SOCIAL FORCES (Version 0.2) –

Revealing the causes of success or disaster

by Dirk Helbing

We have seen that self-organizing systems can be very effective and efficient, but their macro-level behavior crucially depends on the interaction rules, interaction strength, and institutional settings. To get things right, it's important to understand the factors that drive the dynamics of the system. In physics, many phenomena can be understood by means of forces, and it takes suitable measurements to reveal them. I show that in socio-economic systems, too, success and failure depend on hidden forces, which are not directly accessible to our senses. But now, the data about our world increasingly allow us to measure the forces underlying socio-economic change, empowering us to take better decision and more effective actions in the future.

Societies around the world are suffering from financial crises, crime, conflicts, wars, and revolutions. These "societal diseases" do not occur by chance, but for a reason. The fact that they are happening time and again proves that there are hidden regularities behind them, but that we haven't understood them well. This is why we fail to master them. But in the future, I argue, we will be able to understand societal diseases and cure them. One might imagine this to work in a similar way as the x-ray discovered by Wilhelm Conrad Röntgen (1845-1923), which has helped to cure diseases of billions of people by revealing where something is broken in our bodies, or wrong.

In fact, the growing amounts of data about our world will allow us to develop entirely new measurement methods to see hidden patterns in the activities of our global techno-socio-economic-environmental system, very much like microscopes and telescopes in the past have enabled us to discover and understand the micro- and macro-cosmos around us. As we have built elementary particle accelerators to discover the forces that keep our world together, we can now create Socioscopes to reveal the principles that make our society succeed or fail.

Given that the loss of control over a system often results from a lack of knowledge about the rules governing it, it is important that we learn to measure these hidden forces, which govern our economy and societies. This will also put us into a position to use these forces such that we can overcome systemic instabilities and crises. To achieve this, we don't have to save all the data in the world in one database. It's much better to perform tailored measurements as needed for the respective question or purpose. But how can we proceed?

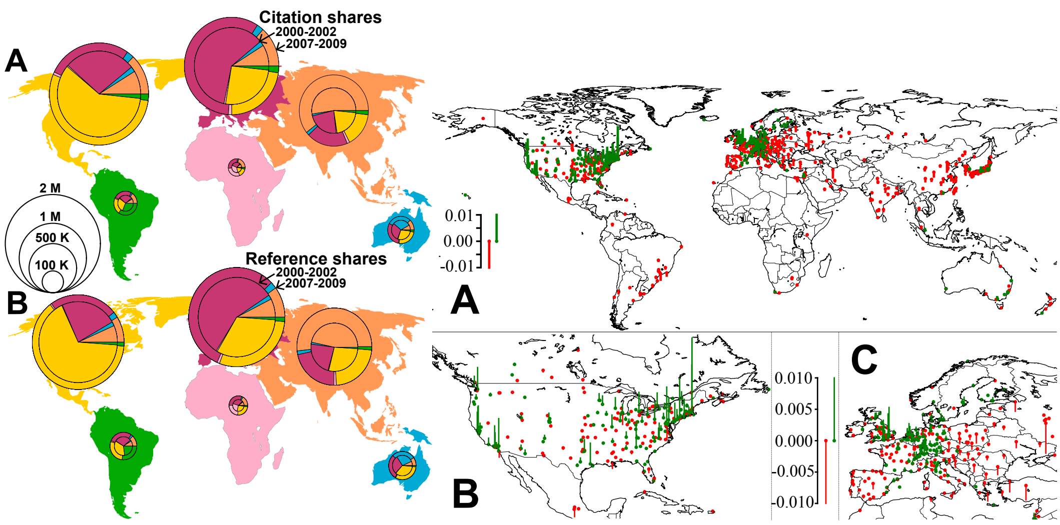
Measuring the world 2.0

Some of the greatest discoveries in human history were made by measuring the world. We have discovered new cultures and new continents. Reaching out for the skies, we have explored our universe and discovered black holes, dark matter, and entirely new worlds. Now, the Internet is offering novel opportunities to quantify our world. Performing a sentiment analysis of blogs, *facebook* posts, or tweets, we can visualize emotions of people such as happiness (see, for example, http://www.wefeelfine.org/index.html, http://hedonometer.org/about.html, and http://sentistrength.wlv.ac.uk/). We can also get a picture of the social, economic, and political "climate," by determining the subjects that people publicly communicate about (http://gdeltproject.org/#watching). Mining data on the Web, one can further determine the gross domestic product per capita,[1] violence, and crime[2], as a function of location and time (http://www.gapminder.org/). One can even reconstruct the three-dimensional world around us from the photos that people upload on platforms such as *flicker* all the time (http://www.youtube.com/watch?v=4cEQZreQ2zQ).

Furthermore, we can create Financial Crisis Observatories to detect the likelihood of financial bubbles and crashes (see http://www.er.ethz.ch/fco). We

[1] http://www.econ.brown.edu/faculty/David_Weil/Henderson Storeygard Weil AER April 2012.pdf
[2] http://www.trulia.com/local/

can build RiskMaps and CrisisMaps, to support first aid teams in a disaster-struck area (see http://crisismappers.net/). And we can map innovations, the spreading of knowledge, and scientific concepts, as I have started to do it with Amin Mazloumian, Katy Börner, Tobias Kuhn, Christian Schulz and others (see pictures below and the Living Science app at http://livingscience.inn.ac/). The spreading of culture in the world over the centuries, as studied by Maximilian Schich together with Laszlo Barabasi, myself and others, is particularly fascinating (see http://www.youtube.com/watch?v=4gIhRkCcD4U, http://www.youtube.com/watch?v=rwmiQ75iW6Y, and http://www.youtube.com/watch?v=231zuH3uMwc). Inspired by *Wikipedia* and *OpenStreetMap*, we could also create an OpenResourcesMap visualizing the resources of the world, and who uses them, to help reduce undesirable shortages. And we could produce an OpenEcosystemsMap to depict environmental change and who causes it.



