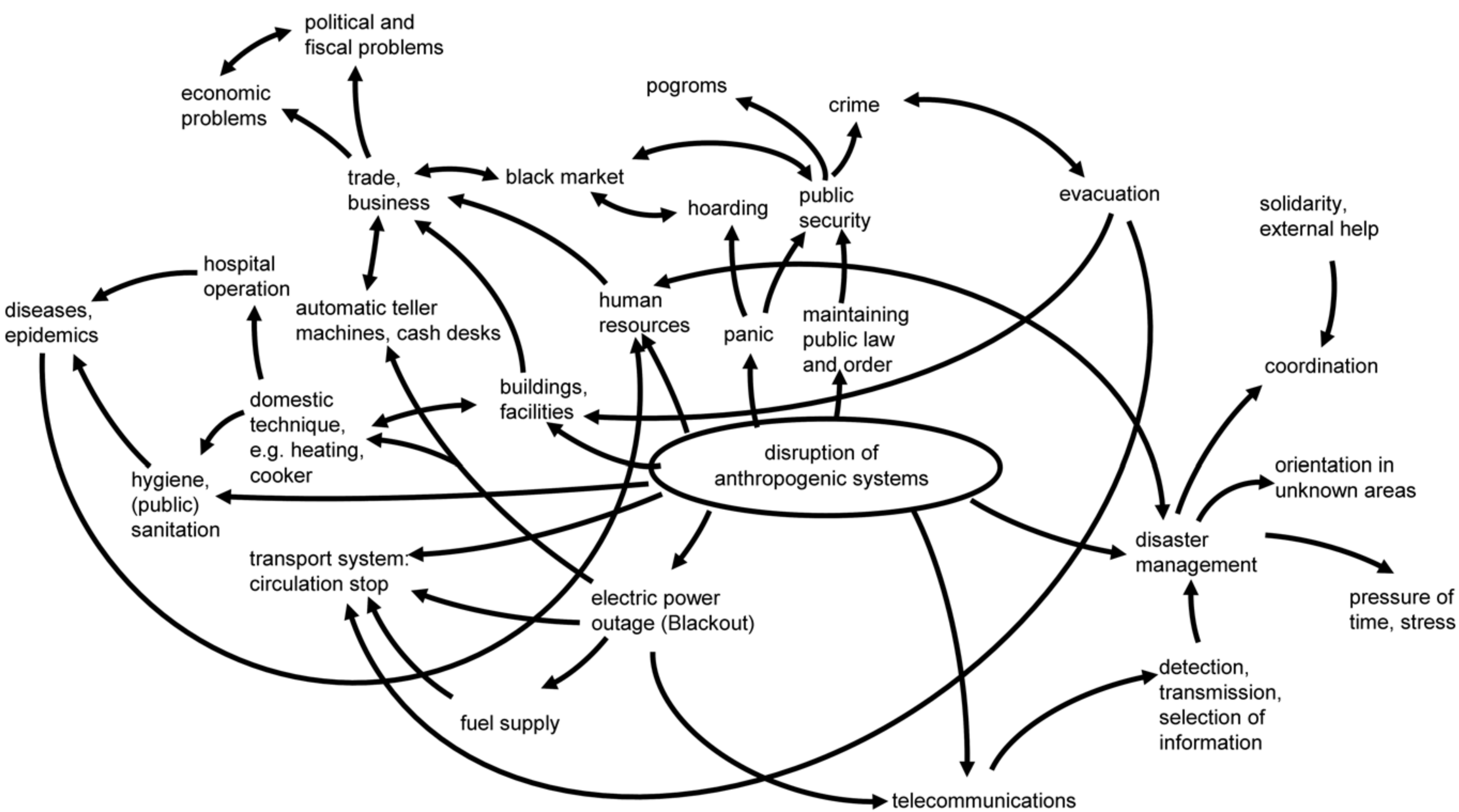
Cascade Failures due to Earthquakes



Impact of Epidemics

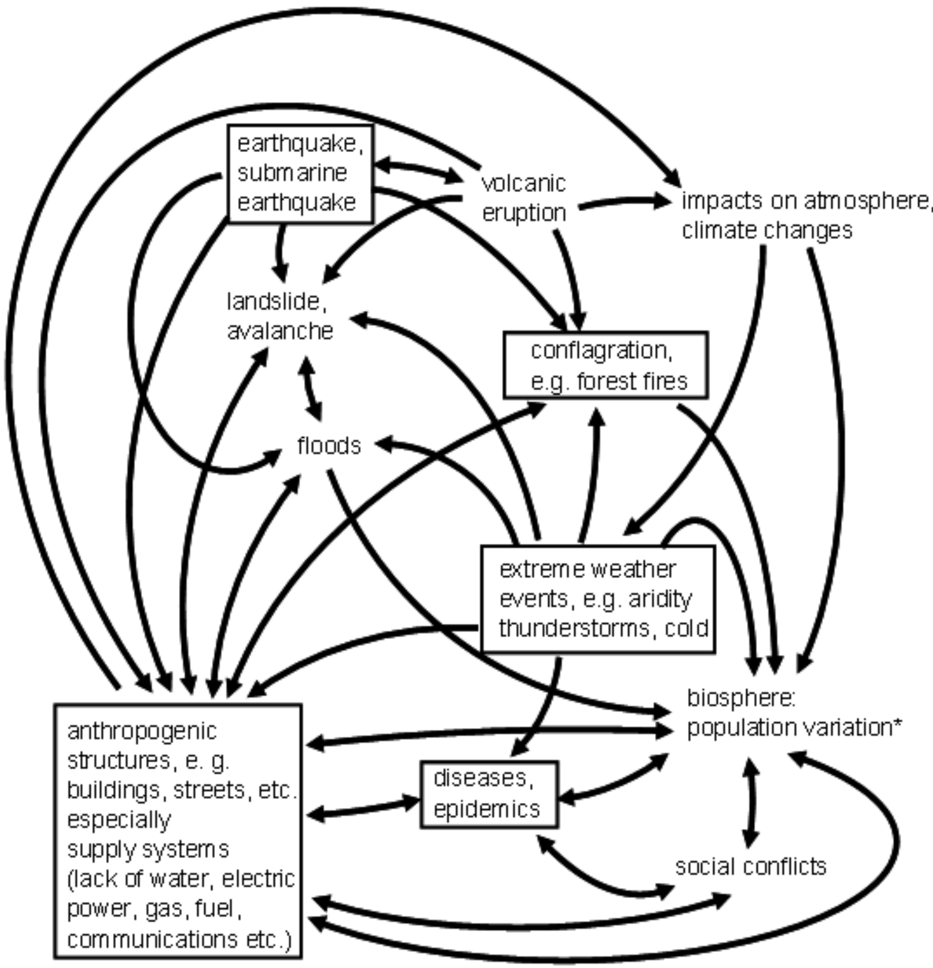


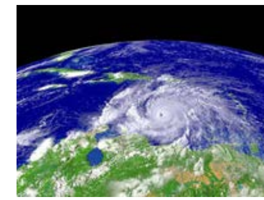
Common Elements of Disasters



Causal Dependencies and Interaction Networks

Disasters cause disasters





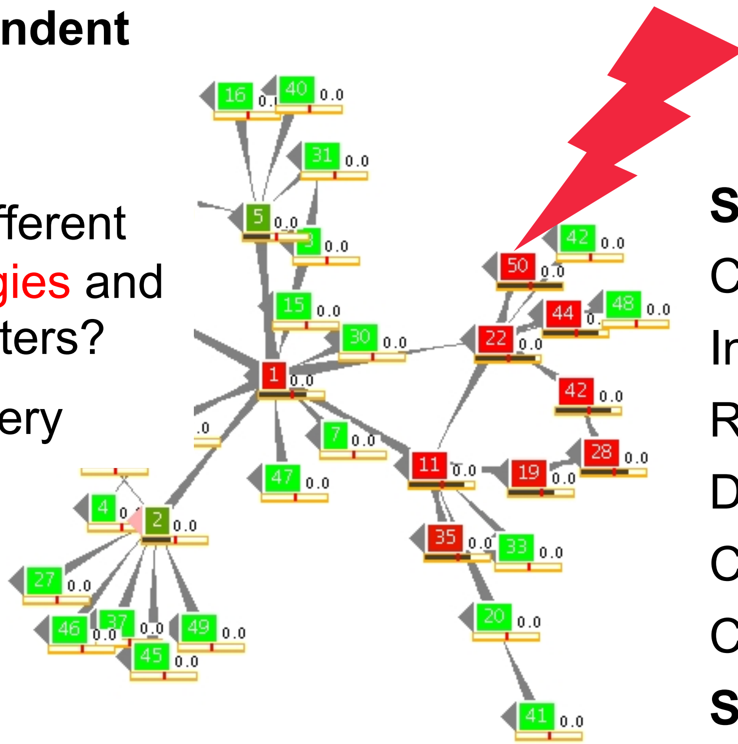
Modeling Cascade Spreading

Modeling and Simulation of Disaster Spreading

Simulation of topology dependent spreading:

- What are the influences of different network topologies and system parameters?

- Optimal recovery strategies?



Spreading of disasters:

Causal dependencies (directed)

Initial event (internal, external)

Redistribution of loads

Delays in propagation

Capacities of nodes (robustness)

Cascade of failures

Scope of research:

Spreading conditions (network topologies, system parameters)

Optimal recovery strategies

Buzna L., Peters K., Helbing D., Modelling the Dynamics of Disaster Spreading in Networks, Physica A, 2006

Mathematical Model of Disaster Spreading

Node dynamics:

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

x_i state of the node

$x_i = 0$ usual situation

$x_i > \theta_i$ node is destroyed

$$\Theta(x) = \frac{1-\exp(-\alpha x)}{1+\exp[-\alpha(x-\theta_i)]}$$

θ_i node threshold

t_{ij} time delay

M_{ij} link strength

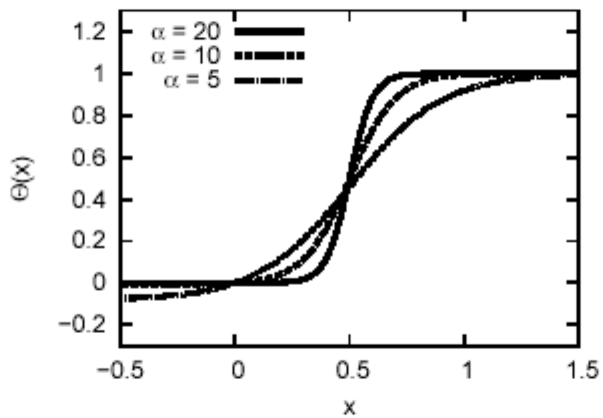
a, b, α, β fit parameters

$1/\tau$ healing rate

$\xi_i(t)$ internal noise

O_i node out-degree

Threshold function:



$$\Theta(x) = \frac{1-\exp(-\alpha x)}{1+\exp[-\alpha(x-\theta_i)]}$$

Node degree:

$$f(O_i) = \frac{aO_i}{1+bO_i}$$

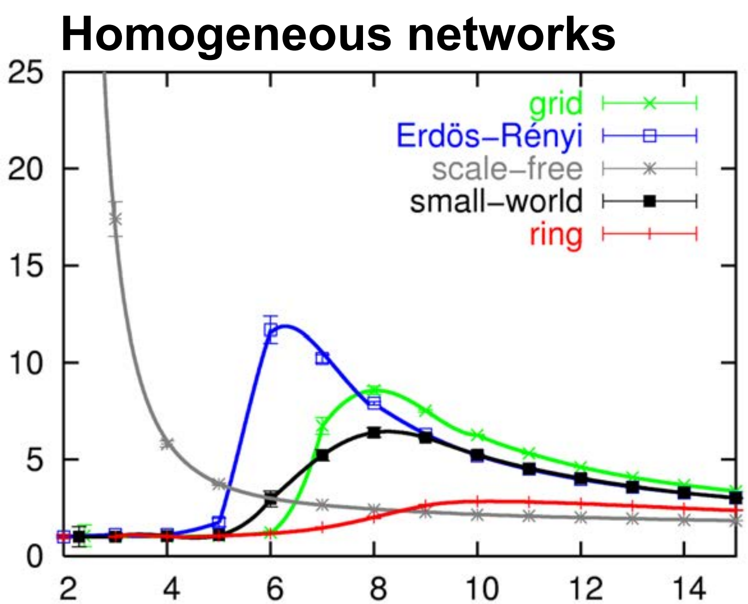
We use a directed network, dynamical, bistable node models and delayed interactions along links.

Failures Triggered by Internal Fluctuations

Coinciding, distributed, random failures:

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

Damage compared to an "unconnected network":



L. Buzna, K. Peters, D. Helbing: Modeling the dynamics of disaster spreading in networks, *Physica A* **363**, 132-140 (2006)

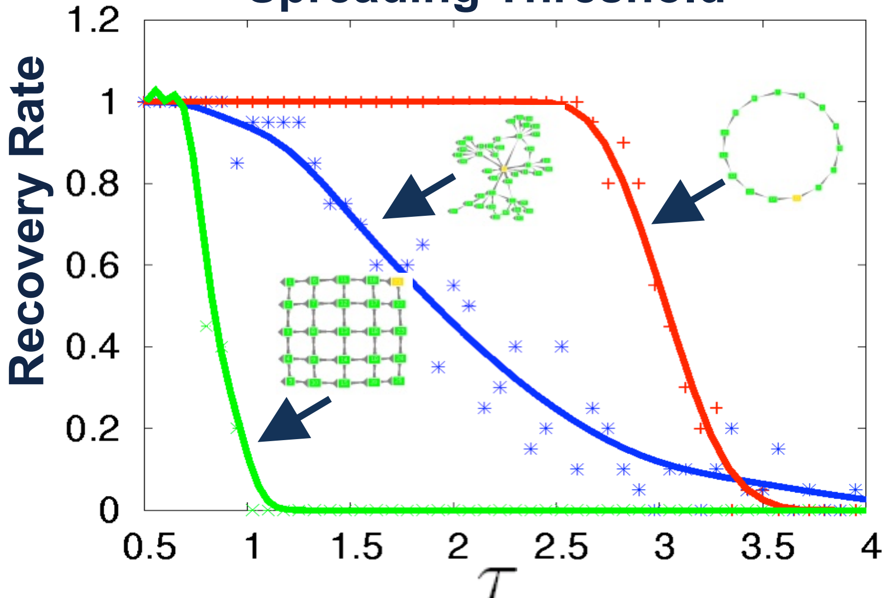
➡ Connectivity is an important factor (in a certain region).

Phase Transition in Disaster Spreading

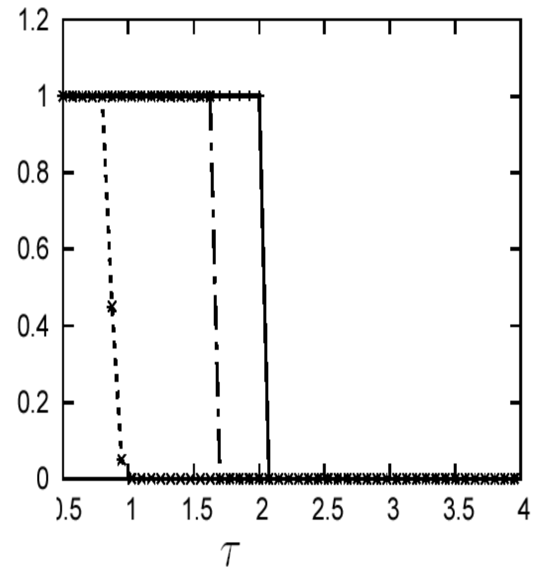
Node robustness vs. failure propagation:

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

Spreading Threshold



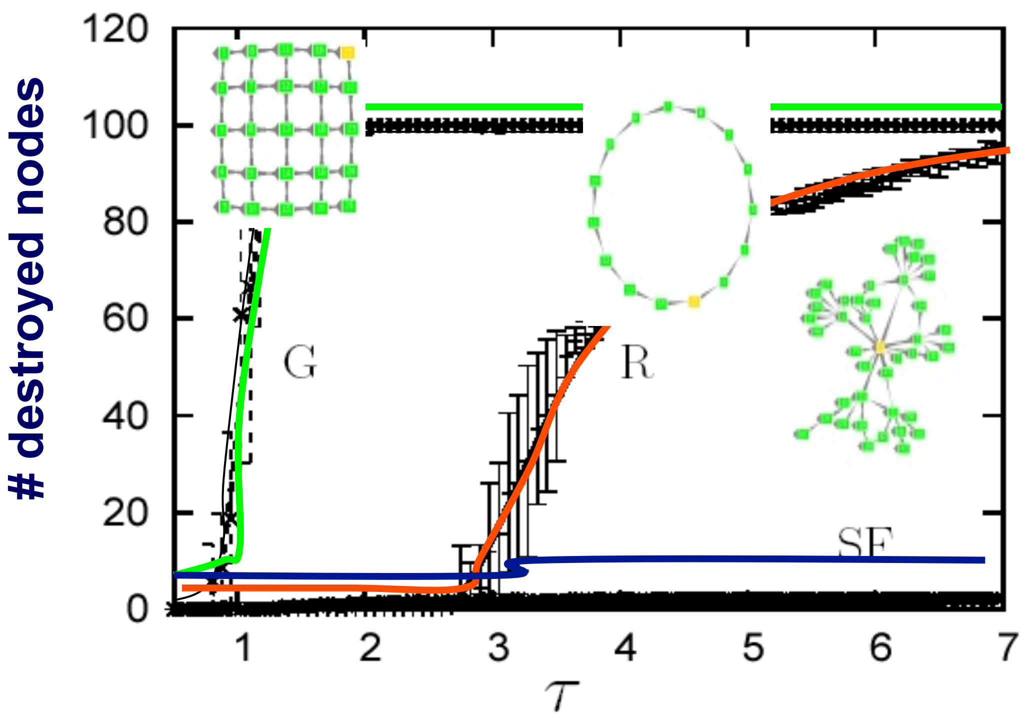
Homogeneous networks



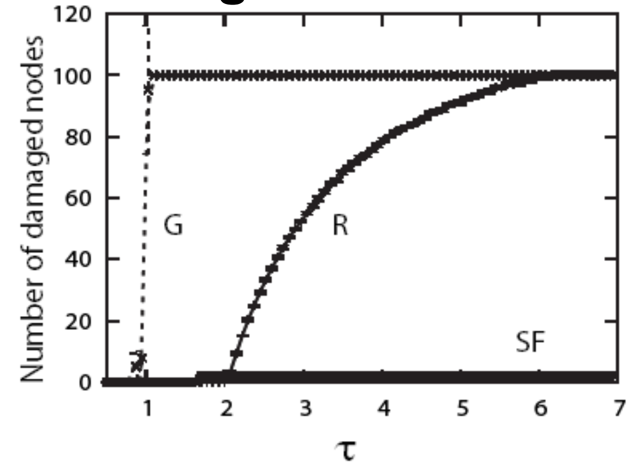
➡ **We found a critical threshold for the spreading of disasters in networks.**
Topology and parameters are crucial.

Topology and Spreading Dynamics

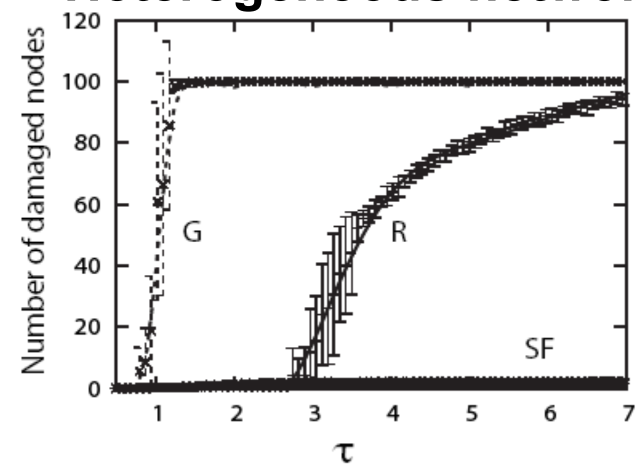
Example: 100 nodes, average state after t=300



Homogeneous network



Heterogeneous network



We found 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 e complex networks, International Journal of Critical Infrastructures, in print (2007).

