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Understanding, creating, and managing complex techno-socio-economic systems: Challenges and perspectives

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Abstract. This contribution reflects on the comments of Peter Allen [1], Bikas K. Chakrabarti [2], Péter Érdi [3], Juval Portugali [4], Sorin Solomon [5], and Stefan Thurner [6] on three White Papers (WP) of the EU Support Action Visioneer (`www.visioneer.ethz.ch`). These White Papers are entitled "From Social Data Mining to Forecasting Socio-Economic Crises" (WP 1) [7], "From Social Simulation to Integrative System Design" (WP 2) [8], and "How to Create an Innovation Accelerator" (WP 3) [9]. In our reflections, the need and feasibility of a "Knowledge Accelerator" is further substantiated by fundamental considerations and recent events around the globe.
The Visioneer White Papers propose research to be carried out that will improve our understanding of complex techno-socio-economic systems and their interaction with the environment. Thereby, they aim to stimulate multi-disciplinary collaborations between ICT, the social sciences, and complexity science. Moreover, they suggest combining the potential of massive real-time data, theoretical models, large-scale computer simulations and participatory online platforms. By doing so, it would become possible to explore various futures and to expand the limits of human imagination when it comes to the assessment of the often counter-intuitive behavior of these complex techno-socio-economic-environmental systems. In this contribution, we also highlight the importance of a pluralistic modeling approach and, in particular, the need for a fruitful interaction between quantitative and qualitative research approaches.
In an appendix we briefly summarize the concept of the FuturICT flagship project, which will build on and go beyond the proposals made by the Visioneer White Papers. EU flagships are ambitious multi-disciplinary high-risk projects with a duration of at least 10 years amounting to an envisaged overall budget of 1 billion EUR [10]. The goal of the FuturICT flagship initiative is to understand and manage

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complex, global, socially interactive systems, with a focus on sustainability and resilience.

1 Relationship between the visioneer and futurICT projects

In the beginning of these reflections, a word of clarification is required, as some of the comments on the Visioneer White Papers have been made with an eye on the FuturICT flagship candidate project. However, the Visioneer and FuturICT projects are not the same, and also not directly tied to each other. Visioneer was a smaller-scale Support Action mandated to identify interesting future research lines for one or several Proactive Calls within the area of ICT-FET, i.e. the Future and Emerging Technologies (FET) area in the Information and Communication Technologies (ICT) sector of the European Commission. Flagships are actually much larger research initiatives, and will be prepared by Coordination Actions in 2011/12, involving a wider community of scientists. From this point of view, Visioneer should not be understood as a description of the FuturICT flagship. While the scope is likely to be overlapping, it is definitely not identical. For example, in FuturICT the development of socio-inspired ICT will play a much bigger role and is not brought out strongly in the Visioneer White Papers. The same applies to the role of the humanities and qualitative research within the FuturICT-related activities. Therefore, some of the comments regarding Visioneer do not apply to FuturICT. Readers are asked to keep this in mind and, at the same time, are encouraged to engage in the preparatory process of FuturICT and deliver inputs for its agenda. The FuturICT webpage www.futurict.eu is trying to document the evolution of the project in a transparent way.

In the rest of this paper (apart from the Appendix), we address the comments made in response to the Visioneer White Papers.

2 Some summarizing quotes

All six commentaries on the Visioneer White Papers suggest that the proposed research program fits the requirements of the EU flagship program very well, as is exemplified by the following quotes (and many similar comments received in response to the White Papers):