Very soon, we will have not only maps accumulating past activities, but also systems delivering real-time answers. When asking a question, this will trigger tailored measurements telling us, for example, what is the traffic situation in London's Oxford street? What's the weather in Moscow, and how might this affect investor decisions and consumer choices? How happy are people in London today, and how much money will they spend shopping? Why did people in Switzerland vote against "mass migration"? What worries people in Paris at the moment? How many people are up between 3 and 4am on

Sunday nights around Manhattan's Central Square, and is it worth selling pizza at that time? How noisy is it to live in the quarter of town I am considering to move to? What's the rate of flu (or Ebola) infections in the place I want to spend my holidays in? Where are the road bumps in my city located? And when did we have the last earthquake greater than 4 on the Richter scale within a range of 500 kilometers?

Information like this can create an increased awareness of the world around us, and empower us to take better decisions and more effective actions. But how will we get all this real-time information?

Creating a Planetary Nervous System as a Citizen Web

The sensor network underlying the emerging "Internet of Things" will enable us to perform real-time measurements of almost everything. It will be possible to get all the information needed to establish real-time feedbacks in complex dynamical systems. This will allow us to support a favorable self-organization – not just of traffic lights and production, but basically of everything that requires proper real-time adaptation.

We can use the "Internet of Things" also to build an intelligent information platform called the "Planetary Nervous System" (PNS). This was proposed by the FuturICT project (http://www.futurict.eu). The Planetary Nervous System would have three main functions: First, to configure sensor networks in order to answer specific queries and provide real-time measurements; second, to create awareness of problems and opportunities around us; and third, to measure the hidden forces underlying socio-economic change and important intangible factors such as trust, reputation, public security or other quantities depending on interactions in social networks.

In fact, my team has already started to develop such an information platform. We will build the Planetary Nervous System as a Citizen Web together with the emerging *nervousnet* community committed to the further development of the project. This approach will give the citizens control over their personal data, in accordance with their right of informational self-determination, and create new opportunities for everyone. *Nervousnet* will be engaged in protecting privacy while offering everyone the possibility to contribute to the measurement of our environment. In some sense, the project may be envisaged to be a real-time Wikipedia of our world. Like OpenStreetMap it will build on data provided by many volunteers. A large share of this data will be Open Data, and you will be able to use it to develop your own business. So, why don't you join the *nervousnet* community today?[3]

The Planetary Nervous System will soon be a large-scale distributed information platform providing real-time social mining services as a public good. While existing Big Data systems threaten social cohesion as they are designed to be closed, proprietary, privacy-intrusive and discriminatory, we will rather create an open, privacy-preserving and participatory platform designed to be collectively built by citizens and for citizens. This will establish a novel social mining paradigm: Users are provided with freedom and incentives to share, collect and, at the same time, protect data of their digital environment in real-time. In this way, social mining turns into a knowledge extraction service for the public good. In perspective, it will provide a public information service for everyone, and perhaps become a foundational public institution for the emerging digital societies of the 21st century. But it takes more than data to understand the world and its problems...

Sociophysics: Revealing the hidden forces governing our society

As previously discussed, analyzing and visualizing data should be only the first step. In the chapter on the Crystal Ball, I have pointed out that data mining alone usually doesn't deliver a good understanding of a complex dynamical system. In order to make sense of data, it's important to have

[3] You can get in touch with us at mailto:nervousnet@ethz.ch. For further information see http://futurict.blogspot.ch/2014/09/creating-making-planetary-nervous.html

explanatory models, which allow one to make predictions for situations that haven't occurred before.

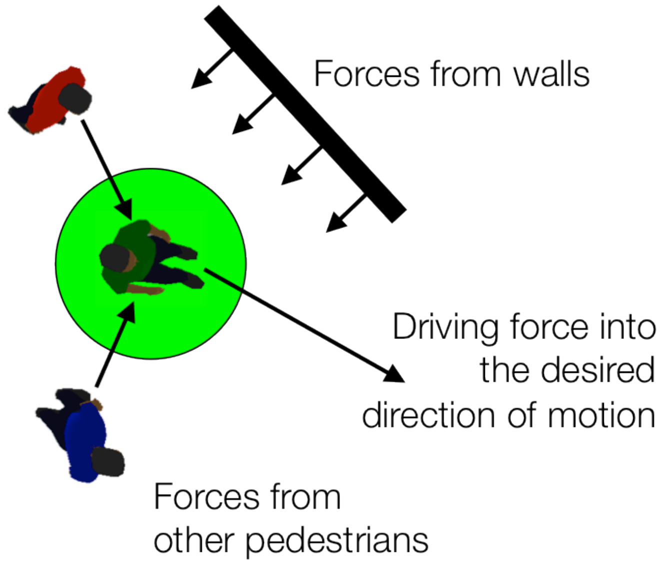
In the last chapter, we have discussed interaction rules ("social mechanisms") that influence human behavior in a similar way as the gravitational force determines the motion of the planets – there is just more diversity and randomness. Social roles, i.e. behaviors that social norms expect from us, are further examples illustrating the existence of such rules. While the scientific approach of "agent-based simulations" specifies these rules by computer codes, the research field of sociophysics expresses them by mathematical formulas. In this chapter, I will discuss the powerful concept of "social forces," which allows one to construct a link between the micro-level interactions between individuals and the often unexpected macro-level outcomes in socio-economic systems resulting from them.

The concept of forces is one of the main pillars of physics. In order to discover it, one had to replace the worldview assuming the Earth to be the center of the universe by a worldview with the planets moving around the sun. This new interpretation of planetary motion data allowed Isaac Newton (1642-1727) to formulate a simple and plausible model based on the concept of gravitational forces. By now, most parts of physics are formulated in terms of forces and the way they influence the world. The predictive power of the respective models is striking. It has been impressively demonstrated by the moon shot of the Apollo program and many other examples.