Modelling the Recovery of Networks

1. Mobilization of external resources:

$$r(t) = a_1 t^{b_1} e^{-c_1 t}$$

2. Formulation of recovery strategies as a function of

- the network topology

- the level of damage

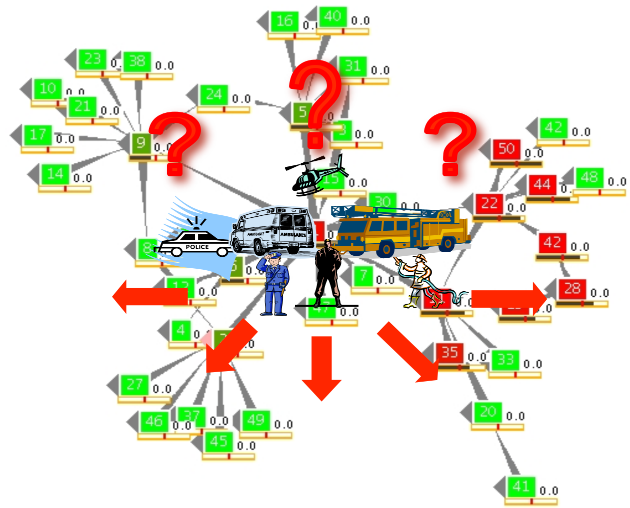
$$\frac{1}{\tau_i(t)} = \frac{1}{(\tau_{start} - \beta_2)e^{-\alpha_2 R_i(t)} + \beta_2}$$

3. Application of resources in nodes

Parameters:

t_D time delay in response

R disposition of resources



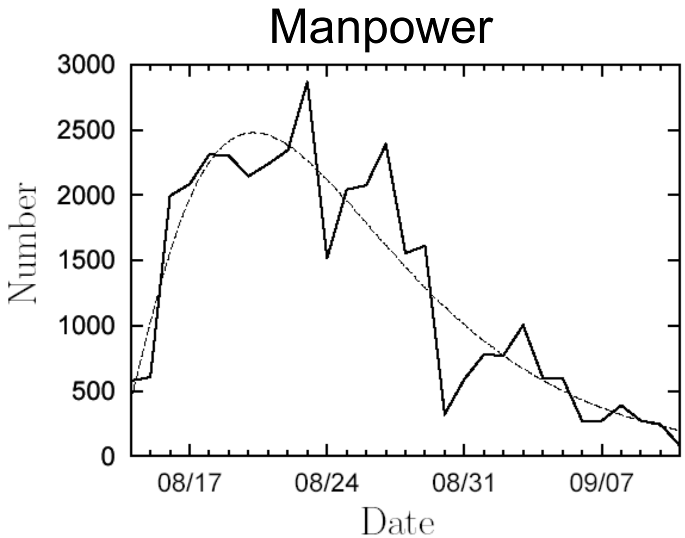
$R_i(t)$ cumulative number of resources deployed at node *i*

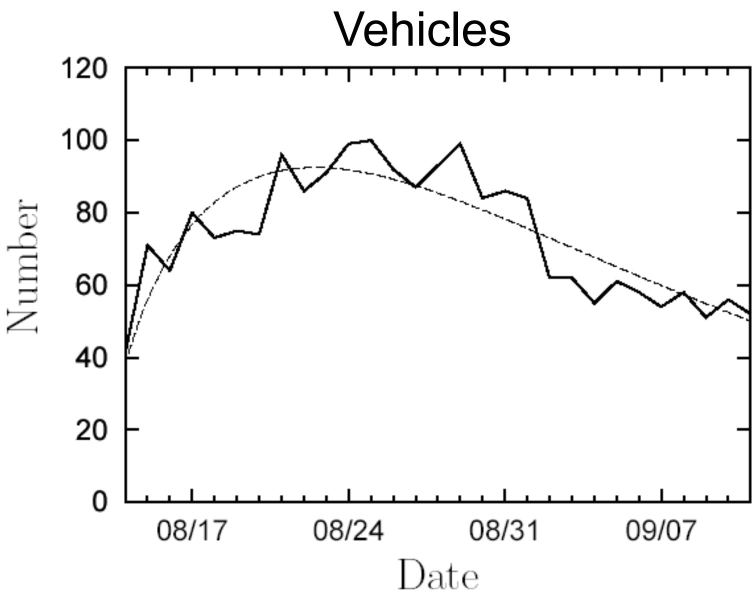
τ_{start} initial intensity of recovery process

α_2 β_2 fit parameters

Mobilization of Resources

Example: Mobilization during the Elbe flood 2002:





Mobilization of resources (time dependent)

External resources become available after a certain response time delay T_D

During mobilization the number of resources increases

Later a phase of demobilization occurs

Number of available resources *r(t)*:

$$r(t) = a_1 t^{b_1} e^{-c_1 t}$$

a_1, b_1, c_1 are fit parameters

How to Distribute Available Resources ?

Formulation of recovery strategies, based on information :

S_0 no recovery

Topology information only:

S_1 uniform deployment

S_2 out degree based dissemination

Damage information:

S_3 uniform reinforcement of challenged nodes ($x_i>0$)

S_4 uniform reinforcement of destroyed nodes ($x_i> \theta_i$)

Damage & topology information:

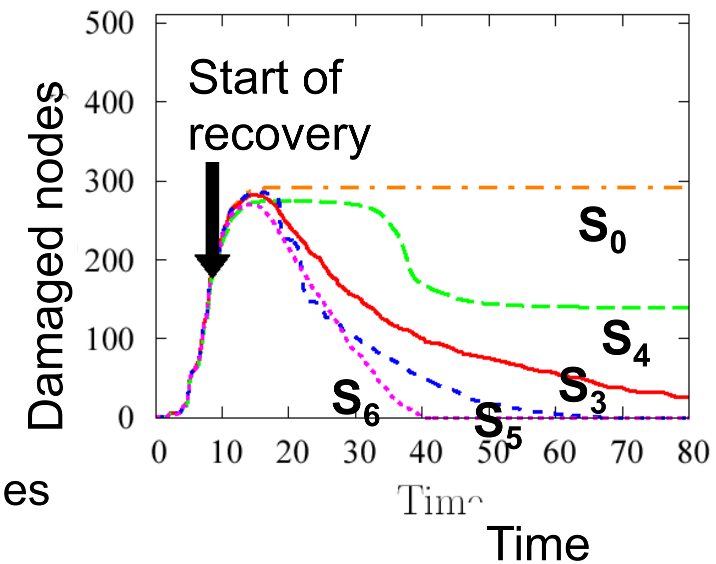
S_5 targeted reinforcement of highly connected nodes

1st priority: fraction q to hub nodes

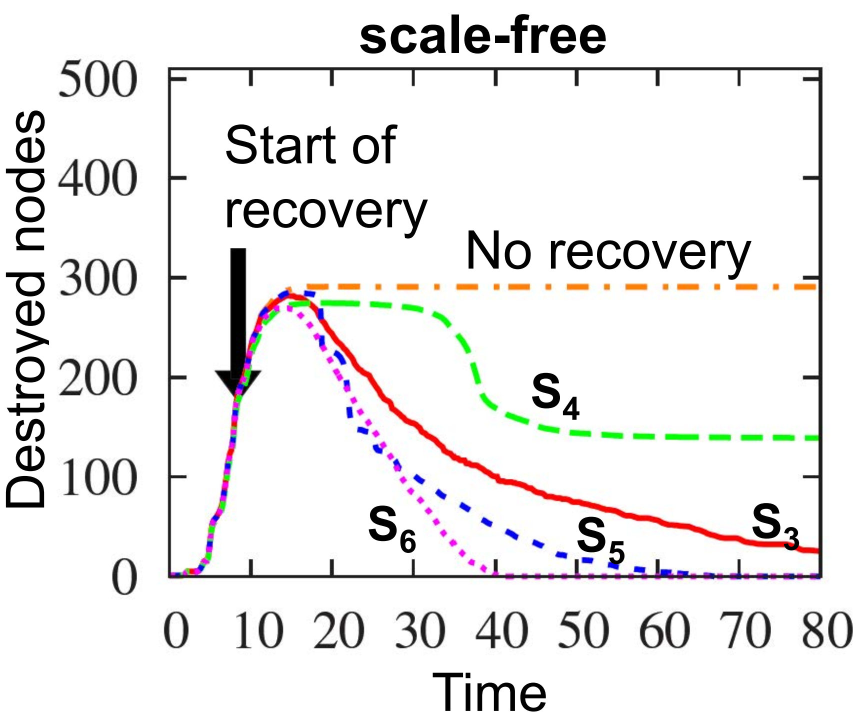
2nd priority: fraction 1-q according to S_4

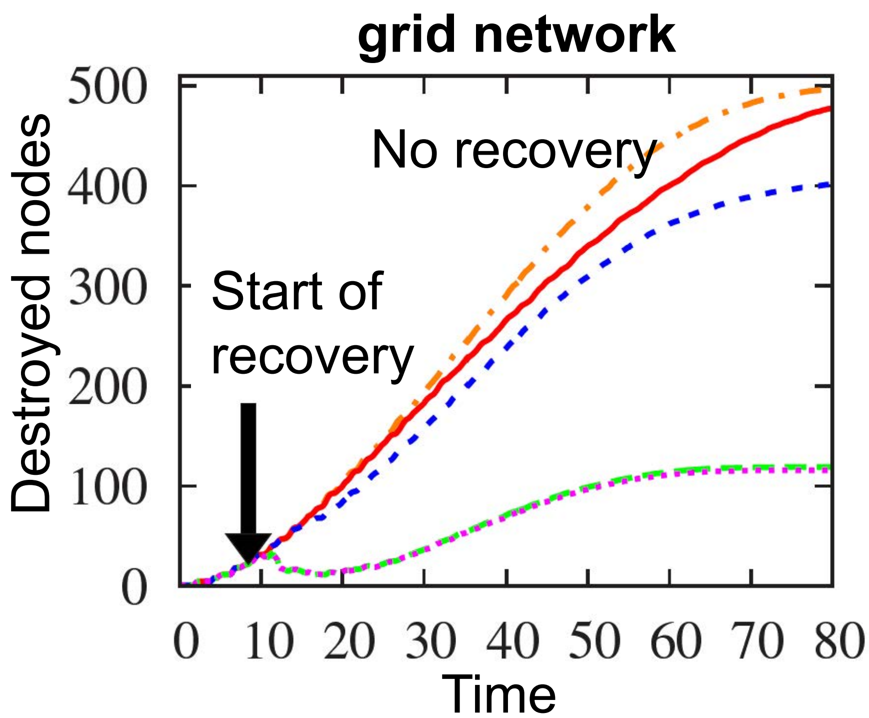
S_6 out-degree based targeted reinforcment of destroyed nodes

Application of resources to a scale-free network



Recovery of Networks





Parameters: Network topology

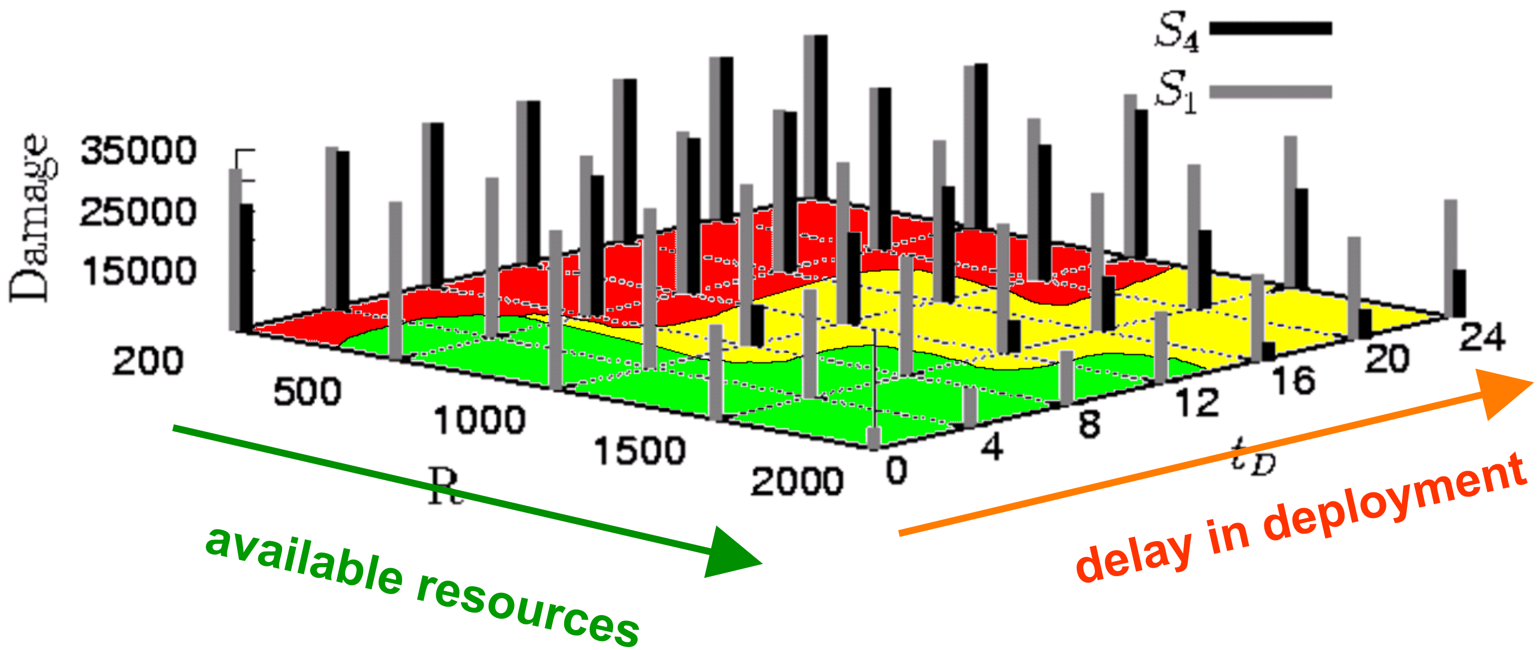
time delay in response $t_D = 8$

disposition of resources $R = 1000$

L. Buzna, K. Peters, H. Ammoser, Ch. Kuehnert and D. Helbing: Efficient response to cascading disaster spreading, *Physical Review E* **75**, 056107 (2007)

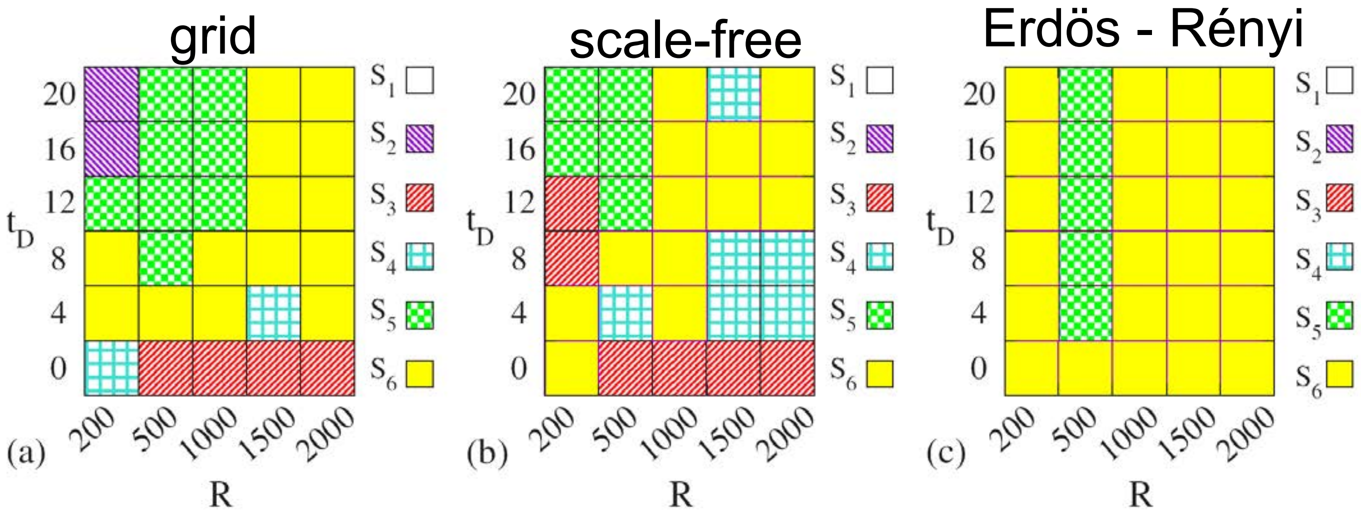
Recovery of Networks: When Does Strategy Matter?

Comparison of efficient and inefficient strategies:



- The delay of recovery activities is crucial.
- Optimization of recovery strategies is promising in certain parameter regions.

Most Efficient Strategies



There is no unique optimal response strategy:

1. Strategies based on the network structure has been proved as a most suitable for scale-free structures.
2. Strategies based on the damage information are more appropriate for regular networks.
3. The situation in Erdős-Rényi and small-world networks depends on

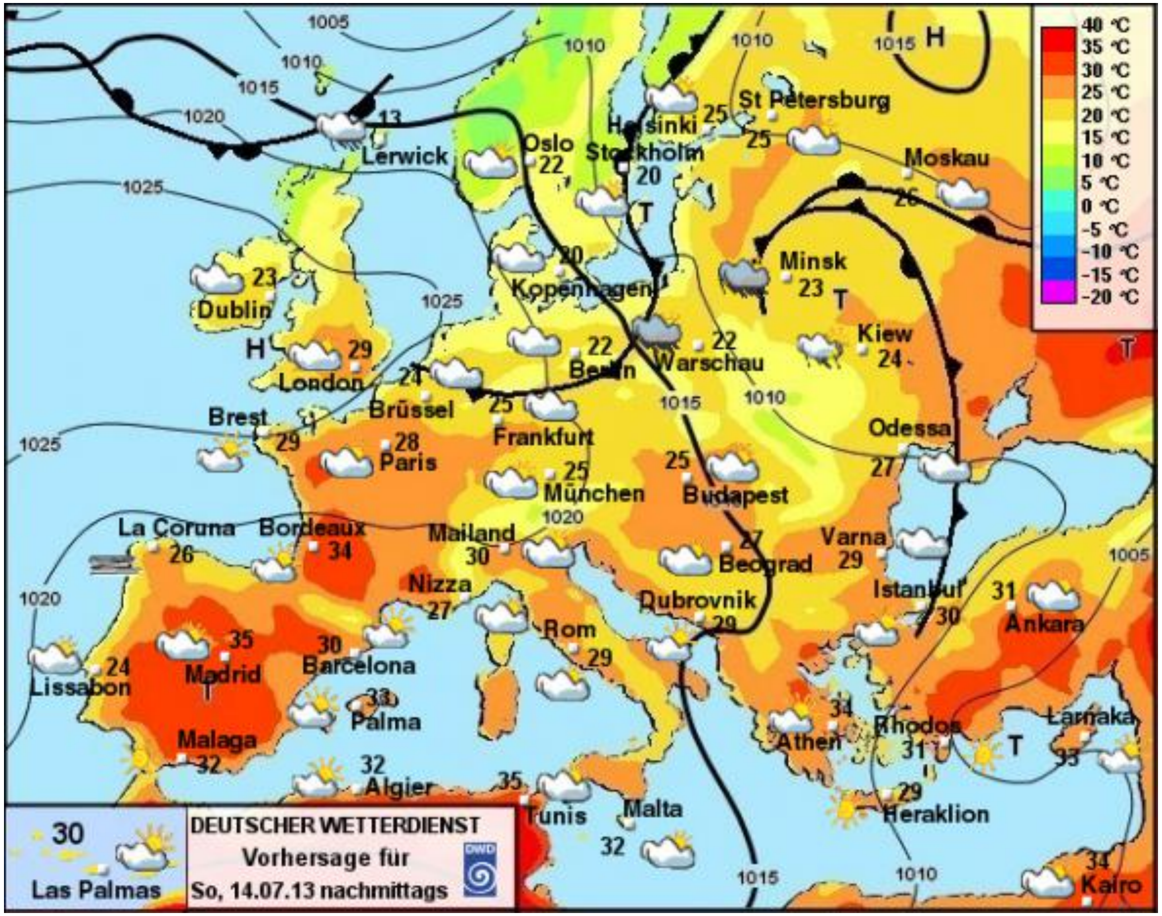
(short t_D => damage based strategies)
(large t_D => network structure based strategies)

Intermediate Conclusions

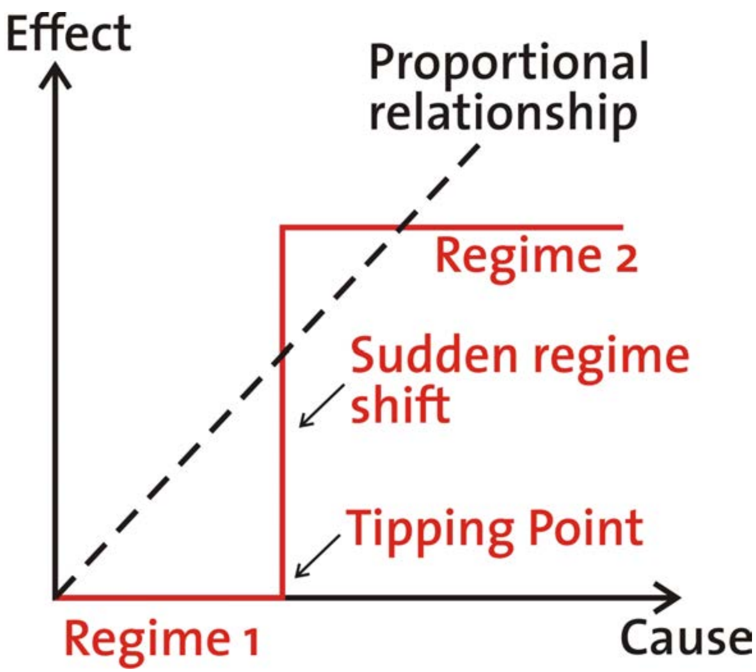
- We have developed models to represent causal interrelationships triggering cascading disaster spreading, allowing to compare the effectiveness of alternative response strategies
- A time-dependent model of disaster spreading allowed us to describe the impact of the topology of interrelationship networks on the spreading dynamics
- The efficiency of different disaster response/relief strategies could be tested by the same model. Different networks require different response strategies! A quick response is crucial.
- A model of cascading failures in power grids showed that stationary spreading models underestimate the robustness of electrical power supply networks by 80% and more.