A further aspect that made physics so successful is its long tradition in building instruments to measure things that are otherwise not accessible to our senses. This reaches from the early stages of our universe to the exploration of elementary particles up to the study of processes in biological cells. Therefore, we should ask ourselves how to build "Socioscopes" that can reveal the hidden forces behind the self-organization of socio-economic systems. In this way, we will eventually learn to understand the counterintuitive behaviors of complex systems. I believe we will soon be able to diagnose emergent "diseases of society" such as financial crashes, crime, or wars, before they happen. This would enable us to avoid or mitigate these problems in a similar way as instruments for medical diagnosis have helped us to cure diseases. Isn't that an exciting perspective?

Social forces between pedestrians

To demonstrate the feasibility of this approach, let me first give an example for the usefulness of force models in the social sciences relating to pedestrian and crowd dynamics. Starting in 1990, when I wrote my diploma thesis, I noticed that pedestrian paths around obstacles looked similar to streamlines in fluids. So, I decided to formulate a fluid-dynamic theory of pedestrian flows, and I derived it from an individual-based pedestrian model, which was inspired by Newton's force model.



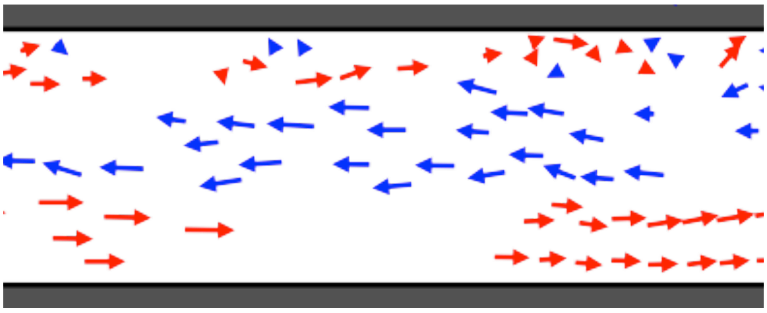
This "social force model" assumes that the acceleration, deceleration and directional changes of pedestrians can be approximated by a sum of different forces, each capturing a different desire or interaction effect. For example, the adaptation of the actual pedestrian velocity to the desired speed and preferred direction of motion of a pedestrian can be modeled by a simple "driving force," describing a gradual adaptation of the velocity within a typical time period.

Moreover, the desire to avoid collisions and to respect a certain "territory" around others is reflected by repulsive interaction forces between pedestrians with a strength that exponentially decays with distance. Repulsive interactions with walls or streets can be captured by similar forces. The attraction toward tourist sites can be described by attractive forces, and the reason for family members to stay together as well. Finally, a random force may reflect behavioral variability.

It is exciting that computer simulations of this model match many empirically observed phenomena surprisingly well despite its simplicity. For example, it is possible to understand the emergence of river-like flow patterns through a standing crowd of people, the wave-like progression of individuals waiting in queues, or the lower densities on dance floors as compared to the people standing around.

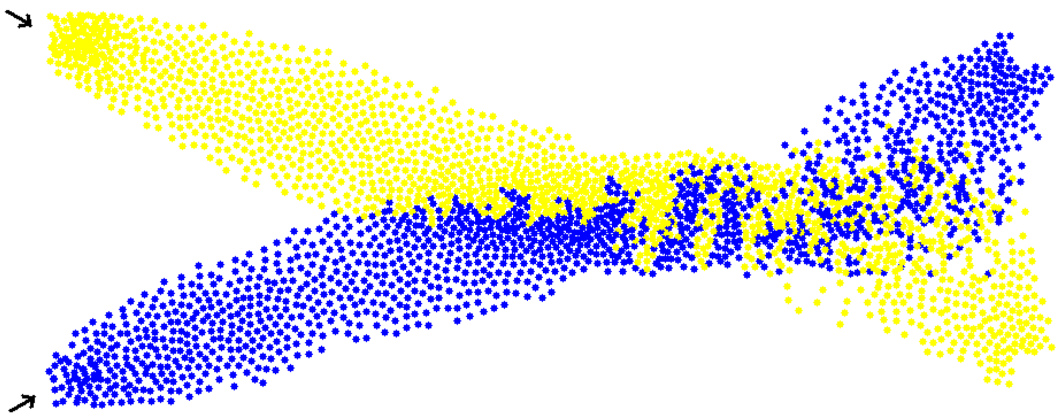
Self-organization of lanes of uniform walking direction

There are also various self-organization phenomena that lead to fascinating collective patterns of motion. For example, when pedestrians are entering a corridor on two sides, we observe the formation of lanes of uniform walking direction (see http://www.youtube.com/watch?v=e2WfvJXB__8). That is, the opposite flows are automatically coordinated in a way that produces an efficient separation of counter-flows. One might see the Invisible Hand at work, here. But we can actually explain how social order is created and how a collectively desirable outcome results from local interactions. Whenever an encounter between two pedestrians occurs, the repulsive interaction force between them pushes the pedestrians a bit to the side. Importantly, these interactions are more frequent between opposite directions of motion, due to the higher relative velocity. This is the main reason that causes opposite directions of motion to separate from each other. A preference of pedestrians to walk on, say, the right-hand side is not needed to explain the phenomenon. From the point of view of complexity science, lane formation is a "symmetry breaking" phenomenon that occurs when a mixture of different directions of motion is unstable.



Walking through a "wall" of people without stopping

Surprisingly, the very same force model also reproduces a number of other interesting findings in pedestrian crowds, such as oscillatory changes of the flow direction at bottlenecks. This results from an alternating pressure relief in the crowd and has inspired the self-organized traffic light control discussed in a previous chapter. Another example of self-organization is the amazing phenomenon of "stripe formation," which allows pedestrians to cross a pedestrian flow without having to stop (see illustrations below). It's almost as if one could walk through a wall! Using the social force model, it's possible to understand how this is possible. The formation of stripes – which occur for similar reasons as the lanes discussed before – allows pedestrians to move forward with the stripes and sideward within the stripes. Taken together, this enables the continuous collective motion through a crossing flow (see http://www.youtube.com/watch?v=yW33pPius8E).



Measuring forces

In physics, forces are experimentally determined by measuring the trajectories of particles, especially changes in their speeds and directions of motion. It would be natural to do this for pedestrians, too. At the time when we developed the social force model for pedestrians, I could not imagine it would ever be possible to measure social forces experimentally. But a few years later, we actually managed to do this. Around 2006, with the advent of powerful video cameras and video processing, my former PhD student Anders Johansson was able to extract pedestrian trajectories. We furthermore adapted the parameters of the social force model to optimally reproduce the trajectories with computer simulations of the model. In 2006/07, such tracking methods became also important for the analysis and avoidance of crowd disasters.

Then, in 2008, Mehdi Moussaid and Guy Theraulaz set up a pedestrian experiment in Toulouse, France, under well-controlled lab conditions. This finally empowered us to do data-driven modeling. While before we had to make assumptions on the functional form of pedestrian interactions, it now became possible to determine the functional dependencies directly from the wealth of tracking data generated by our pedestrian experiment. After fitting the social force model to individual pedestrian data, it was finally used to simulate flows of many pedestrians. To our excitement, the computer simulations yielded a surprisingly accurate prediction of the pedestrian flows observed in a wide pedestrian walkway.

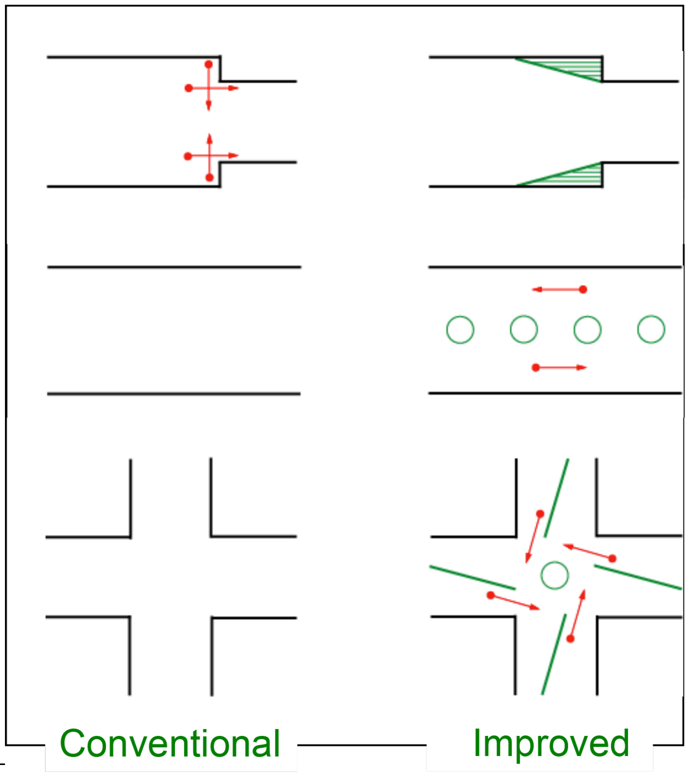
So, pedestrian modeling can be considered a great success of sociophysics. Over time, pedestrian studies had evolved from a social to a natural science, bringing theoretical, computational, experimental and data-driven approaches together. This even led to practical and partly surprising lessons for the better design of pedestrian facilities and the planning of safer crowd events such as the annual pilgrimage in Mecca.

Most pedestrian facilities are inefficiently engineered

Back in 1994/95, when comparing different designs of pedestrian facilities, Peter Molnar and I surprisingly found that obstacles in the way, if properly placed, can make pedestrian counter-flows more efficient (see figure below). In fact, all the conventional design elements of pedestrian facilities – corridors, bottlenecks, and intersections – turn out to be not well designed. They can be substantially improved! In many cases, "less is more," i.e. providing less space for pedestrians produces better flows. This surprising discovery can be best understood for bottlenecks such as doors. Here, a funnel-shaped design can reduce disturbances in the pedestrian flow, which result when the directions of motion are not well aligned (e.g. when some people approach the door from the front and others from the side).

In busy bi-directional pedestrian flows, the efficiency of motion can be improved by a series of pillars in the middle. It turns out that these pillars help to stabilize the interface between the opposite flows, thereby reducing disturbances. The effectiveness of the design becomes particularly obvious in subway tunnels, where pedestrians move both ways and pillars exist for static reasons.

Finally, an obstacle in the middle of a pedestrian intersection may also improve the flow. When Peter Molnar and I discovered this, it took us a long time to understand. But eventually we noticed that, at intersections, many different collective patterns of motion can emerge, for example, clockwise or counter-clockwise rotary flows, or oscillatory patterns of the crossing flows. The problem is that the different collective patterns of motion destroy each other after a short time, such that none of them is stable. Putting a column in the center can increase the likelihood of rotary flows and thereby increase the overall efficiency. But a further improvement can be reached by replacing an intersection of four flow directions by four intersections of two flow directions each, as it may be reached by suitably located railings. In this way, a rotary flow pattern is supported, and disturbances can be drastically reduced.



Crowd disasters

Unfortunately, pedestrian flows don't always self-organize in an efficient way. Sometimes, terrible crowd disasters happen, and dozens or hundreds of people may die, even though everyone has peaceful intentions and does not behave in a ruthless or otherwise improper way. How is this possible?

When I got interested in the problem in 1999, crowd disasters were often treated as God-given or natural disasters that are beyond human control. But the root cause for the breakdown of social order in pedestrian crowds has something in common with the occurrence of traffic jams. If the density gets too high, pedestrian flows turn unstable. The resulting crowd dynamics can be uncontrollable for individual people, and even for hundreds of security forces. But I will show below that crowd disasters can nevertheless be avoided, when their reasons are understood and when proper preparations are undertaken.