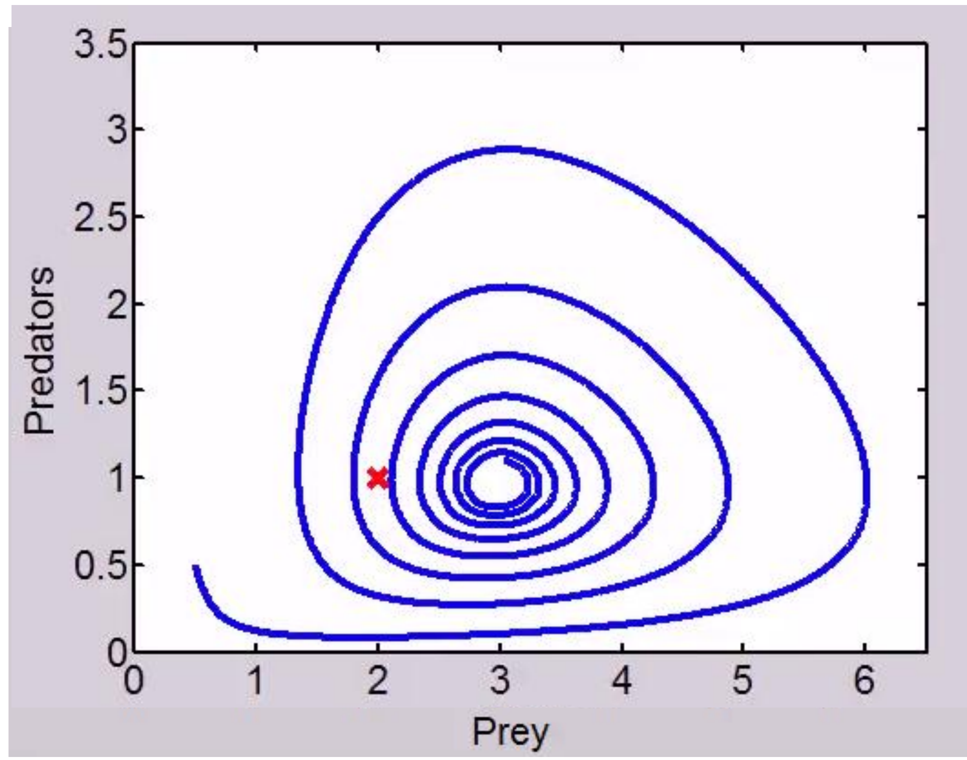
Dynamical Instability

Limits of Predictability due to Turbulence or Chaos

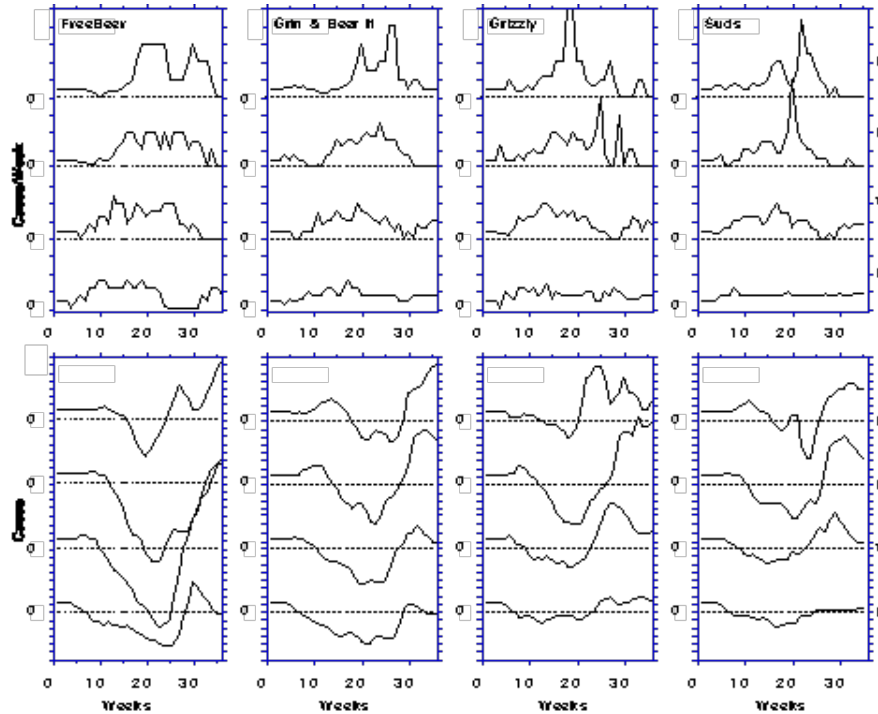


Complex Systems: The Illusion of Control

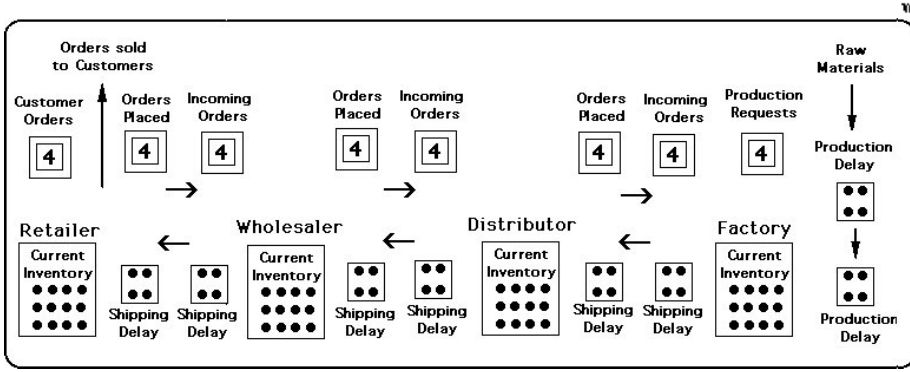


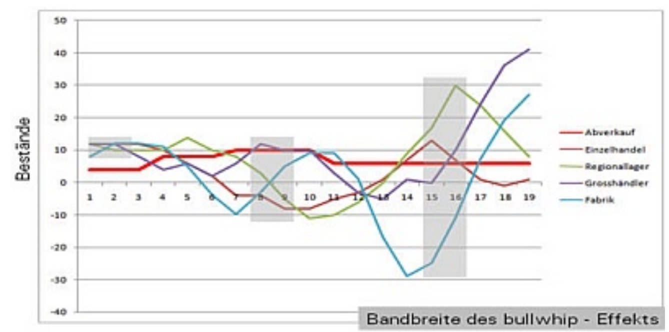


John D. Sterman‘s Beer Game

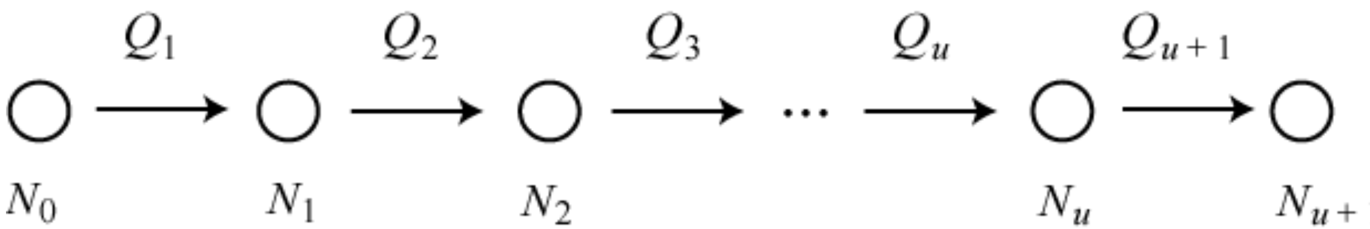


Perturbations in demand amplify





Modeling Linear Supply Chains



The stock level ("inventory") N_b at supplier b changes in time t according to

$$\frac{dN_b}{dt} = Q_b(t) - Q_{b+1}(t)$$

$Q_b(t)$ … rate at which supplier b receives ordered products from supplier $b - 1$

$Q_{b+1}(t)$ … rate at which supplier b delivers products to the next downstream supplier $b + 1$

D. H., *New Journal of Physics* **5.90,** 1-28 (2003).

Modeling Linear Supply Chains

The temporal change of the delivery rate is proportional to the deviation of the actual de-livery or production rate from the desired one W_b (the order rate). Its adaptation takes on average some time interval τ:

$$\frac{dQ_b}{dt} = \frac{1}{\tau}[W_b(t) - Q_b(t)]$$

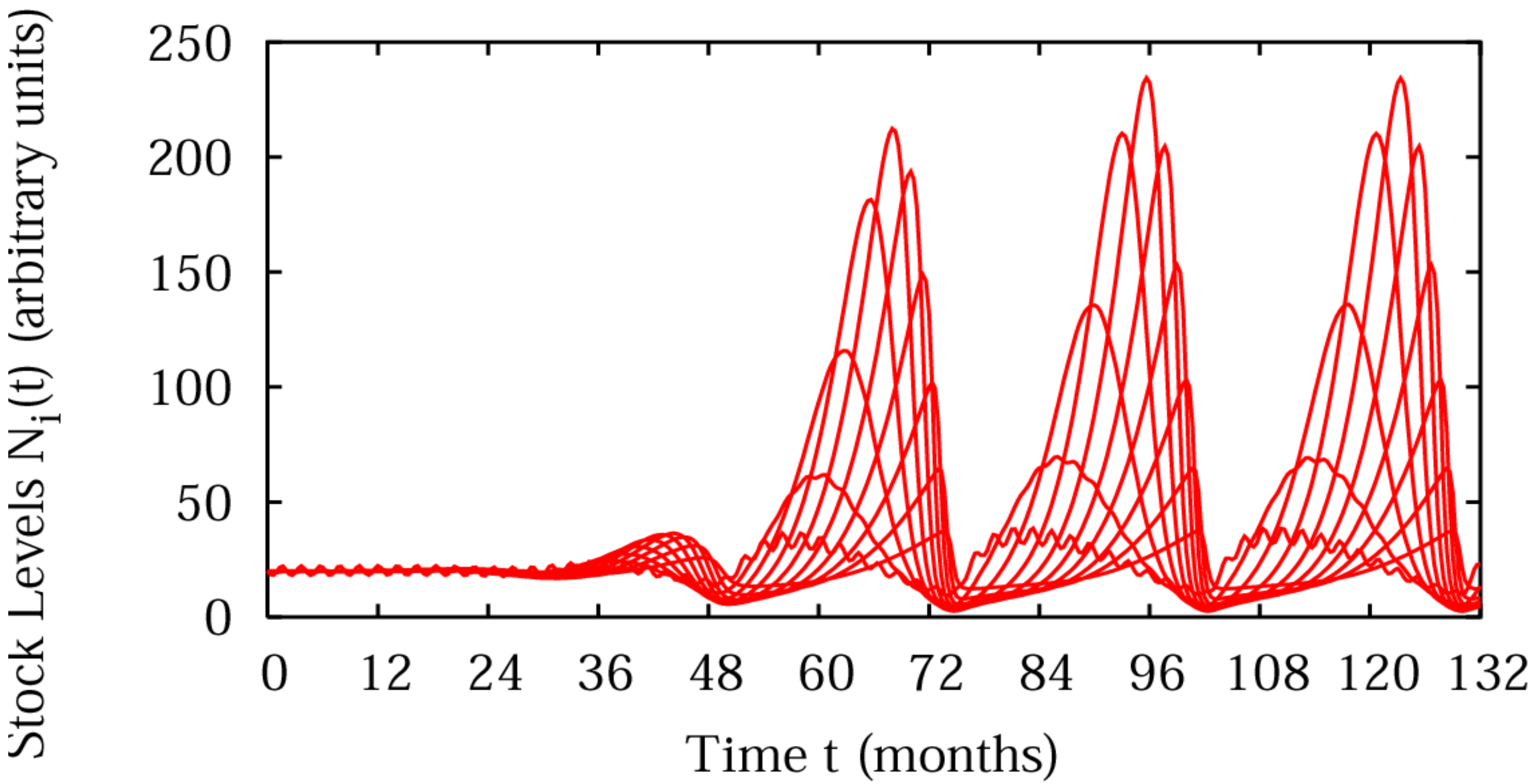
with $W_b(t) = W_b(\{N_a(t)\}, \{dN_a(t)/dt\}) = W(N_{(b)}(t))$

$$N_{(b)}(t) = \sum_{c=-n}^{n} w_c \left(N_{b+c} + \Delta t \frac{dN_{b+c}}{dt} \right)$$

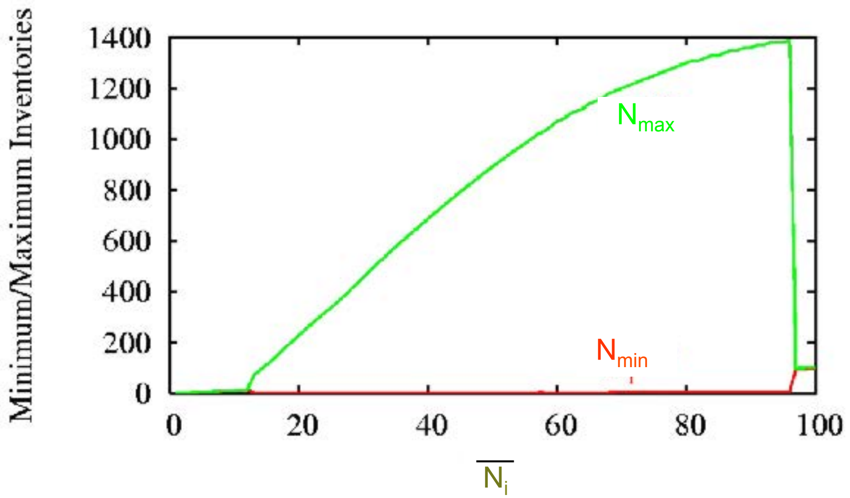
is a weighted mean value of the own stock level and the the ones of the next n upstream and n downstream suppliers. The weights w_c are normalized to one:

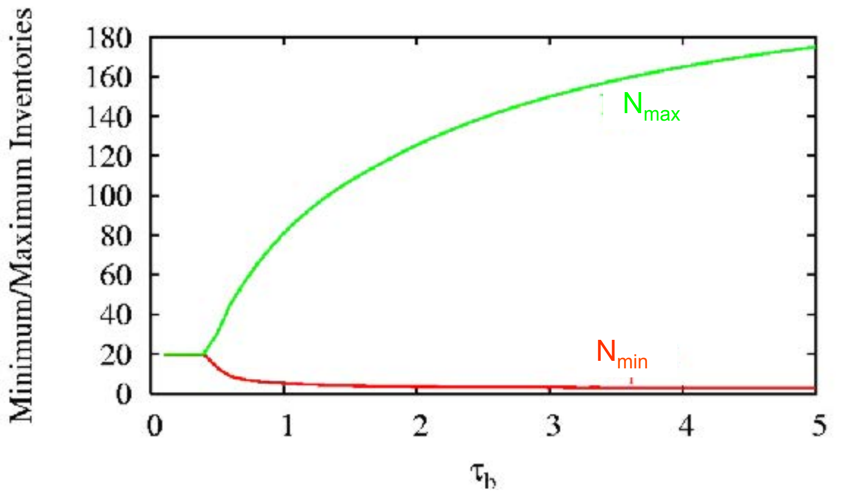
$$\sum_{c=-n}^{n} w_c = 1.$$

Bullwhip Effect

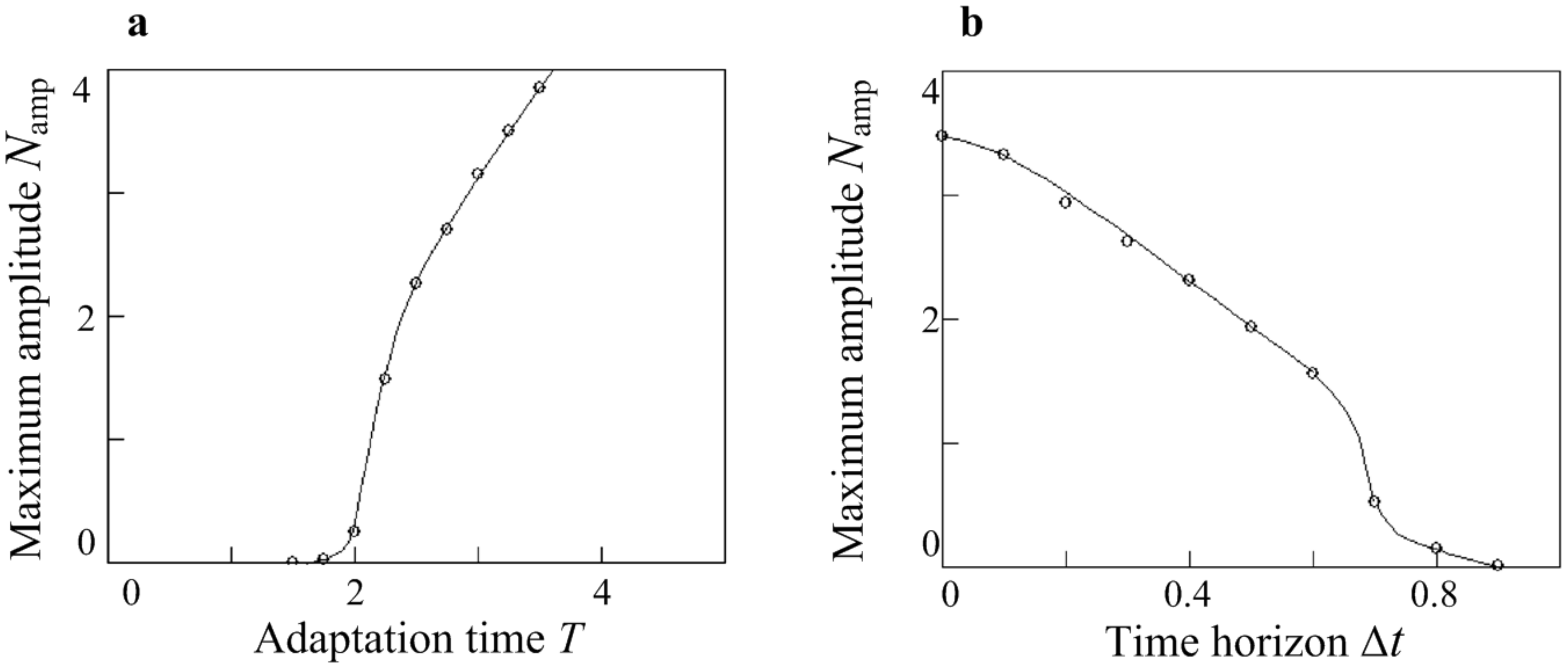


Phase Transitions in Supply Chains





Parameter Dependencies

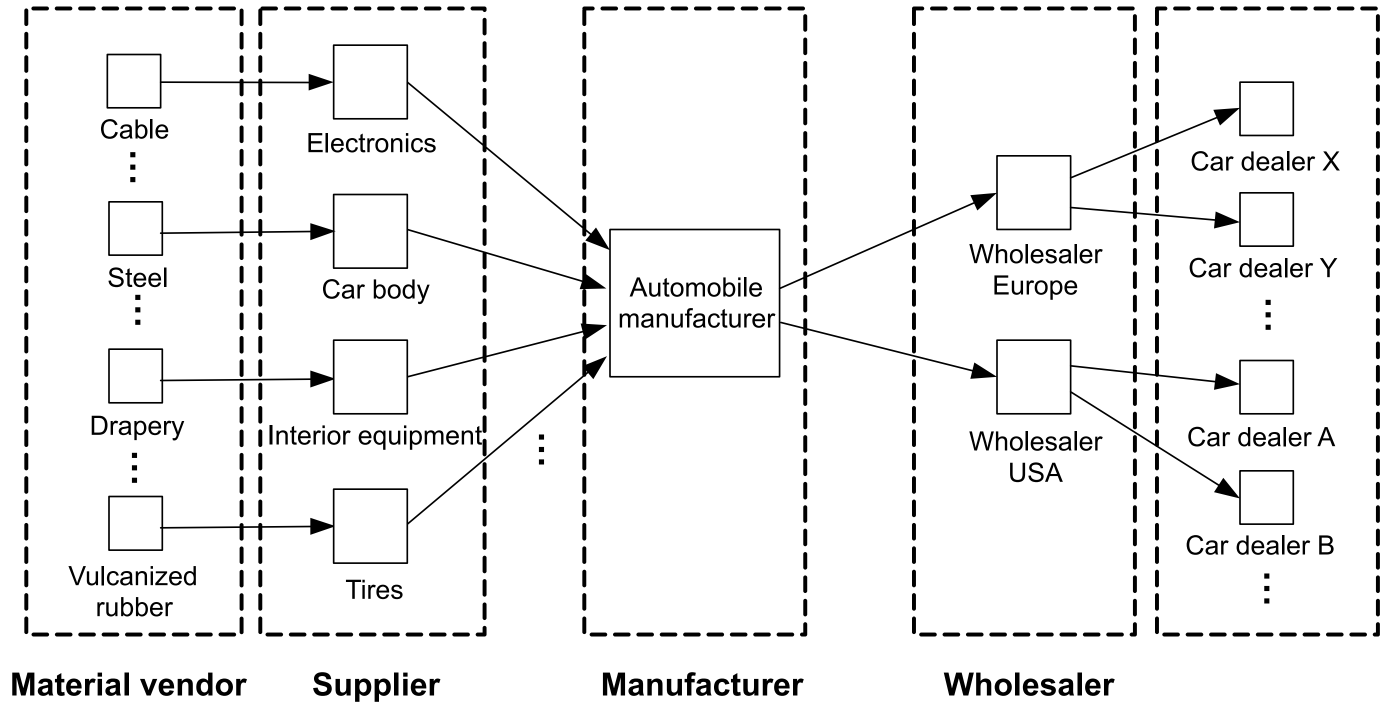


Material Flows in Supply Networks

Open questions:

- **Inventory** vs. **just in time** production?
- How important is the **network topology**?

Supply Chain as a network structure:



Modeling Supply Networks

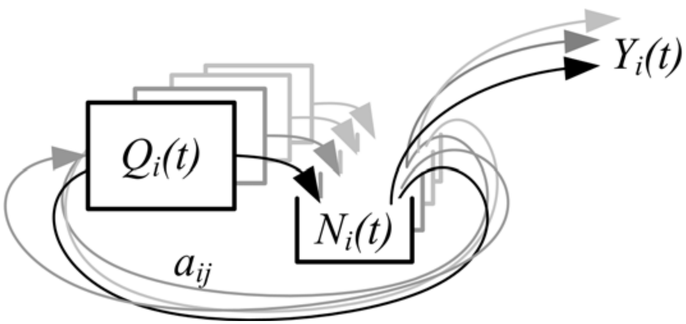
Conservation of resources

$$\dot{N}_i(t) = \underbrace{Q_i(t)}_{\text{supply}} - \underbrace{\sum_{j=1}^{m} a_{ij} Q_j(t)}_{\text{re-entrant}} - \underbrace{Y_i(t)}_{\text{outflow}}$$

(a_{ij})	input matrix $\mathbf{A}$
$N_i(t)$	inventory level
$Q_i(t)$	delivery rate
$Y_i(t)$	consumption rate
$P_i(t)$	price level

Adaptation of delivery rates

$$\frac{\dot{Q}_i(t)}{Q_i(t)} = \hat{\nu} \underbrace{\left(\frac{N_i^0}{N_i(t)} - 1 \right)}_{\substack{\text{deviations from} \\ \text{desired level}}} - \hat{\mu} \underbrace{\frac{\dot{N}_i(t)}{N_i(t)}}_{\substack{\text{temporal} \\ \text{changes}}}$$

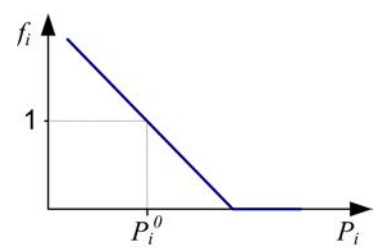


Adaptation of prices

$$\frac{\dot{P}_i(t)}{P_i(t)} = \nu \underbrace{\left(\frac{N_i^0}{N_i(t)} - 1 \right)}_{\substack{\text{deviations from} \\ \text{desired level}}} - \mu \underbrace{\frac{\dot{N}_i(t)}{N_i(t)}}_{\substack{\text{temporal} \\ \text{changes}}}$$

Consumption

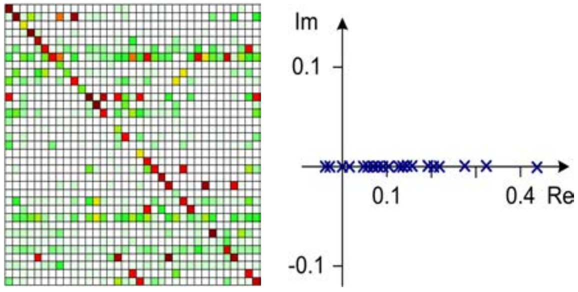
$$Y_i(t) = \left[Y_i^0 + \xi_i(t) \right] f_i \left(P_i(t) \right)$$

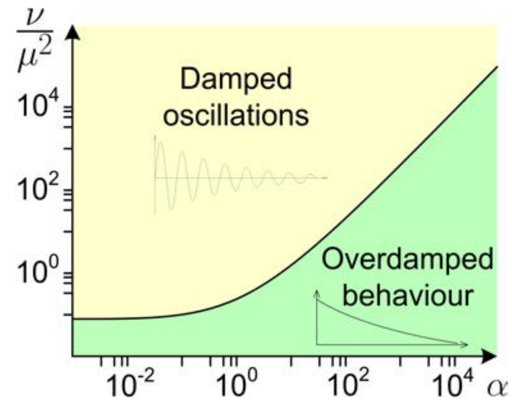


D. H., U. Witt, S. Lämmer, T. Brenner, *Physical Review E* **70**, 056118 (2004).

Network-Induced Oscillatory Behavior

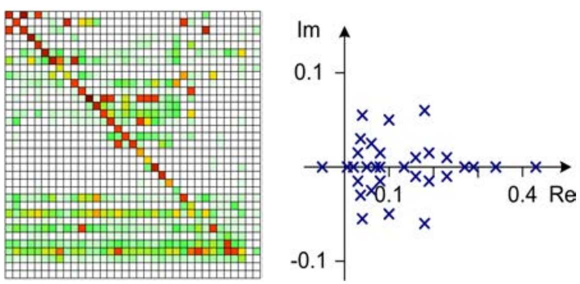
Input matrices with **real** eigenvalues only

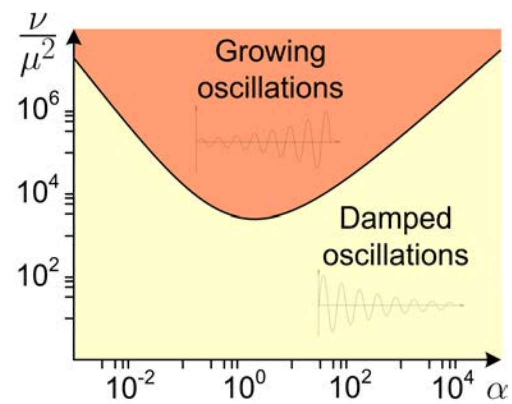




Overdamped behaviour possible.
Oscillations are **never growing**.

Input matrices with **complex** eigenvalues



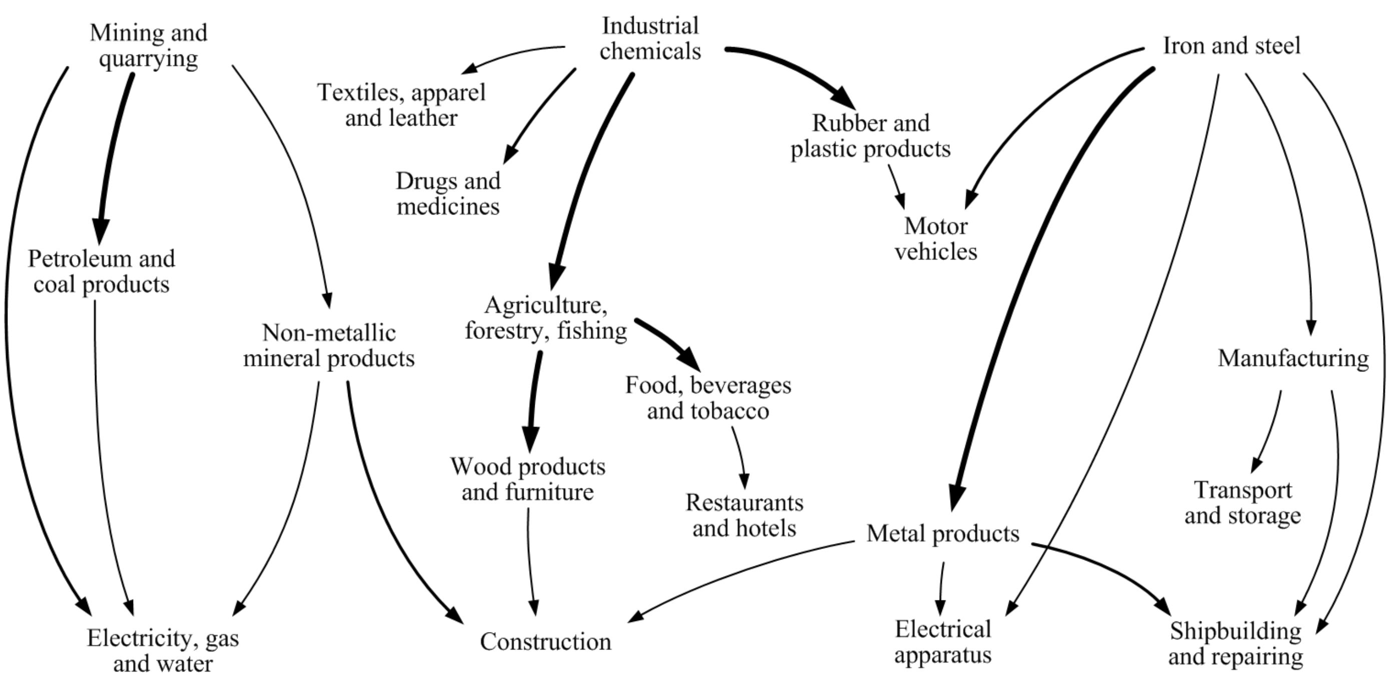


Always oscillating.
Growing oscillations are likely.

Supply Network of Economic Sectors

Commodity flow (average of FRA, GER, JAP, UK, USA)

Network structure



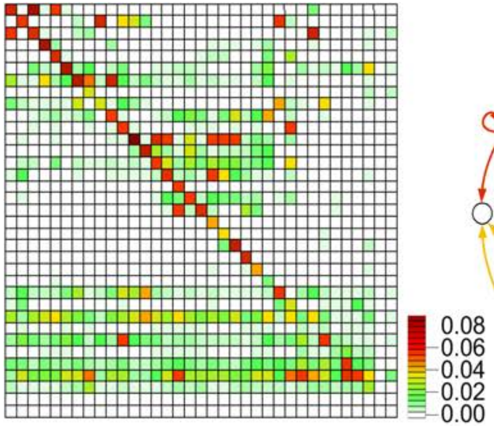
D. H., U. Witt, S. Lämmer, T. Brenner, *Physical Review E* **70**, 056118 (2004).

Business Cycles as Result of Network Flows

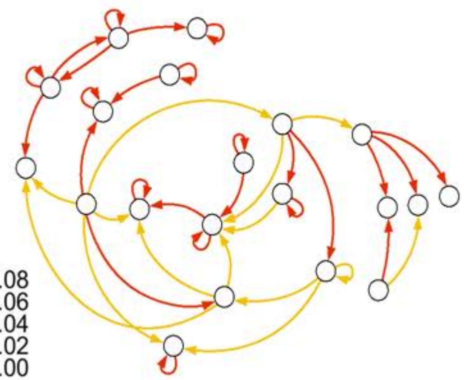
Investigation of the effect of network structure:

- Positive and negative feedbacks in production processes
- Time lags in the information flow and adaptation process

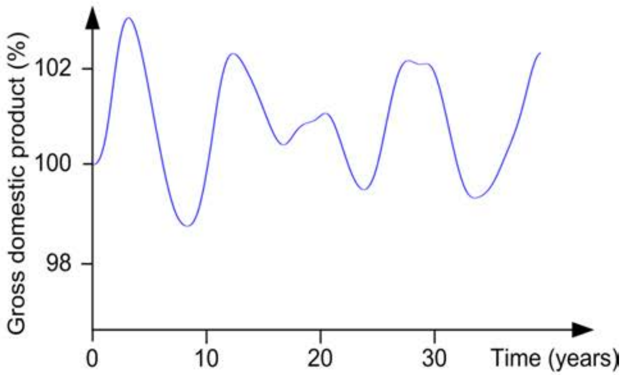
Business cycles because of the structure of production networks?



Input output matrix

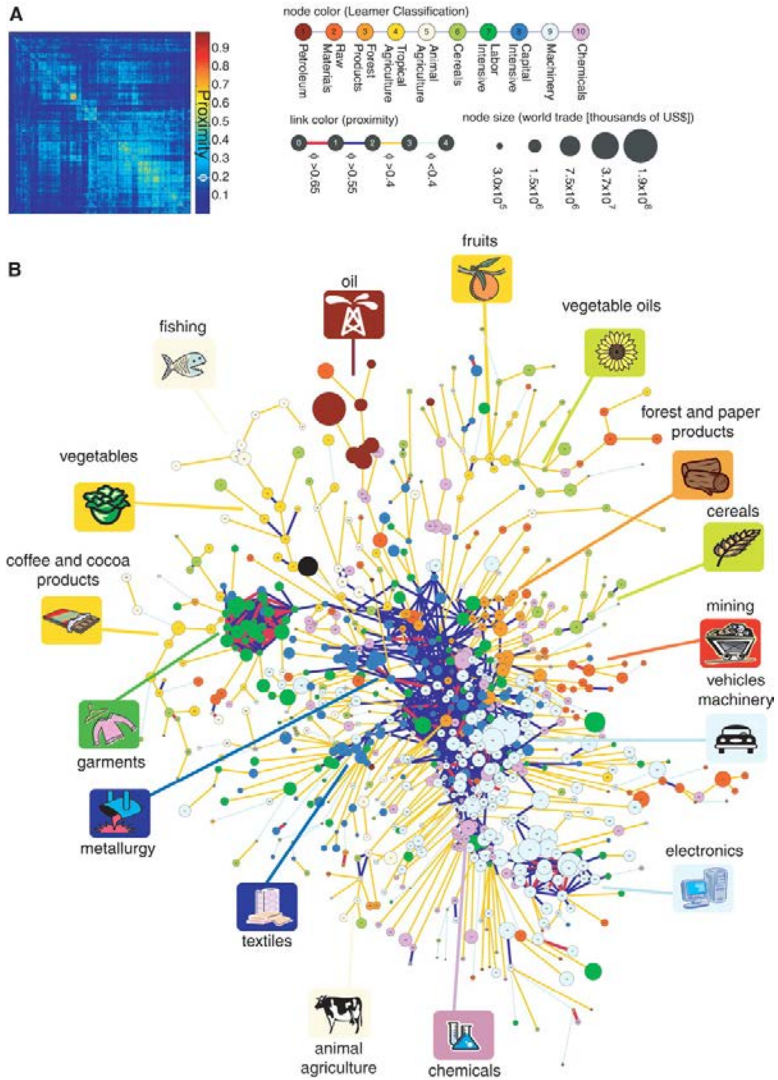


Related delivery network



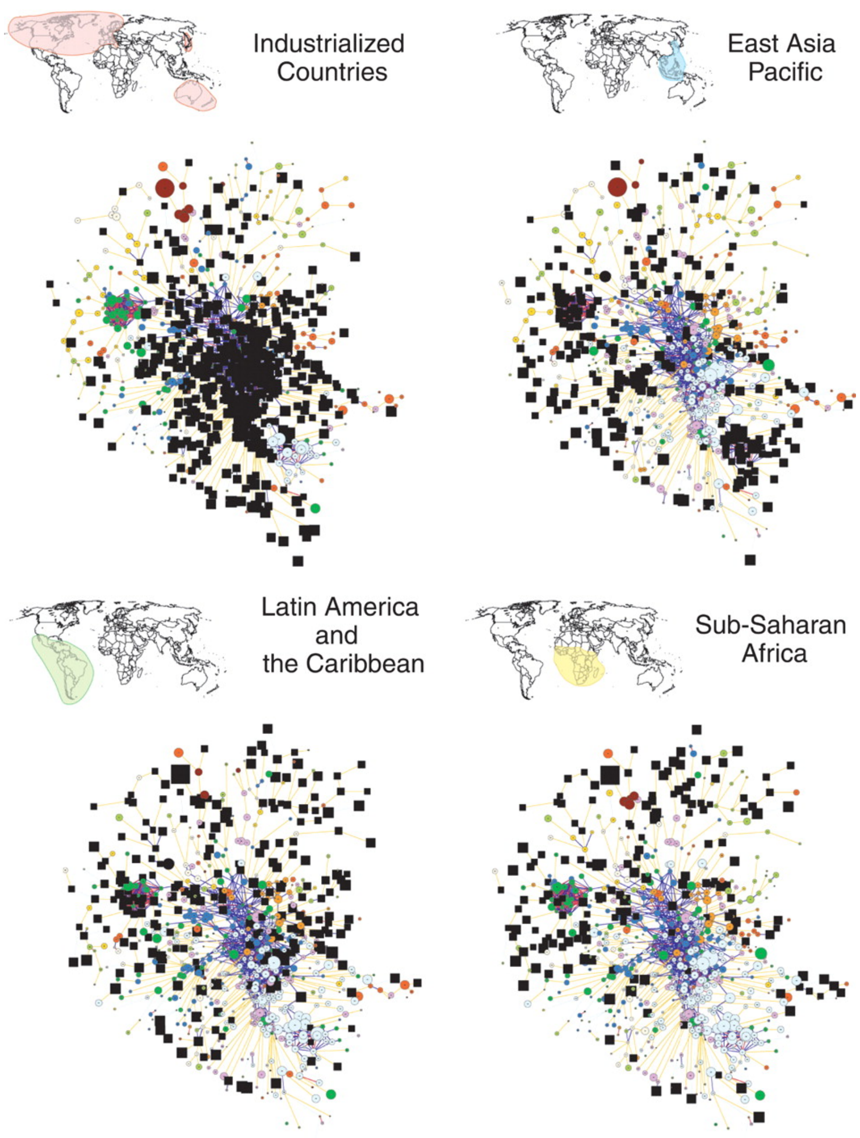
Resulting oscillations in the gross domestic product

Supply Network of Economic Sectors



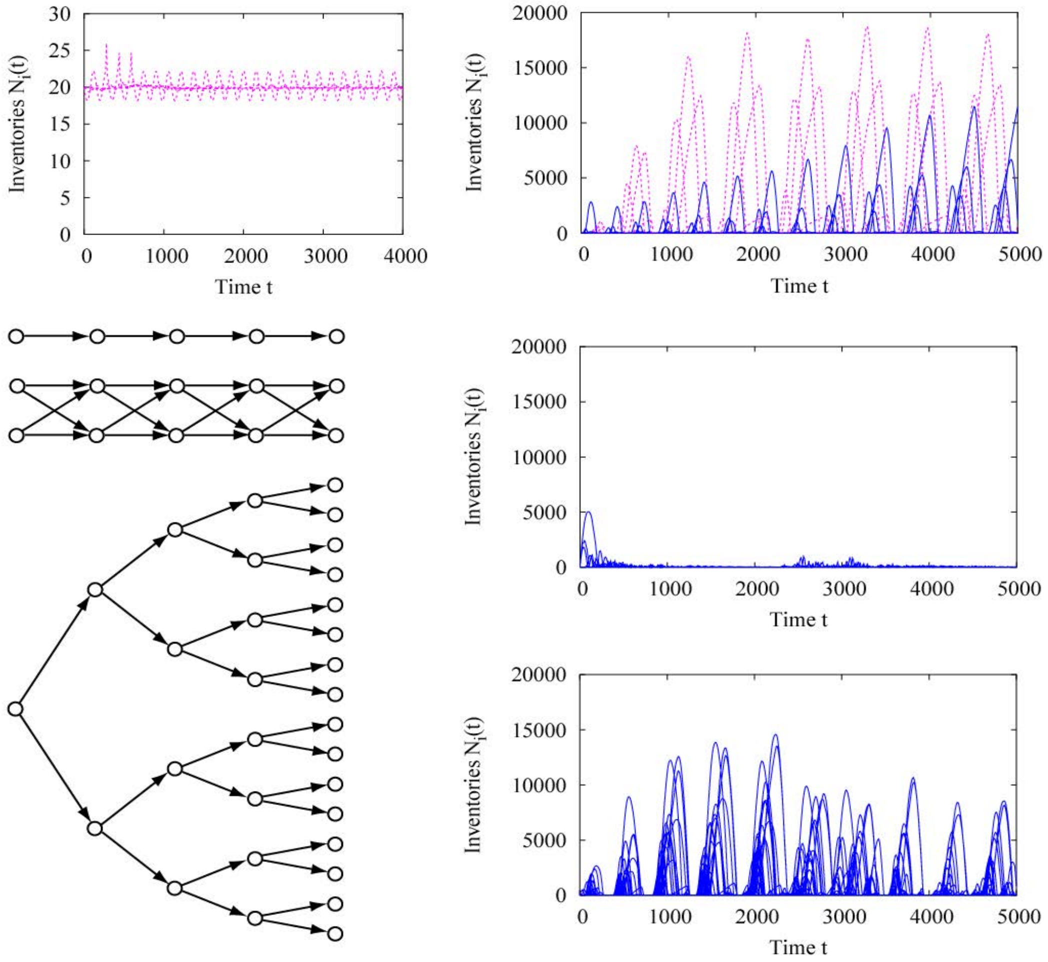
C.A. Hidalgo, B. Klinger, A.L. Barabasi, R. Hausmann, The product space conditions the development of nations. *Science* **317**, 482-487 (2007).

Supply Network of Economic Sectors



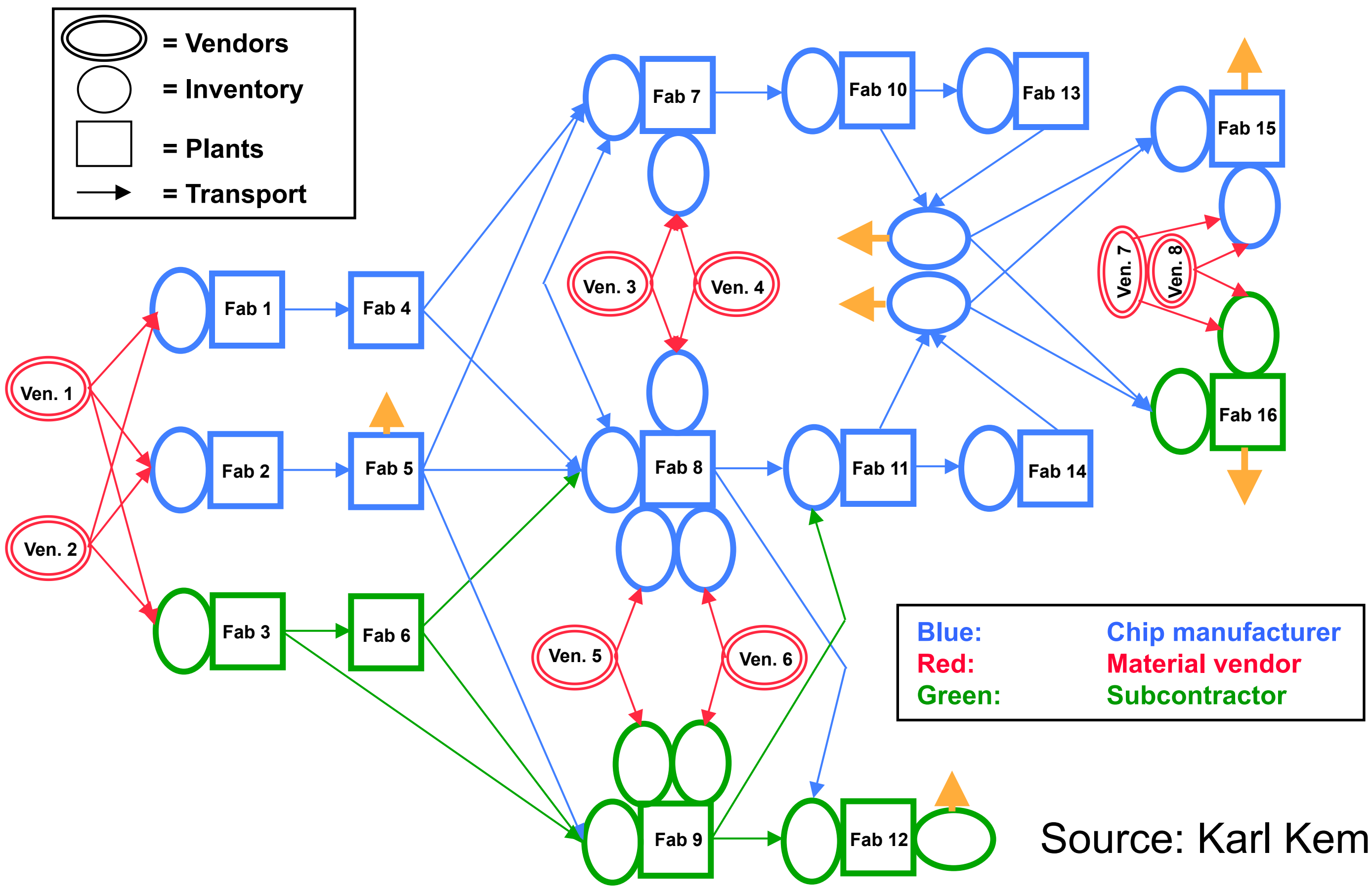
C.A. Hidalgo, B. Klinger, A.L. Barabasi, R. Hausmann, The product space conditions the development of nations. *Science* **317**, 482-487 (2007).

Structure of Supply Networks Can Stabilize



D. H., *New Journal of Physics* **5.90**, 1-28 (2003).

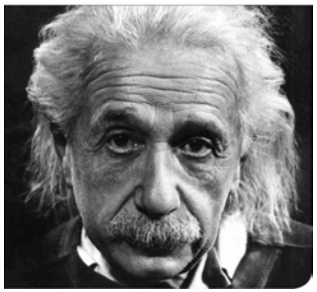
Distribution Network of Intel Technologies: Redundancy Matters

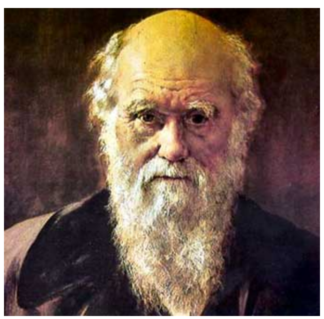


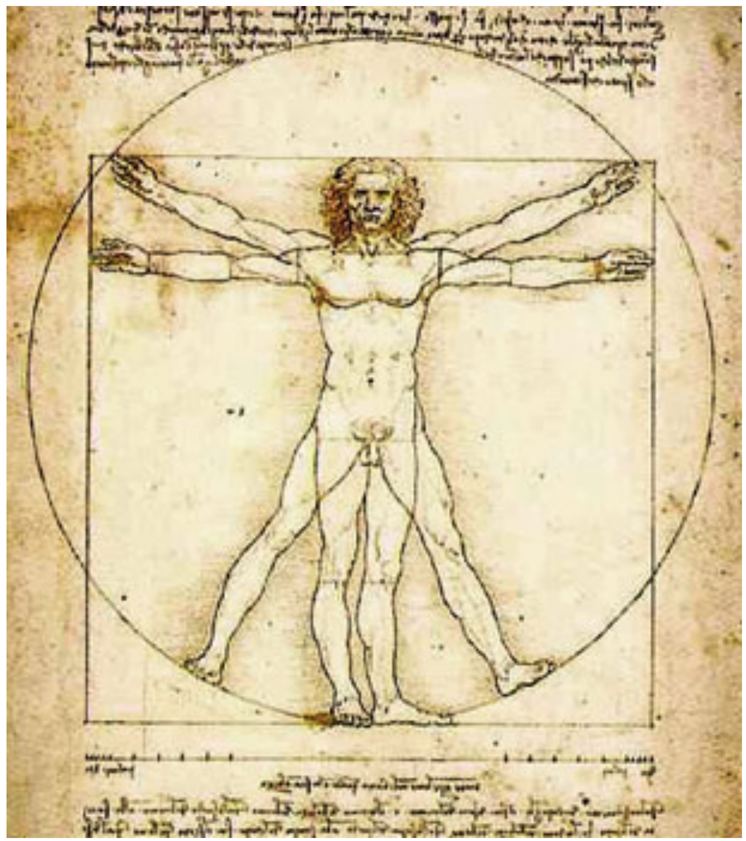
Source: Karl Kempf

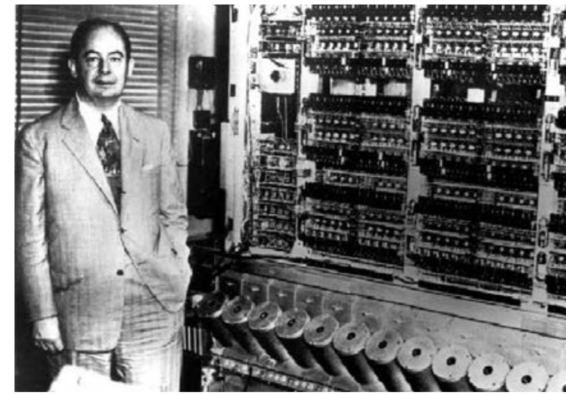
Confronting Disasters

The Need of Integrative Systems Design and Complex Systems Science







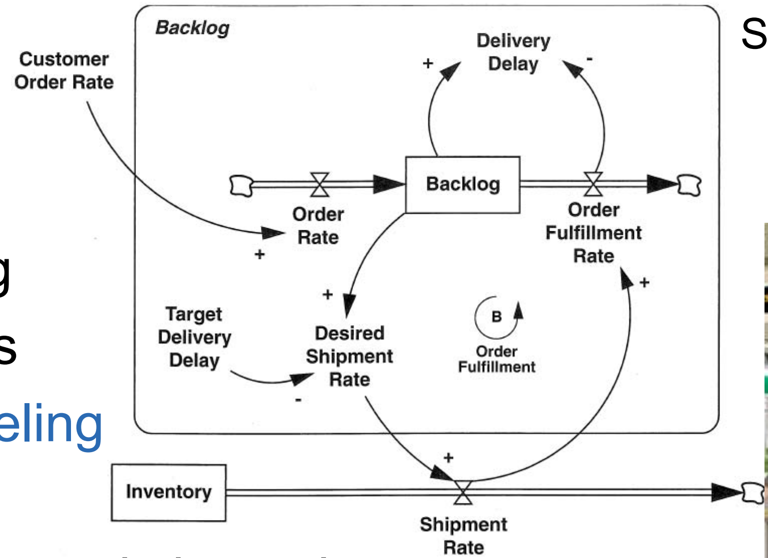


Is It a Lost Battle?

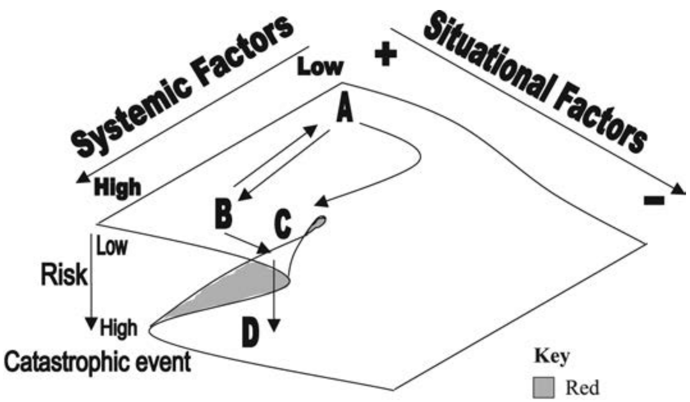
- In a strongly varying world, strict stability and control is not possible anymore or excessively expensive
- Example: Public spending deficits
- Hierarchically organized structures have a critical size, beyond which they become unstable
- Examples: Decay of Soviet Union; many failed mergers in the last decade (Daimler-Chrysler, BMW-Rover, Allianz-Dresdner Bank, …)
- A paradigm shift towards flexible, agile, adaptive systems is needed, possible - and overdue!

Techniques Used in Complexity Science

- Data mining
- Network analysis
- System dynamics
- Scenario modeling
- Sensitivity analysis
- Agent-based modeling
- Statistical physics
- Non-linear dyamics and chaos theory
- Systems theory and cybernetics
- Catastrophe theory
- Statistics of extreme events
- Theory of critical phenomena



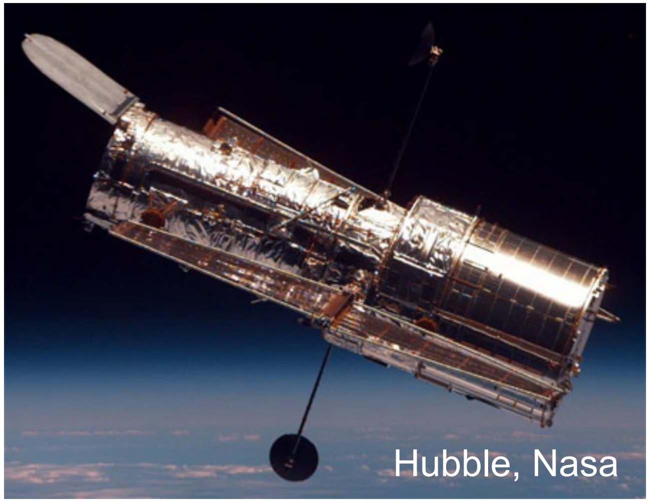
Source: J. D. Sterman



With all the Big Data of Human Activities Now Becoming Available, What Could We Do?

PHOTO (C) LION TV/422 SOUTH PBS 2012 FROM THE HUMAN FACE OF BIG DATA

Instruments to Explore the World



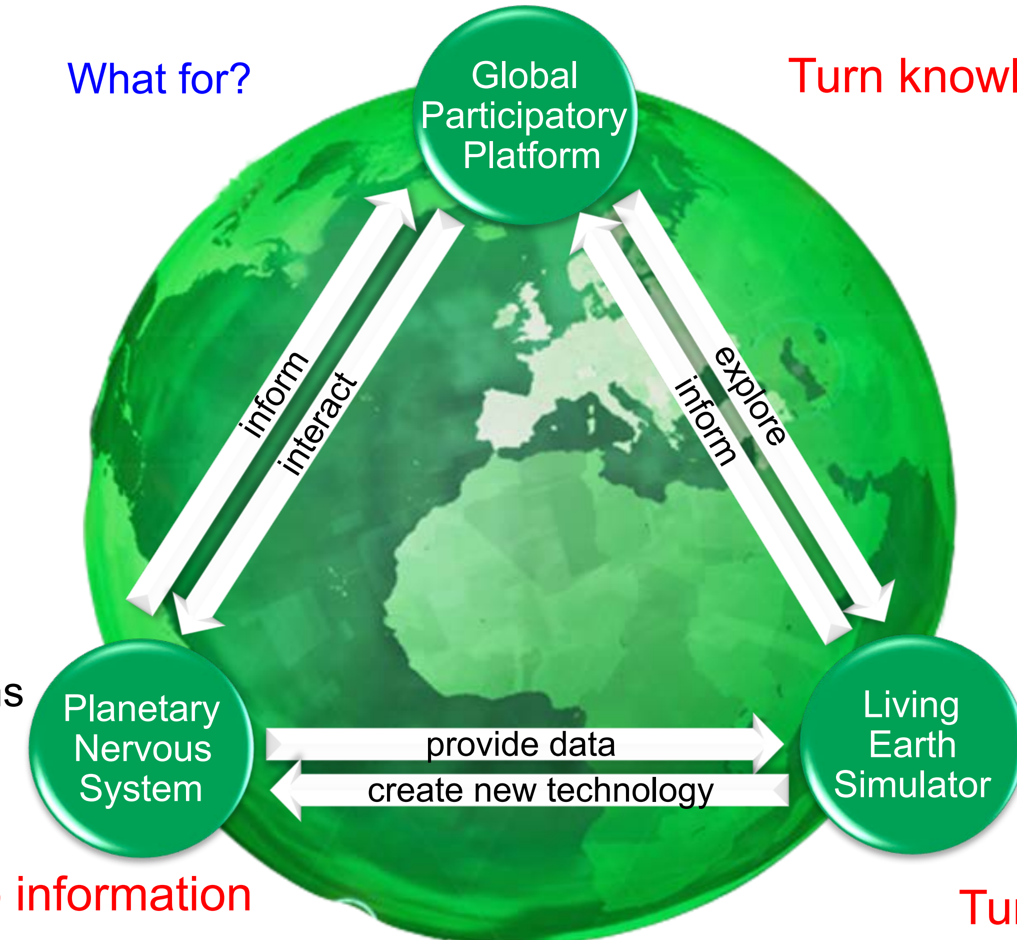
Connect web experiments with data mining and modelling tools to reach an acceleration of knowledge generation as in the Human Genome Project

FuturICT

Build platforms
to explore & interact

What for?