Crowd disasters have happened since at least Roman times. That's why building codes were developed for stadiums, as exemplified by the Coliseum in Rome. The Coliseum had 76 numbered entrances and could accommodate between 50,000 and 73,000 visitors, who would exit through the same gate through which they had entered. With these rules and its generous provision of exits, the Coliseum could be evacuated within 5 minutes. Modern stadiums, which generally have a smaller number of exits, can rarely match this figure.

Despite the frequent and tragic occurrences of crowd disasters in the past, they still continue to happen. In other words, they are not properly understood. Media reports often suggest that crowd disasters occur when a crowd panics, causing a stampede in which people are crushed or trampled. The implication is that crowd disasters would be the result of unreasonable or aggressive behavior, with some individuals pushing others relentlessly as they try to escape. But why would people panic? Referring to crowd disasters, Keith Still once said to me: "People don't die because they panic, they panic because they die."

In fact, in my studies with Illes Farkas, Tamas Vicsek, Anders Johansson, Wenjian Yu and others, we reveiled that many crowd disasters have physical rather than psychological causes. They may occur even if everybody behaves reasonably and tries not to harm anyone else. Therefore, the view that crowd disasters are mostly a result of panic is outdated. Alternatively, one might suspect that people are crushed when the inflow into a spatially constrained area exceeds the outflow for an extended period of time. Certainly, the density can become life-threatening under such conditions, as more and more people accumulate in too little space. But when in 2006 another crowd disaster happened during the Hajj – the annual Muslim pilgrimage around Mecca – it occurred on a large plaza.

Being experts in crowd dynamics, Anders Johansson and I were asked to evaluate videos showing the accident area. In the beginning, when we played the videos, we saw nothing informative. Due to the high pedestrian density, people just moved very slowly, some centimeters per second. However, when I asked Anders to play the videos 10 or even 100 times faster, we were totally surprised!

The accelerated videos showed some striking phenomena. First we discovered an unexpected, sudden transition from smooth pedestrian flows to stop-and-go flows (see the long-term photograph above and the video at https://www.youtube.com/watch?v=muKC5bZezlo). In contrast to freeway traffic, however, these stop-and-go flows were previously unknown and unlikely to result from delayed adaptation. We discovered that they were caused by a competition of too many pedestrians for too few gaps in the crowd, i.e. by a coordination problem. The stop-and-go movement set in, when the overall flow suddenly dropped as a critical pedestrian density was crossed. As a consequence of the drop, the outflow from the area was drastically reduced, while the inflow stayed the same. So, the density increased quickly, but this was not the final cause of the tragedy!

To our further surprise, some minutes later we witnessed another unexpected transition – from stop-and-go flows to a phenomenon we call "crowd turbulence" (see picture above and the video at http://www.youtube.com/watch?v=F6EJnMbyM-M). In this situation, people were pushed around in random ways. Eventually, Anders Johansson and I discovered in 2006/07 that it was not the density, but the density times the variability of speeds, the so-called "crowd pressure," which determined the onset and location of the crowd disaster.

It turned out that, when the density crosses a critical threshold, any body movements – even unintentional ones – can create forces acting on another pedestrian body. These forces can add up from one body to the next, such that the resulting force quickly changes the strength and direction. Therefore, people find themselves pushed around in unpredictable and uncontrollable ways.

It is just a matter of time until someone loses the balance, stumbles, and falls to the ground. This produces a "hole" in the crowd, such that the forces acting on the surrounding people get unbalanced, as the counter-force from the front is missing. Therefore, the surrounding people tend to fall on top of previously fallen persons or are forced to step on them. The situation ends with many people piled up on top of each other, such that those on the ground have difficulties to breathe and die of suffocation. Similar observations were made in other crowd disasters, for example, the Love Parade disaster in Duisburg, Germany.

Countering crowd disasters

Can we use the above knowledge to avoid crowd disasters in the future? Yes, indeed! Some years back, together with several colleagues, I became involved in a project aiming to improve pedestrian flows during the annual Muslim pilgrimage to Mecca. We were asked to find a better way of organizing the crowd movements around the New Jamarat Bridge, a focal point of the pilgrim route (see http://www.trafficforum.org/crowdturbulence). On and around the previous Jamarat Bridge, thousands of pilgrims had died in tragic crowd disasters over the years. How could one avoid them?

This was a challenge that required us to take into account not just technical matters such as crowd densities, but also dozens of religious, political, historical, cultural, financial, and ethical factors. Our use of crowd modeling led us to propose measures including the counting and monitoring of crowds through newly developed video analysis tools,[4] the implementation of time schedules for pilgrim groups, re-routing strategies for crowded situations, contingency plans for possible incidents, an awareness program to inform pilgrims in advance about the procedures during the Hajj, and an improved information system that had to guide millions of pilgrims speaking about 200 different languages. After implementing these proposals, the 2007 Hajj (in

[4] For example, one may play back videos of security cameras in an accelerated fashion, say, every 60 seconds, which allows the brain to notice advance warning signals of critical crowd conditions such as stop-and-go waves. Video post-processing can overlay colors representing the local density, or arrows representing the average flow in a certain location – important information that the naked eye cannot see.

1427H) was indeed safely performed.[5] Like for the traffic assistant system discussed before, the main underlying success principle was to gather real-time information and respond to it adaptively.

Since then, the principle of providing real-time feedback has widely spread. An interesting example for this is crowd sensing. Paul Lukowicz, a member of the FuturICT project, and a number of further scientists such as Martin Wirz and Ulf Blanke, recently developed an *app* for safer mass events. In a number of festivals in London, Vienna and Zurich, they used voluntarily provided GPS traces of visitors to determine the crowd densities and pedestrian flows, i.e. averaged quantities determined from the GPS data of many people. These data were then provided to the visitors of the mass events, to give them a better idea of over-crowded areas that they should better avoid.