Turn knowledge into wisdom



What is?

Create systems
to sense &
understand

What if?

Develop models
to simulate &
predict

Turn data into information

Turn information into
knowledge

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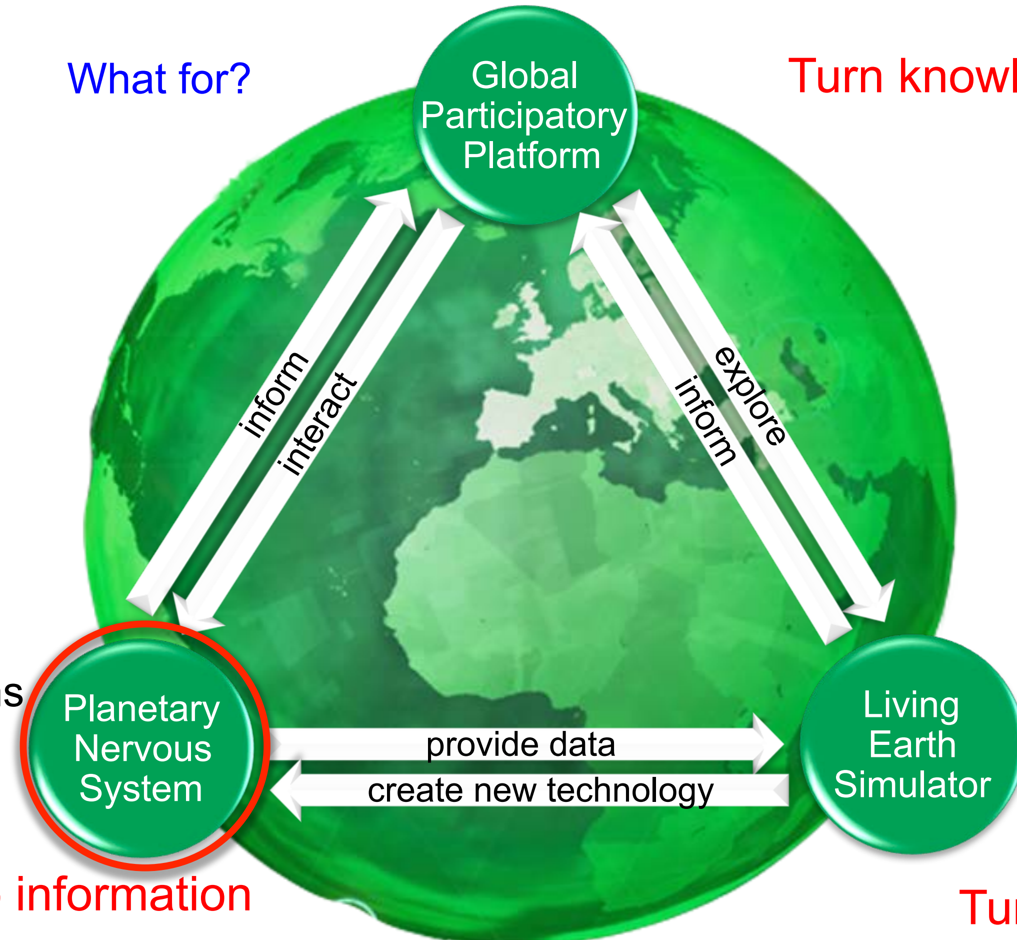

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Crowd-Sourcing 3D Environments

Thanks to Marc Pollefeys

See also Open Streetmap - the free Wiki world map

More Sustainability and Resilience through Collective, ICT-enabled (Self-)Awareness

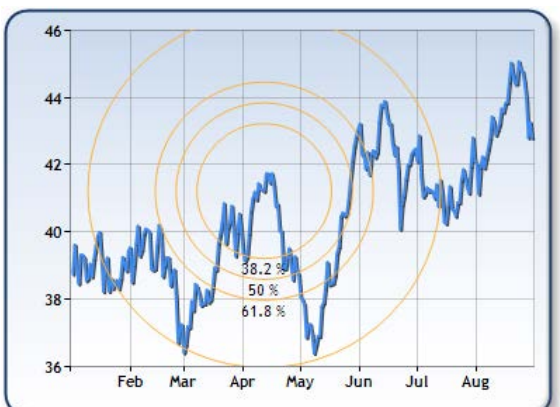
1. Goal: Measure the world's state, 'social footprint' and social capital (e.g. trust) in real time, detect possible threats and opportunities

2. Privacy-respecting data mining

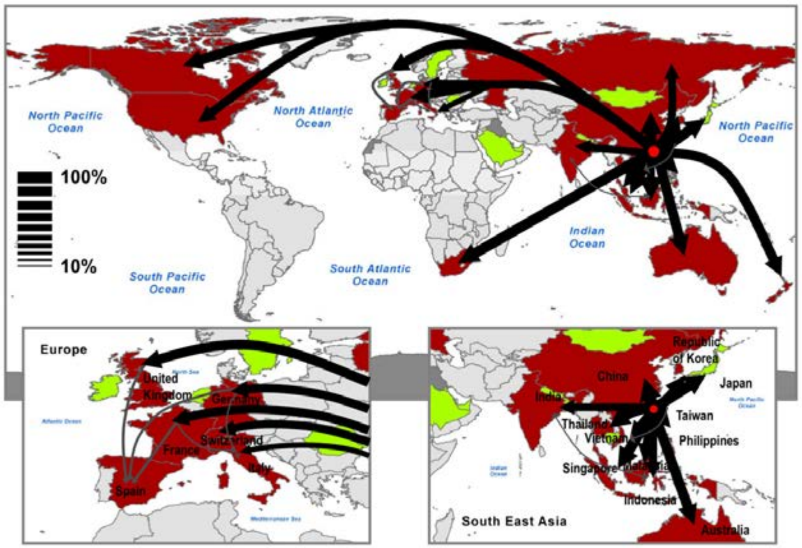
'CERN-like' vision: Create a measurement instrument for techno-socio-economic-environmental systems

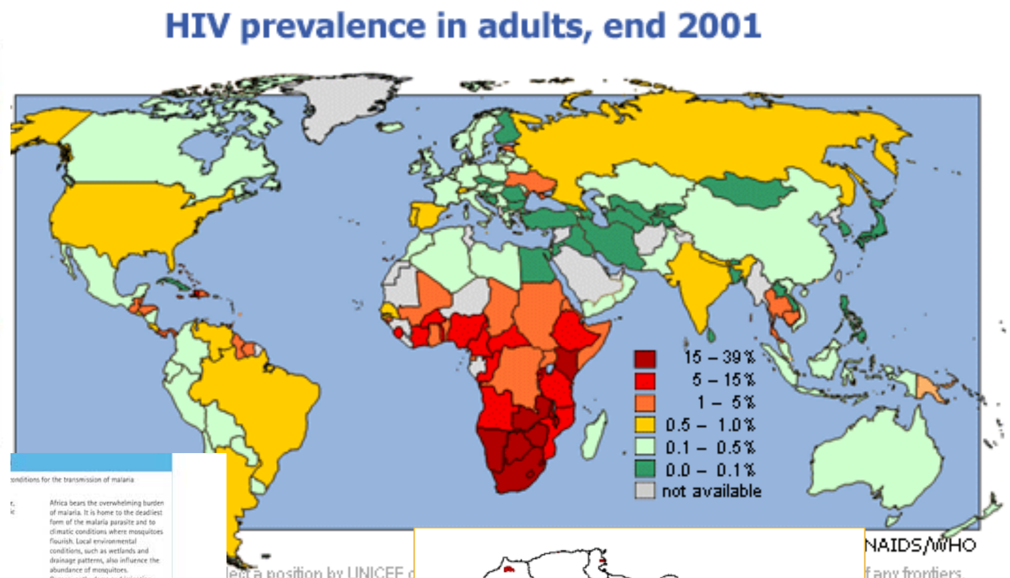
Painting by Maurits Cornelis Escher

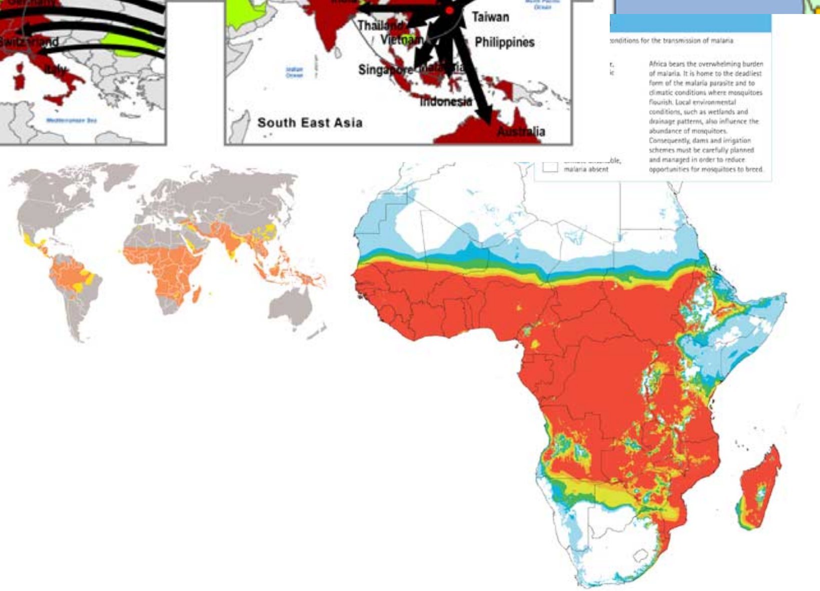
Observatory for Financial Instabilities

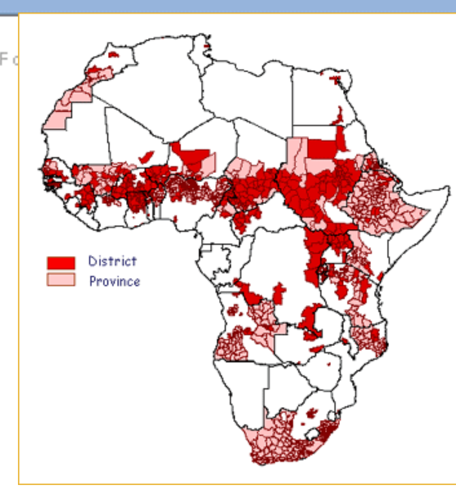


Observatory for Epidemic Spreading and Health Risks

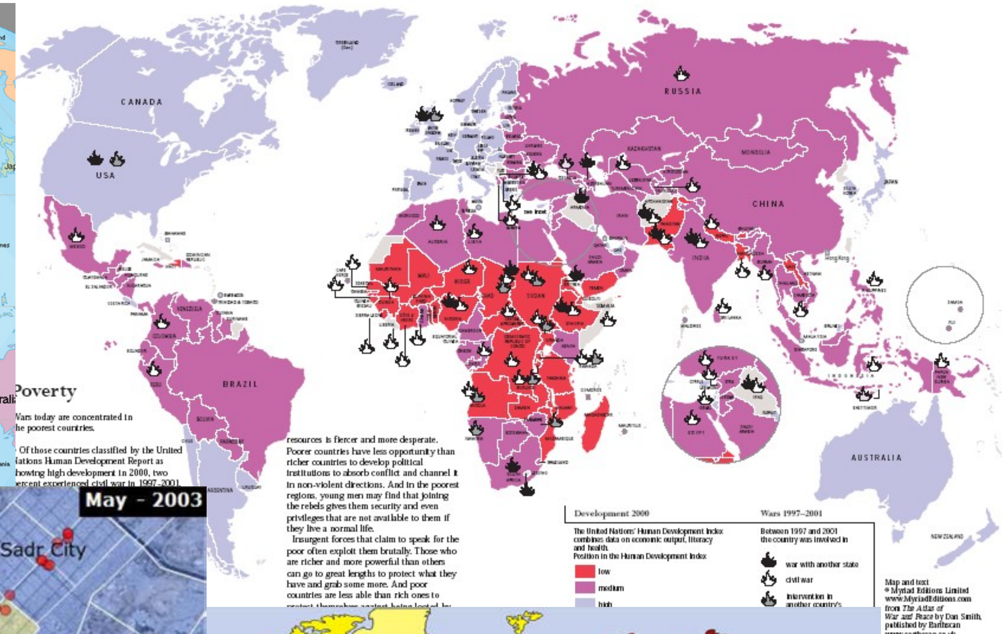


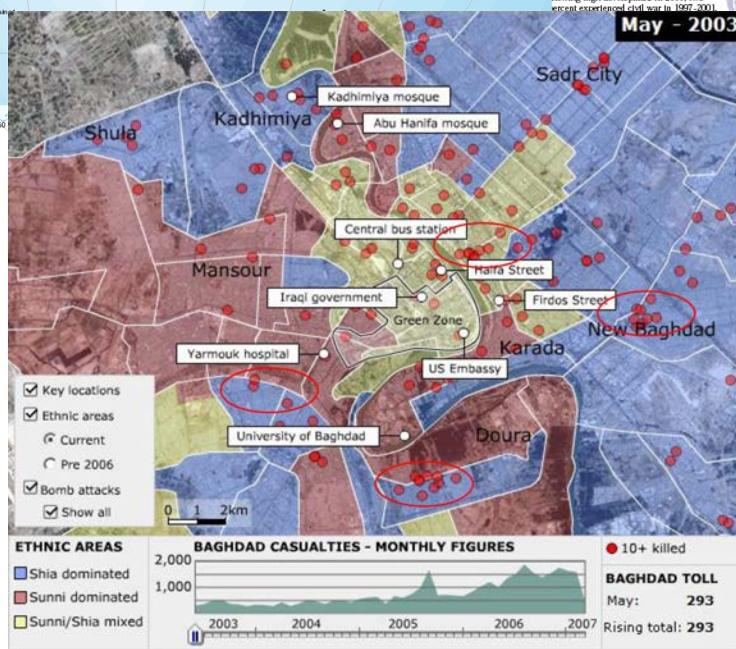


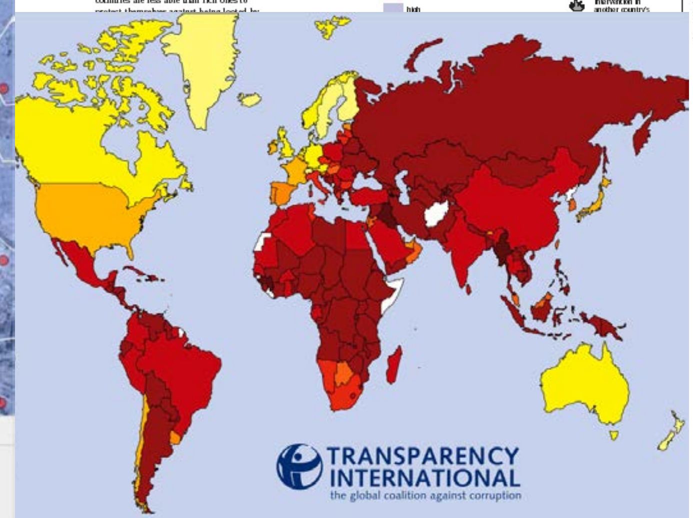




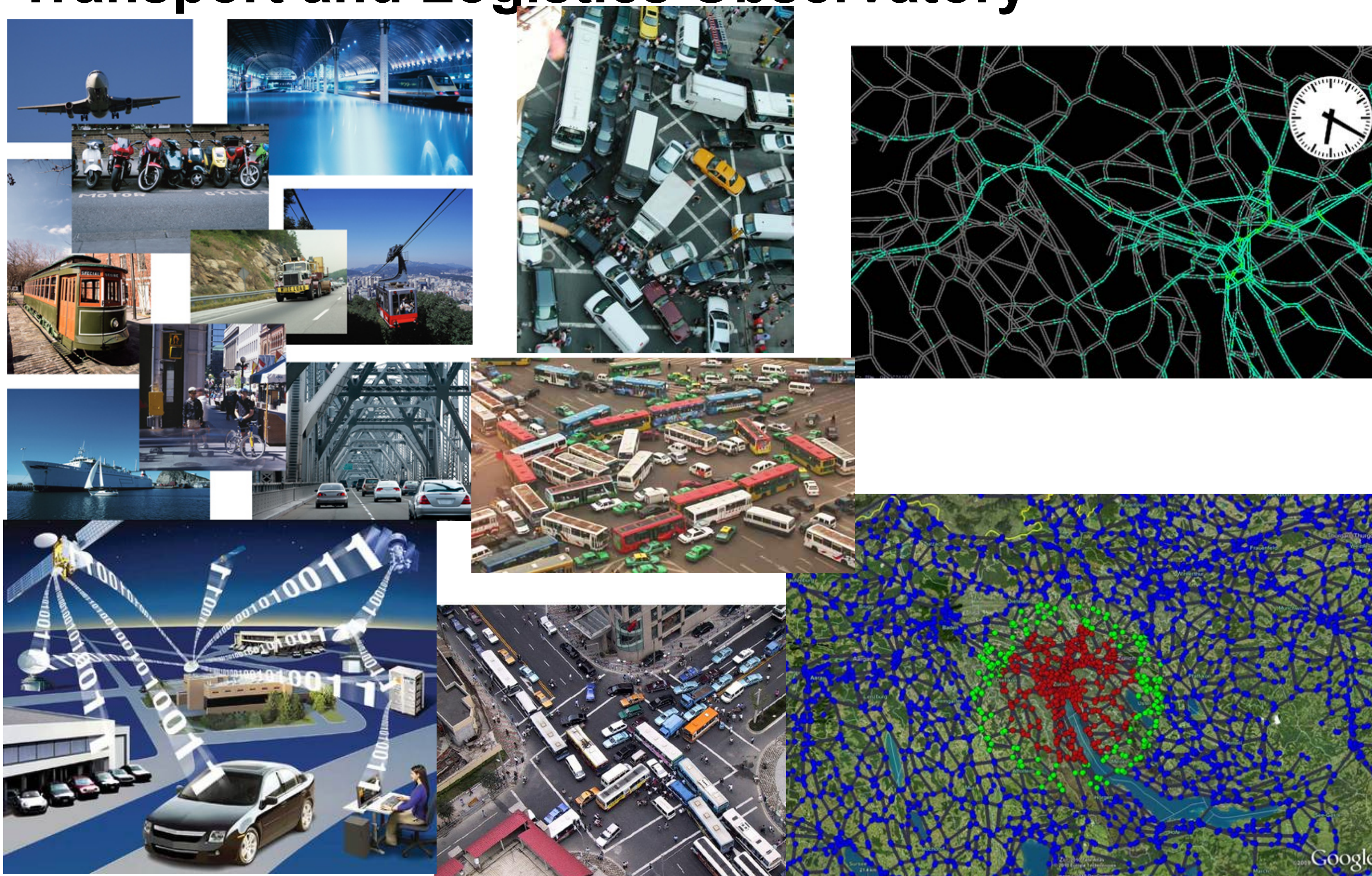
Observatory for Wars and Conflicts



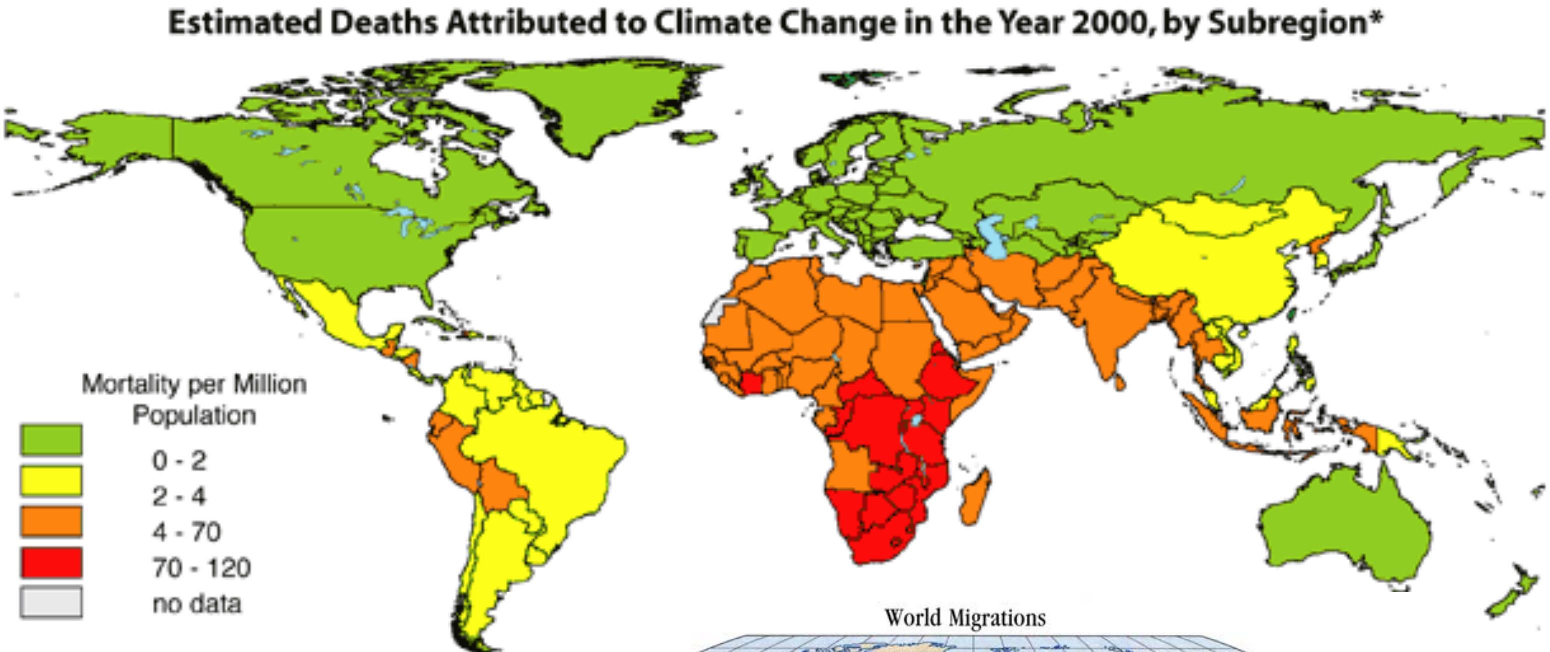


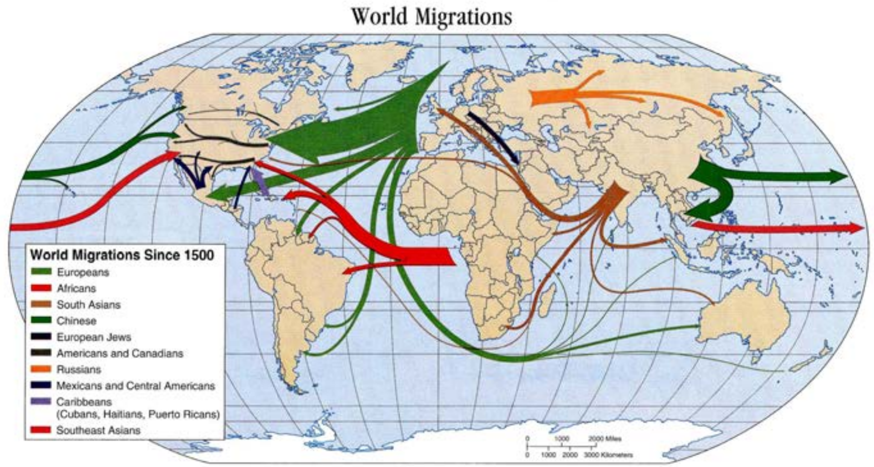


Transport and Logistics Observatory

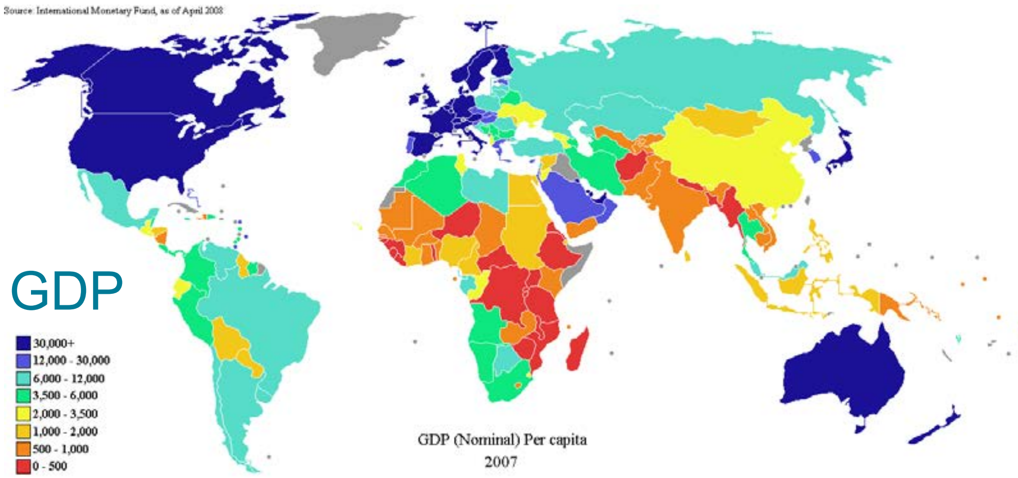


Towards Measuring the Social Footprint





Observatory for Social Well-Being, e.g. Measurement of Social Capital

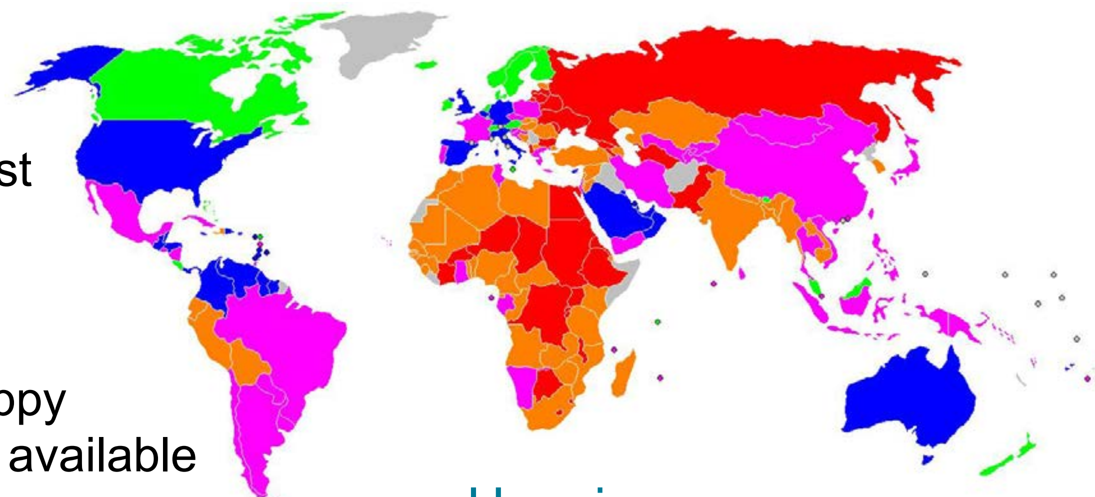


GDP

- Solidarity, cooperativeness,
- compliance,
- reputation, trust,
- attention, curiosity,
- happiness, mental health,
- environmental care…

Goal: Creating indices better than GDP

Green = Happiest
Blue
Purple
Orange
Red = Least Happy
Grey = Data not available



Happiness

FuturICT

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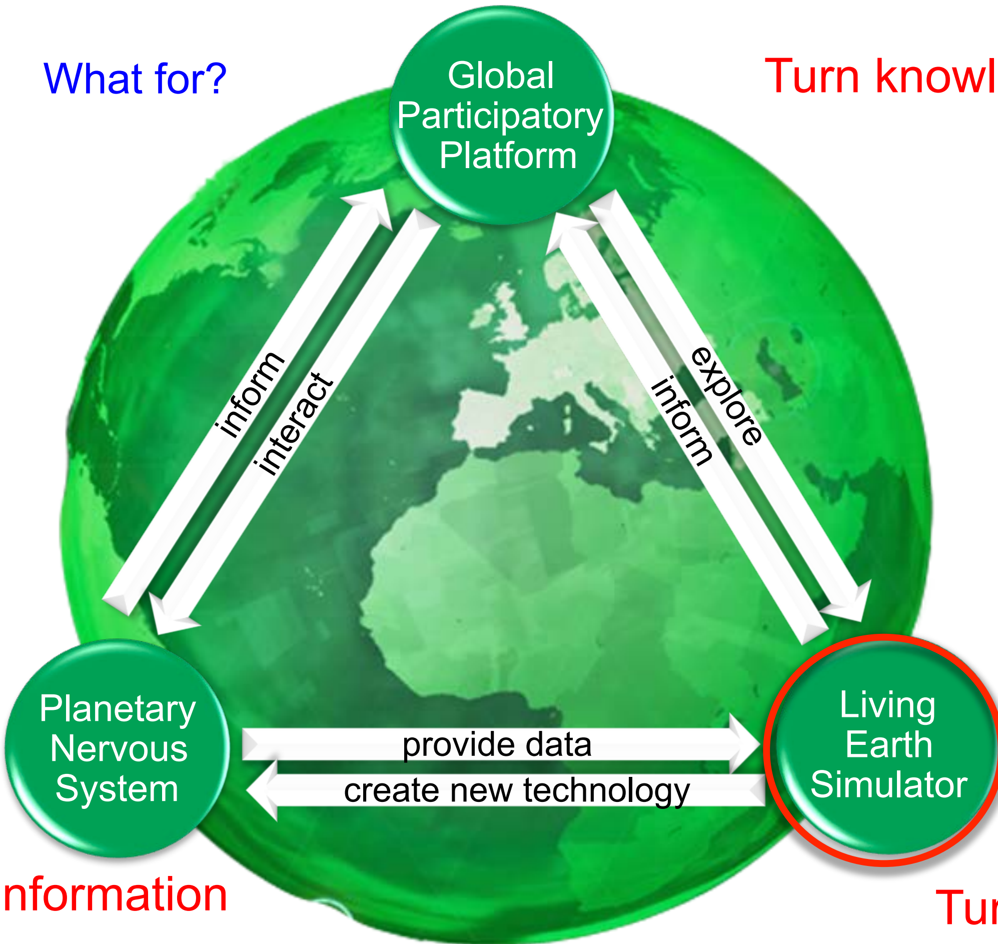

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Turn information into knowledge

Example: Global Epidemic Spreading

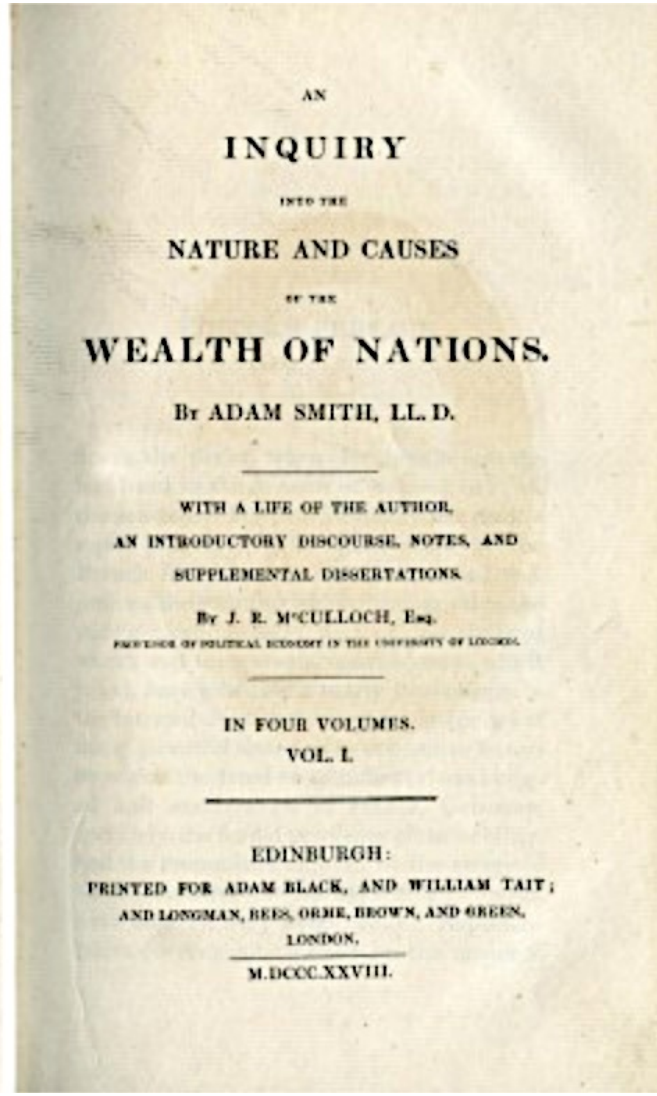
Thanks to our FuturICT partner Alex Vespignani et al.

Building FuturICT's Living Earth Simulator

- Integrate existing models (traffic, production, economic system, crow behavior, social cooperation, social norms, social conflict, crime, war…)
- Scale them up to global scale
- Increase degree of detail, accuracy (statistical and sensitivity analysis, calibration, validation, identification crucial and questionable modeling assumptions,…)

Classical Control Approaches

Self-Organization: Adam Smith's Invisible Hand



AN

INQUIRY

INTO THE

NATURE AND CAUSES

OF THE

WEALTH OF NATIONS.

By ADAM SMITH, LL. D.

WITH A LIFE OF THE AUTHOR,
AN INTRODUCTORY DISCOURSE, NOTES, AND
SUPPLEMENTAL DISSERTATIONS.

By J. R. M'CULLOCH, Esq.

IN FOUR VOLUMES.
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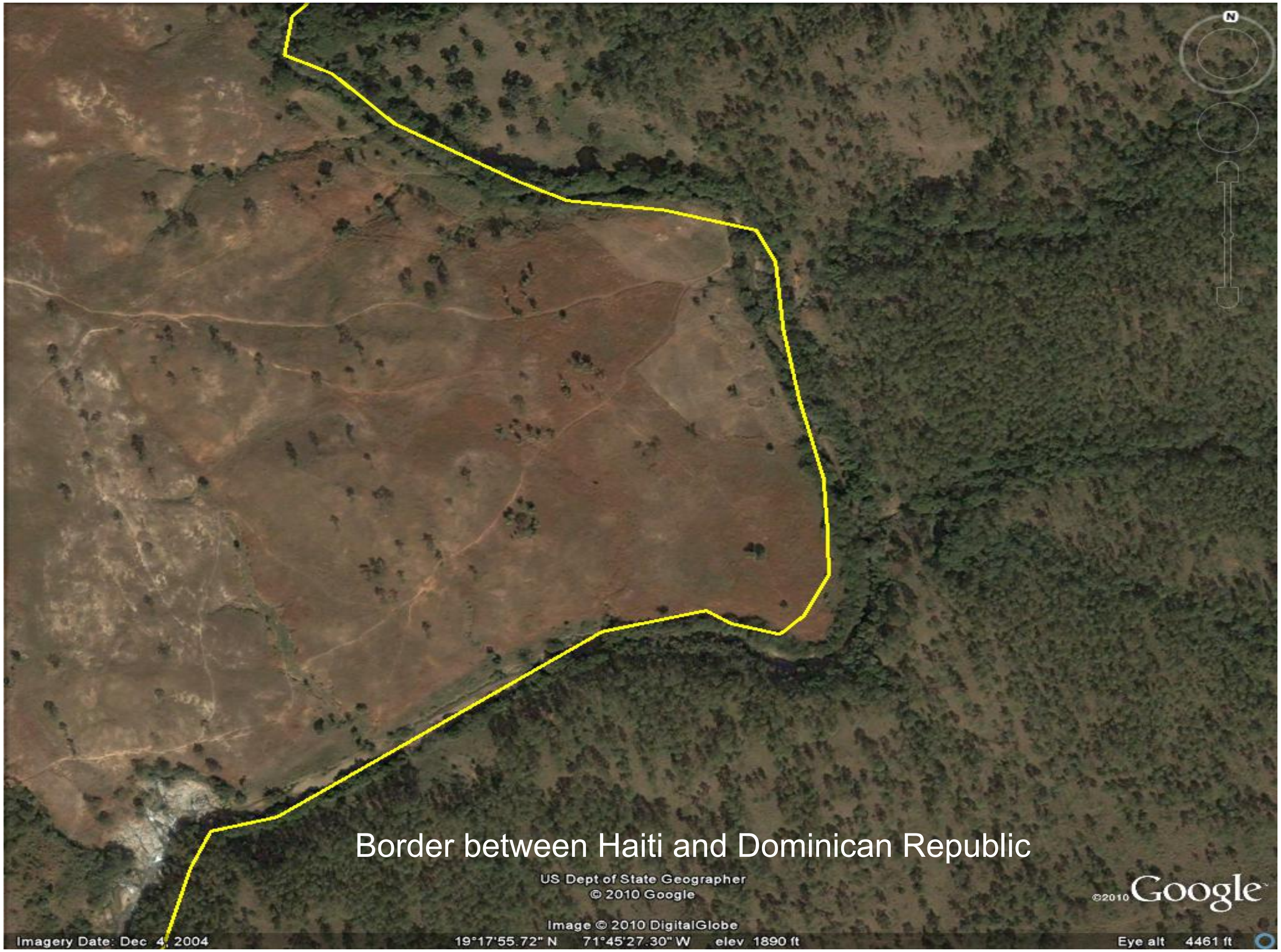
Self-Organization Can Work Out Well

When Self-Organization Fails: Global Warming

Another Tragedy of the Commons: Enviromental Pollution

Overfishing

Enviromental Exploitation

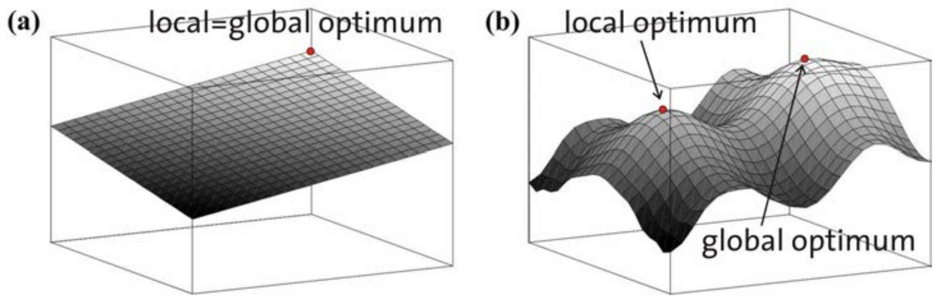


Towards Self-Regulating Systems

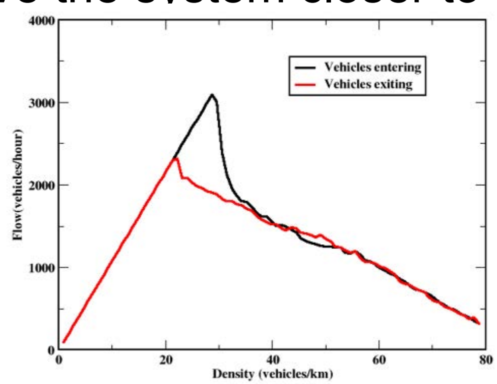
The Classical Regulation Approach

Weaknesses of Classical Optimization

- One can only optimize for one goal at a time, but usually, one needs to meet several objectives
- Optization routine may get stuck in a local optimum