Forces describing opinion formation and other behaviors

Of course, one might ask whether the concept of social forces can be also used to understand different social phenomena and to overcome other kinds of problems, too, such as crime or conflict. I am convinced of this! The success of force models in describing pedestrian flows is related to the fact that pedestrians are moving continuously in space. Therefore, the dynamics of a pedestrian can be represented by an equation of motion, which says that the change of its spatial position with time is given by the velocity. Complementary to this, the change of velocity with time, i.e. the acceleration, is modeled by a sum of forces. But can we understand opinion formation processes or other behavioral changes by social forces as well? Surprisingly, the answer is "yes," if we have more or less gradual changes on a continuous opinion scale or in a continuous behavioral space. Otherwise, one must use generalized models, which exist as well.

[5] and, in fact, in the following years as well. However, as I moved to another university, where I focused on new tasks, I haven't been involved in the changes that have been made since 2007.

After formulating the social force concept for pedestrians in Göttingen, Germany, in 1990 I joined the team of Professor Wolfgang Weidlich at the University of Stuttgart. He was probably the only physicists at this time working on modeling socio-economic processes and systems. In some sense, Professor Weidlich might be seen as grandfather of sociophysics. My plan at this time was to learn, how opinion formation and decision making could be modeled. Since my work on pedestrians, I had the idea that both, the individual and collective behavior of people could be understood through social forces, and I managed to formulate a corresponding theory (see Information Box 1).

Interestingly, social force models can be formulated for migration processes, too, when people are assumed to relocate within a certain (not too large) radius. In one of my models formulated in 2009, I assume success-driven migration, where individuals try to avoid locations, in which they expect bad outcomes, but seek locations that appear to be favorable. Bad neighborhoods (those, where people were uncooperative) turn out to have a repulsive effect, while good neighborhoods (where people were cooperative) have an attractive effect. It is even possible to calculate the direction and strength of the repulsion or attraction effect, i.e. the force describing the average direction and speed of motion in a certain location.

A great advantage of using the concept of "social forces" is that it can help us to get a better imagination of complex processes underlying social change. Movements towards some subject or object are reflected by attractive forces, movements away by repulsive forces. It is also important to recognize that such forces may not be attributed to individuals, but rather to groups of individuals, companies, or institutions. In other words, social forces may be a collective effect. Group dynamics or "group think," as a result of some emergent group identity, is probably a good example for this. There, the interaction of individuals creates a collective "group" perspective, which in turn changes the behavior of individuals. In fact, the theory of social milieus knows that the behavior of an individual is largely influenced by its environment. This can now increasingly be quantified and put into mathematical formulas with predictive power. But what is more powerful: physical or social forces?

Culture: More persistent than steel

It has often been claimed that war is the mother of civilization, and whoever has better weapons will rule the world. However, I don't buy this. Even though war may have spread civilization, I believe the underlying mechanism is migration and the exchange of goods and ideas. Today, with the Internet, civilization can spread in ways that does not have to cost human lives.

But what is the basis of civilizations? It's culture! Culture is largely a collection of rule sets, such as procedures and social conventions, norms, values and roles. These determine the success and failure of societies and guide their evolution over sometimes thousands of years. Just take religious values, which can determine the behaviors of people over thousands of years. It is therefore not exaggerated to say that culture is more persistent than steel. And culture is more relevant for success than weapons. In other words, social forces can be stronger than physical ones. A good example is the ancient Greek culture, which managed to spread to their Roman occupants, since it was more advanced.

However, while we all learned about physical forces at school, only very few people have an explicit knowledge of the social forces determining the behavior of socio-economic systems. This has to change, if we want to overcome or at least mitigate socio-economic problems. As the last chapter has shown, it's now possible to identify the interaction mechanisms that promote social order. Information Box 2 on social capital further illustrates that the success and failure of societies largely depends on invisible factors. In a sense, social norms are the fabric of our society, and social capital acts like a catalyst of socio-economic success.

Avoiding conflicts

Conflicts, wars and revolutions, too, can be understood with a social force approach. They relate to forces that destabilize a system and may break it into pieces. There are at least three types of conflict situations: (1) An encounter (say, between two countries) causes losses on both sides. This might be avoided by better advance awareness of the likely outcomes of such an encounter. (2) The encounter is beneficial for one side and unfavorable for the other, while it causes an overall damage. Here, the second party needs to be protected from exploitation (e.g. by solidarity from third parties or by establishing an efficient separation of the conflict-prone parties). (3) The encounter is advantageous for one side and undesirable for the other, but this time the overall outcome is positive. Then, value exchange can make the interaction beneficial for both sides, i.e. it's possible to align the interests and create a win-win situation. Recently, I have proposed Social Information Technologies that aim to reduce the occurrence of conflicts between companies or people.

Would it also be possible to measure the forces creating conflict? I think so. We could build a ConflictMap, revealing regional and international tensions and how they come about. In fact, when working in my team, Thomas Chadefaux mined millions of news articles over a period of more than 100 years and performed a sentiment analysis for words indicating conflict. This allowed him to quantify the level of tension between countries in the world. Moreover, he could show that the level of tension allows one to predict the likelihood of war outbreaks in the next six or twelve months. Such advance warning signals can provide valuable time for diplomatic efforts to reduce political tensions before it's too late for a peaceful solution. Our analyses also revealed how tension spreads from one country to the next, as it happened after the war on Iraq, thereby destabilizing the entire region. Apparently, this has produced fertile ground for the rise of the Islamic State (IS).

Conflict in the Middle East

Another data-driven study analyzed a problem that worries the world since many decades, namely, the conflict in the Middle East. Why haven't we so far been able to stop this conflict? A classical Big Data approach, even if we knew all the trajectories of all bullets shot, couldn't really reveal the causal interdependencies underlying the conflict. Therefore, in a study with Ravi Bhavnani, Dan Miodownik, and Maayan Mor, Karsten Donnay, we developed instead an empirically grounded agent-based model. The validation procedure of our model suggests that intercultural distance is the main driving force of the conflict.