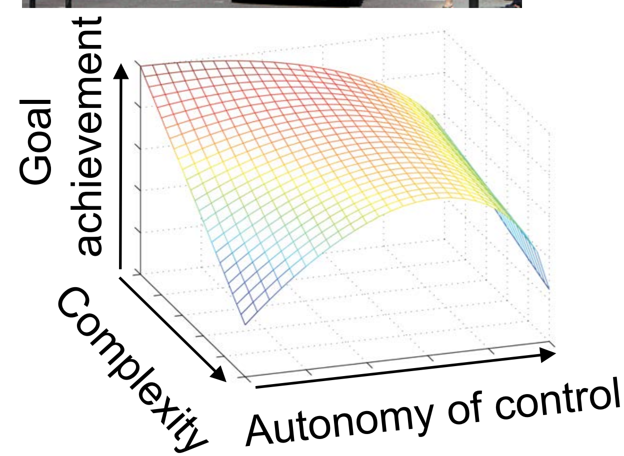


- Evolutionary dead ends: The best solution may be the combination of two bad solutions (i.e. gradual optimization may not work)
- Optimization tends to drive the system closer to instabilities
- Example: Utilization of maximum road capacity will eventually cause capacity drops



Weaknesses of Classical Optimization II

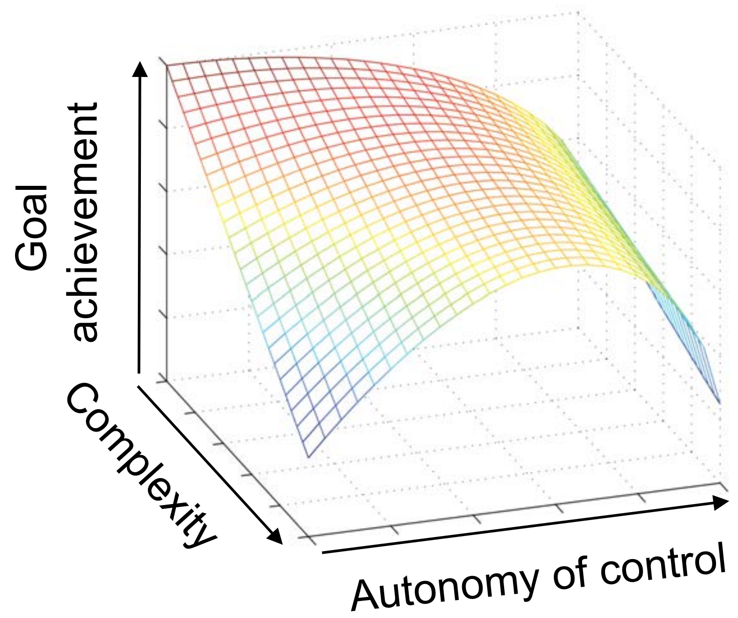
- NP-hardness: Complexity of optimization problem often prevents exact onlinOptimization based e optimization
- on average or past data optimizes for a non-existent situation, i.e. it the applied solution is NOT optimal in reality
- Example: Today's traffic light control
- Often, there is a lack of data to determine model parameters accurately
- Example: Portefolio optimization
- I. Kondor: „The complexity of financial systems exceeds what is knowable"
- Other problems: Information delays or overloads, and inconsistent information
- Problem: What ARE the relevant indicators or control variables?



(Windt, Böse, Philipp, 2006)

Centralized Control and Its Limits

- Advantage of centralized control is large-scale coordination
- Disadvantages are due to
  - vulnerability of the network
  - information overload
  - wrong selection of control parameters
  - delays in adaptive feedback control
- Decentralized control can perform better in complex systems with heterogeneous elements, large degree of fluctuations, and short-term predictability, because of greater flexibility to local conditions and greater robustness to perturbations



Do We Need a Paradigm Shift?

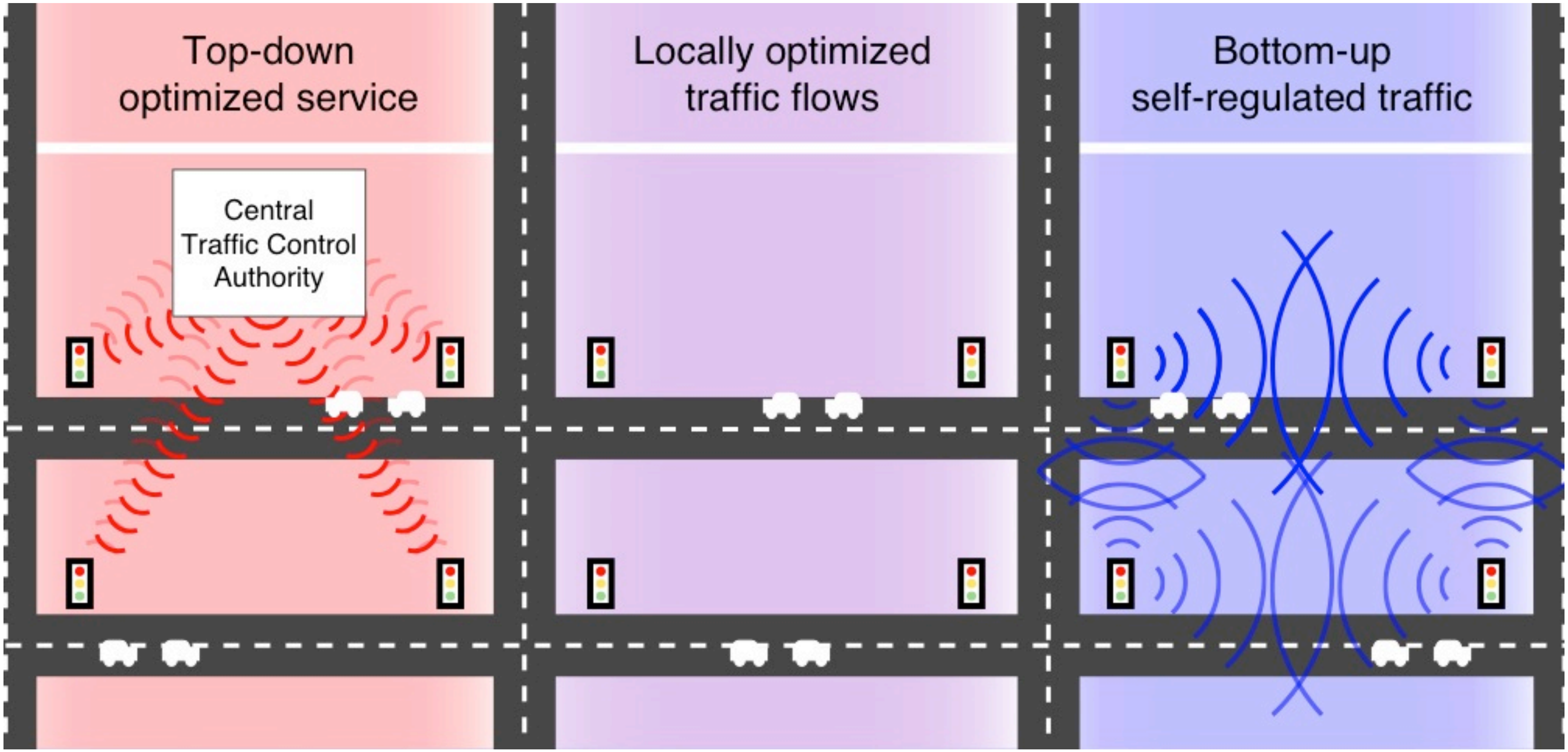
“We cannot solve our problems with the same kind of thinking that created them”

Albert Einstein

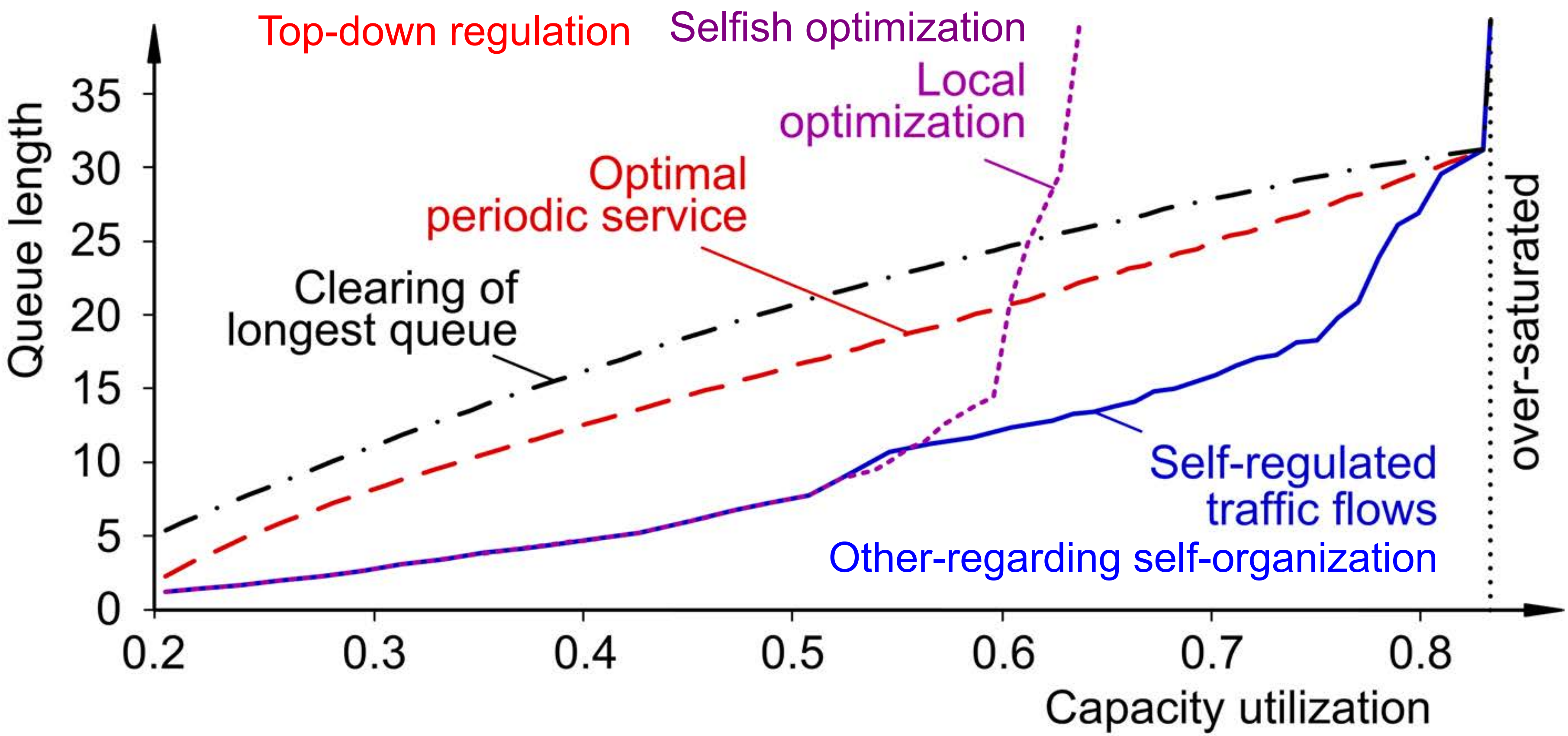
Three Ways of Organizing Complex Systems

Market System	Centrally Planned Economy	Conventional Market Economy	Participatory Market Society
Agent	Central Planner	Homo Economicus	Homo Socialis
Organization	top down	bottom up	bottom up
Regulation	top down	top down	bottom up

Comparing Three Ways of Organizing Traffic Lights



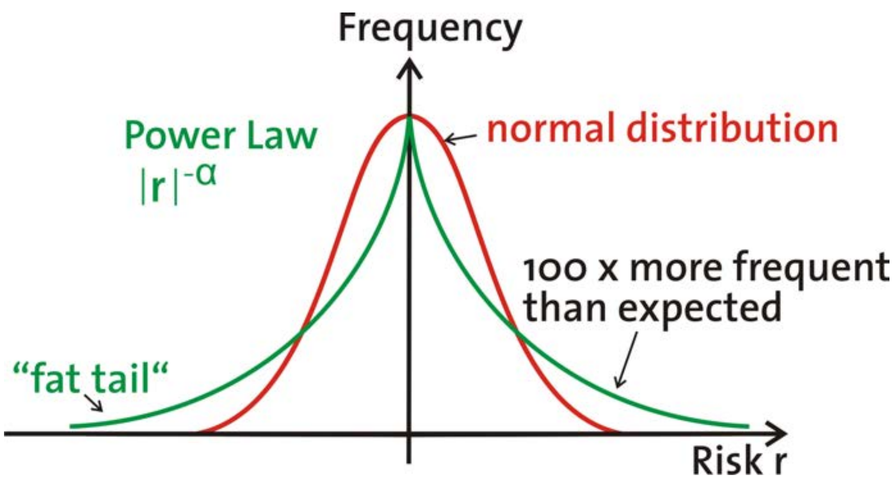
Decentralized Can Outsmart Centralized Control



Summary and Conclusions

Strongly Coupled and Complex System Behave Fundamentally Different

1. Faster dynamics
2. Increased frequency of extreme events – can have any size
3. Self-organization dominates system dynamics
4. Emergent and counterintuitive system behavior, unwanted feedback, cascade and side effects
5. Predictability goes down
6. External control is difficult
7. Larger vulnerability



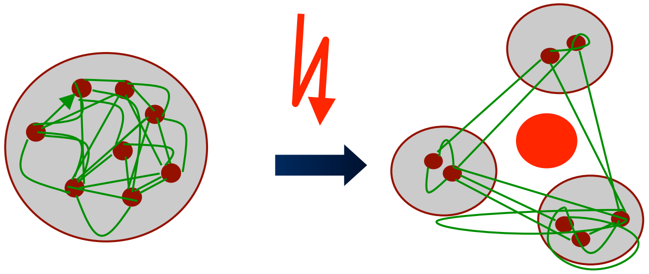
Change of perspective (from a component- to an interaction-oriented view) will reveal new solutions!

Need a science of multi-level complex systems!

Drivers of Systemic Risks and How to Respond

Drivers of systemic risks:

- reduced redundancies
- more networking
- higher complexity
- faster dynamics
- high pace of innovation



Network vulnerability can be reduced by

- backup strategies, redundancies, reserves, alternatives (‚plan B'),
- stabilizing real-time feedback
- flexible, decentralized, self-organization and self-control mechanisms
- Mutually compatible time scales and frictional effects
- symmetrical interactions
- a simplification of complex system designs
- diversity
- limitation of system size
- reduced connectivity
- dynamic decoupling strategies
- transparency, accountability, responsibility, and awareness

Engineered Breaking Points to Stop Cascades

Take Home Messages

- Network interdependencies enable cascade spreading
- This creates a heavy-tail distribution of damage sizes
- Small triggers or random coincidences may cause global-scale crises
- Complexity makes systems hard to predict and control
- There are many drivers of systemic instability
- Redundancies, backup systems, diversity, and engineered breaking points can increase systemic resilience
- Planning, optimization and regulation may be ineffective
- Real-time data and feedbacks can be used to create self-regulating systems
- A paradigm shift in the management of complex systems is needed

Further Reading

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Further Reading

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PERSPECTIVE

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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 solar storms, organized (cyber-)crime, or cyberwar. Our world is already facing some of the consequences: global problems such as fiscal and economic crises, global migration, and an explosive mix of incompatible interests and cultures, coming along with social unrests, international and civil wars, and global terrorism.

In this Perspective, I argue that systemic failures and extreme events are consequences of the highly interconnected systems and networked risks humans have created. When networks are interdependent[2,3], this makes them even more vulnerable to abrupt failures[4–6]. Such interdependencies in our "hyper-connected world"[1] establish "hyper-risks" (see Fig. 1). For example, today's quick spreading of emergent epidemics is largely a result of global air traffic, and may have serious impacts on our global health, social and economic systems[6–9]. I also argue that initially beneficial trends such as globalization, increasing network densities, sparse use of resources, higher complexity, and an acceleration of institutional decision processes may ultimately push our anthropogenic (man-made or human-influenced) systems[10] towards systemic instability—a state in which things will inevitably get out of control sooner or later.

Many disasters in anthropogenic systems should not be seen as 'bad luck', but as the results of inappropriate interactions and institutional settings. Even worse, they are often the consequences of a wrong understanding due to the counter-intuitive nature of the underlying system behaviour. Hence, conventional thinking can cause fateful decisions and the repetition of previous mistakes. This calls for a paradigm shift in thinking: systemic instabilities

'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.

BOX 1

Risk, systemic risk and hyper-risk

According to the standard ISO 31000 (2009; http://www.iso.org/iso/catalogue_detail?csnumber=43170), risk is defined as "effect of uncertainty on objectives". It is often quantified as the probability of occurrence of an (adverse) event, times its (negative) impact (damage), but it should be kept in mind that risks might also create positive impacts, such as opportunities for some stakeholders.

Compared to this, systemic risk is the risk of having not just statistically independent failures, but interdependent, so-called 'cascading' failures in a network of *N* interconnected system components. That is, systemic risks result from connections between risks ('networked risks'). In such cases, a localized initial failure ('perturbation') could have disastrous effects and cause, in principle, unbounded damage as *N* goes to infinity. For example, a large-scale power blackout can hit millions of people. In economics, a systemic risk could mean the possible collapse of a market or of the whole financial system. The potential damage here is largely determined by the size *N* of the networked system.

Even higher risks are implied by networks of networks[4,5], that is, by the coupling of different kinds of systems. In fact, new vulnerabilities result from the increasing interdependencies between our energy,

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DISCUSSION PAPER

Economics 2.0: The Natural Step towards a Self-Regulating, Participatory Market Society

Dirk Helbing*

ETH Zurich, Swiss Federal Institute of Technology, Department of Humanities, Social and Political Sciences; Clausiusstrasse 50, 8092 Zurich, Switzerland. * E-mail: dirk.helbing@gess.ethz.ch

Abstract

Despite all our great advances in science, technology and financial innovations, many societies today are struggling with a financial, economic and public spending crisis, over-regulation, and mass unemployment, as well as lack of sustainability and innovation. Can we still rely on conventional economic thinking or do we need a new approach? Is our economic system undergoing a fundamental transformation? Are our theories still doing a good job with just a few exceptions, or do they work only for "good weather" but not for "market storms"? Can we fix existing theories by adapting them a bit, or do we need a fundamentally different approach? These are the kind of questions that will be addressed in this paper. I argue that, as the complexity of socio-economic systems increases, networked decision-making and bottom-up self-regulation will be more and more important features. It will be explained why, besides the "homo economicus" with strictly self-regarding preferences, natural selection has also created a "homo socialis" with other-regarding preferences. While the "homo economicus" optimizes the own prospects in separation, the decisions of the "homo socialis" are self-determined, but interconnected, a fact that may be characterized by the term "networked minds." Notably, the "homo socialis" manages to earn higher payoffs than the "homo economicus." I show that the "homo economicus" and the "homo socialis" imply a different kind of dynamics and distinct aggregate outcomes. Therefore, next to the traditional economics for the "homo economicus" ("economics 1.0"), a complementary theory must be developed for the "homo socialis." This economic theory might be called "economics 2.0" or "socionomics." The names are justified, because the Web 2.0 is currently promoting a transition to a new market organization, which benefits from social media platforms and could be characterized as "participatory market society." To thrive, the "homo socialis" requires suitable institutional settings such a particular kinds of reputation systems, which will be sketched in this paper. I also propose a new kind of money, so-called "qualified money," which may overcome some of the problems of our current financial system. In summary, I discuss the economic literature from a new perspective and argue that this offers the basis for a different theoretical framework. This opens the door for a new economic thinking and a novel research field, which focuses on the