An analysis of the violent events reveals that they are correlated with each other. There is rather a responsive dynamics, where each side "pays back" for the previous attacks from the other side (see the movies http://youtu.be/JG86BPezqAU and http://youtu.be/J64kEPa2LaI). For example, Palestinians retaliate violence on the Israeli side and vice versa. What does this tell us? Basically, both sides punish each other for the violence they were suffering from before. From a rational choice point of view, this should stop the chain of violence, as one event triggers another, usually bigger one, or even several ones. Therefore, the conflict is costly for both sides, and increasingly so over time. The Israeli movie "Gatekeepers," which interviews previous chiefs of secret service, therefore, comes to a remarkable conclusion: "We have won every battle, but we are losing the war." In other words: it does not pay off to be violent – on the contrary. It seems that each party tries to send a message to the other one: "Stop being violent to us – you will otherwise have to pay a high price!"

So, why does such counter-violence cause escalation rather than stopping the chain of violence? Because both sides think they are right in what they do. In fact, they apply the right principles, but to the wrong situation. It is very important to recognize that the reason that makes us punish others is related to the way we use to establish social order.

We have learned that punishment is a mechanism that can establish and stabilize social norms. Therefore, we punish those who do not follow our norms. However, such punishment is only effective, if the punished side accepts the punishment. Otherwise it will strike back and pay revenge, which gives rise to an escalating conflict. It is, therefore, important to recognize that punishment will only be effective, if people share the same values, norms, and culture.

Therefore, in a multi-cultural society, punishment may not be effective in creating social order. Under such conditions, a possible way to reduce the level of conflict would be to separate the opposing parties, i.e. to live in different areas. Another one is to develop a culture of tolerance, understanding and respect. In fact, as we have seen in the last chapter, there are many social mechanisms that support the creation of social order, for example, reputation mechanisms. I am, therefore, confident that the deeper understanding of the mechanisms and forces producing conflicts will eventually allow us to overcome or mitigate them. Personally, I would strongly advice to go away from a punitive culture and to engage in a differentiated, reputation-based culture appreciating diversity. This means, almost all of us would have to change the way we are treating others. It would require a global change of culture. But the Internet may (help to) bring it on the way.

Flu prediction, better than Google

Not just wars, but pandemics too are a major threat to humanity. Some of them have killed millions of people. The Spanish flu in 1918 was a shocking example of this. Such pandemics are, in fact, expected to happen again, as viruses mutate all the time, finding our immune systems more or less (un)prepared. The world has also been surprised by the recent outbreak of Ebola.

To contain epidemic spreading, the World Health Organization (WHO) is continuously monitoring emerging diseases. It takes about 2 weeks to collect the data from all the hospitals of the world, such that one typically gets an overview of the actual situation with a two weeks delay. Then, *Google Flu Trends* invented an approach called "nowcasting," which was celebrated as major success of Big Data analytics. It was claimed that it was possible to estimate the number of infections in real-time, based on the search queries of *Google* users. The underlying idea was that queries such as "I have a headache" or "I don't feel well" or "I have a fever" and so on might be indicative of having a flu. Recently, however, the *Google Flu* approach was found to be unreliable, partly because of *Google* steadily changes its search algorithms and also because advertisements may bias people's behaviors. Fortunately, there is a model-based approach using much less data, which considers the mechanism of disease spreading. It looks at infection data in a way that is augmented by a model based on air travel data. How did Dirk Brockmann and I discover this approach in 2012/13?

Independently of each other, we had been interested in modeling epidemic spreading processes already for a couple of years. In 2002, in the wake of the September 11 attacks in 2001, there were fears of bioterror using anthrax or other deadly germs, which threatened the USA and the rest of the world. At this time, I was proposing to Otto Schily, the then German Minister of Internal Affairs, to build a self-calibrating epidemic simulator to predict the spreading of pandemics. While infection and recovery rates are often not well known after a disease outbreak, the idea was that a self-adaptive calibration model would produce increasingly accurate predictions, as more data of infected people would become available. However, I received a letter that such an approach wouldn't be feasible. I did not really believe this, but it delayed progress for an entire decade, because I did not have any funding for such a study.

Dirk Brockmann, however, started to investigate the spatio-temporal spread of diseases by means of computer simulations, and also by analyzing the paths of dollar bills in his famous "Where is George?" study (http://www.youtube.com/watch?v=kn32vavZqvg). However, when visualizing spatio-temporal spreading patterns of epidemics, the patterns looked frustratingly chaotic and unpredictable. The relationship between the arrival time of a new disease as a function of the distance from its origin location was so scattered that one could not make much sense of it. But it became increasingly clear that this problem resulted from the high volumes of air passenger travels. So, Dirk had the idea to define an effective distance based on the travel volumes between all airports in the world and to study the spreading dynamics as a function of this alternative distance measure.

Our collaboration finally emerged in 2011, when Germany was shocked to see the spreading of the deadly, food-borne EHEC epidemic. I got in touch with Dirk, because I thought we could combine his epidemic spreading model with a model of food supply chains and, thereby, help to identify the origin location of the disease, which was unknown at that time. Unfortunately, we could not get hold of proper supply chain data at that time. But our discussion triggered a number of important ideas. Particularly, our attention moved from predicting the spreading of diseases to detecting their origin locations.

In fact, looking at the empirical infection cases in an effective distance representation from the perspective of all airports in the world, we found that the most circular spreading pattern identified the most likely origin of the disease. But what is more important: once the origin location is known, combined with the circular spreading pattern in the effective distance representation, it becomes possible to predict the order, in which cities will be hit by a pandemic wave (see the movie http://www.youtube.com/watch?v=ECJ2DdPhMxI). Furthermore, it turns out that this technique can be successfully applied even if the epidemic spreading parameters such as the infectiousness and recovery rate are not well-known, which is typical the case after the outbreak of a new disease. The only data important for our analysis are the air travel volumes between all airports, which are needed to specify the effective distance.

Shortly later, Ebola broke out and, using our previously developed method, Dirk made early predictions of Ebola imports into other countries, which became the basis of international preparations to contain its spreading (http://rocs.hu-berlin.de/projects/ebola/). I would also like to mention the team of Alessandro Vespignani and Vittoria Colizza, both partners of the FuturICT initiative, who have build a sophisticated simulator to predict diseases and test the effectiveness of political measures (see http://www.gleamviz.org/).

INFORMATION BOX 1: Social Fields and Social Forces

When I worked on the social force model, I soon discovered the book by Kurt Levin (1890-1947) on the social field concept. I like his idea a lot, even though a behavioral and theoretical foundation of the concept was missing. So I decided to develop such a foundation in my PhD thesis in 1992. This resulted in the derivation of Boltzmann-like and Boltzmann-Fokker-Planck equations from behavioral assumptions.

These equations contain a quantity determining the systematic motion in the behavioral space, which can be interpreted as "social force" and often expressed as the slope of a "social field." Such a social field can be imagined like a mountain chain in behavioral space, where the steepest slope in a location determines the social force that a person with the corresponding behavior would feel. This social force describes the expected size and direction of the behavioral change. Valleys of the social field correspond to social norms. If complying with the norm, the social force is zero. But when deviating from a social norm, one will feel a social force, as it happens in reality.

Note, however, that the above discussed "mountain chain" and, with it, the corresponding social field is variable. It changes depending on the behavioral changes of others. Therefore, the social field influences the behavior of a person, but at the same time, it is potentially modified by that person's behavior and the behaviors of others. In other words, social norms may change over time as a result of social interactions.

INFORMATION BOX 2: Social Capital

Most of us have probably learned that money makes the world go round and all that matters is to have enough of it. Money is certainly a powerful invention, but there is more that contributes to economic development. This includes human capital (like education), but also social capital.

So, what is social capital? I define it as everything that results from social network interactions and can potentially be turned into a benefit. Examples are cooperativeness, public safety, a culture of punctuality, reputation, trust, respect, and power. While our own actions influence our social capital, we can't fully control it, which is in contrast to money. In many cases, we can't buy social capital (or only to a limited extent), but social capital creates value added. Interestingly, by doing certain things, we are not automatically entitled to get a certain amount of social capital. As we know from reputation and respect, these things are given to us by others. They depend on interaction effects.

Note that the amount of social capital also determines the resilience of a system, and its risk of failure. Social capital influences both, the probability and size of damage. This became clear to me in a seminar of ETH Zurich’s Risk Center. The Risk Center brings together experts in probability theory with experts in complexity and network theory. We discussed that large disasters have an over-proportional impact on public opinion. That's why plane crashes and terror attacks matter a lot to people, while they seem to feel less threatened by everyday risks such as car accidents or deaths of smokers. Therefore, it is often believed that "size matters," i.e. large disasters make people respond in an irrational, perhaps even panic way.

However, having studied the phenomenon of panic for some time, I rather concluded it was more likely that "people respond to the fact that there has been more damage than just the physical one – namely damage to the social capital." For example, a large-scale disaster often damages the trust into the risk management of companies or public authorities, in particular when it was caused by unprofessional behavior or corruption. While people care about such things, no insurance company is covering this damage to social capital.

Hence, we must protect social capital in a similar way as we protect economic capital or our environment. Social capital can be damaged and exploited, but this should be prevented. In order to get there, we must learn to measure social capital and to quantify its value. Quantifying the value of our environment also helped eventually to protect it better.

Trust and power

To stress the importance of social capital, it is important to recall that the financial crises resulted from a loss of trust: banks did not trust other banks anymore and did not want to lend their money; customers did not trust their banks anymore and emptied their bank accounts; banks did not want to give loans to companies anymore; people did not want to invest in financial derivatives anymore, etc. In the end, the resulting financial meltdown amounted to an estimated 20,000 billion US dollars. So, trust has a pretty high value, and when it gets lost, the economic losses are tremendous. To give another example: the recent loss of trust into US cloud storage companies after the NSA scandal was estimated to cause an economic loss of up to one third of the previous business volume.

Trust is also the basis of power and legitimacy. When I studied in Göttingen, Germany, one day a deadly car accident, caused by a mistake of the police, triggered a large public outcry and massive demonstrations. This was the first instance, when I noticed that public institutions can easily lose their public support, in other words: their social capital. This happens, if trust gets lost over something that the authorities should not have done according to the moral beliefs of the public. I made the same observation in Zurich, Switzerland, when there were many complaints about the work of the migration office. During this time, the windows of the migration office were broken time and again, but when the office director was replaced, the problem disappeared.

Interestingly, soft factors such as credibility and trust are the basis of power. For example, the loss of control during the England riots in 2011 occurred, after the London police shot a person without giving a sufficient justification to the public. A similar thing happened 2014 in the US city of Ferguson, Missouri. In fact, riots in many other countries, too, were triggered by events where public authorities hadn't done a proper job in the eyes of the people. The Arab spring, for example, started in Tunisia, after Mohamed Bouazizi burnt himself, because of police corruption and bad treatment.

In other words: legitimacy and power result from doing the right thing in the eyes of the people. When people don't offer their idealistic or practical support anymore, authority and power are gone. While one may buy weapons and, with this, destructive power, constructive power depends on the trust and support of the people – otherwise they won't provide support, and this basically means that one hasn’t got any power. Brutality does not create respect. It might create fear, but this can replace legitimacy only up to a certain degree. As the situation gets increasingly unacceptable, more and more people will lose their fear, start to resist the previously respected authorities actively or passively, or even become ready to sacrifice their lives. The problem of such extremism or even terrorism is well-known from freedom fighters, who have previously led normal family lives.

But even passiveness of its citizens can make a country fail within just a few years or decades. This could, for example, be seen in the former German Democratic Republic. I, therefore, believe that trust is the only sustainable basis of power and social order. It must, therefore, concern us all that, in many countries, politics and management are currently the professions with the lowest levels of reputation. In contrast, "social" professions that create public goods – firefighters, scientists, doctors, nurses and teachers – earn the highest levels of reputation. As we will see later, this has some important implications for the future.