- "We can build simulations of such processes and they represent a significant class of complex systems models that can help us understand and improve the performance of human and socio-economic systems." "This initiative therefore represents a worthwhile 'experiment' in improving our understanding and models of complex human systems..." "I think that together these papers represent an excellent and comprehensive attempt to provide a remarkable view of what 'could be done' in using complexity science to tackle problems of social and economic systems." "In summary, I would welcome the development of research in the direction indicated by the paper ..." (Peter Allen)
- "The Proposal ... is a very timely and desirable one. The Proposal is well thought out and detailed. ... the proposed initiative is a pioneering one in this scale." (Bikas Chakrabarti)
- "I see the WPs as a plan for a grand synthesis of computational and social sciences for understanding and predicting social phenomena, somewhat in Kepler's and maybe Newton's spirit." (Péter Érdi)
- "Let me state from the beginning that I am for allocating more funds to scientists whose research can spare us from social, economic and ecological crises and I

commend [the proposer] for bringing it energetically and persistently to the attention of the relevant communities and funding bodies." (Sorin Solomon)
- "I like the paper 'How to Create an Innovation Accelerator' by D. Helbing and S. Balietti mainly because it could have the potential of triggering an overdue debate on the ways science, research and technology is managed, rated and disseminated. ... many of the suggestions contained in the paper could be very useful and important." (Stefan Thurner)
- "... the last four decades are dominated by the qualitative 'hermeneutic culture' of society, with *modernism* and subsequently *postmodernism* as their two dominant approaches. Complexity theories of society ... can be seen as the second attempt to develop a science of society – this time, however, on the basis of two strong and interrelated foundations: the new theories of complexity and the progress made in communication and information technologies." (Juval Portugali.)

3 The science-historical context

The comments, particularly the ones of Péter Érdi and Juval Portugali, put the scientific vision of the project proposed by Visioneer nicely into a historical perspective. The list of names includes exceptional masterminds such as Galileo Galilei, Johannes Kepler, Isaac Newton, Albert Einstein on the physics side and Norbert Wiener, Hermann Haken, and Wolfgang Weidlich on the side of cybernetics and synergetics. One should not forget to add Ludwig Boltzmann, who suggested even long before the pioneering work of Elliott Montroll and Wolfgang Weidlich that certain aspects of social systems may be understood from a statistical physics perspective.

Although the following analogy has some drawbacks, the transition from a geocentric to a helio-centric world view may indeed serve as an illustration of the paradigm shift that a rapidly growing number of people believe will take place in the social sciences. Note that the early geo-centric description of planetary motion, based on a linear superposition of circular movements (called "epicycles"), was actually working quite well from a descriptive point of view. However, assuming the sun to be in the center of the planetary system offered a much simpler and at the same time explanatory approach, based on a law of gravity. Revealing this law required an enormous abstraction: When falling in air, objects behave individually! The underlying universal law of gravity can only be found by abstracting from air resistance – conditions which are highly idealized and artificial on Earth. For this discovery, scientists had to overcome their visual impression and experience. However, as a reward, they learned how to launch satellites and send men to the moon. Understanding social reality from elementary principles would certainly require similarly daring abstractions.

Such abstractions have even a sociological tradition. While considering sociology as "queen of sciences", Auguste Comte, often called the "father of sociology", proposed a "social physics" approach to studying society [11]. Talcott Parsons advocated using "analytical realism" [12] to build sociological theory, pointing out that theoretical concepts should be abstracted from empirical reality (with all its diversity and confusion) into common analytical elements, in order to isolate phenomena from their embeddedness in the complex relations constituting social reality. Moreover, Max Weber proposed to identify "ideal types" [13] as abstract statements of the essential characteristics of social phenomena. Today, it is more common to talk about "stylized facts". Finally, we would like to quote James Coleman, who noted that "Social theory ... is a guide to social construction, no less than Newtonian mechanics is a guide to architecture and civil engineering" [14].

However, in order to avoid misunderstandings, let us state straight away that we are not particularly in favor of a "positivistic" or a narrow "socio-physics" approach, but rather promote a pluralistic research approach [15] (see also Sec. 6). Despite the enthusiasm of some scientists that the puzzles of socio-economic life will be solved in the future, our opinion is that the range of phenomena accessible to a mathematical description will probably be limited (see also Sec. 6). Nevertheless, we believe that these limits have not been reached so far, and exploring them with all necessary care can be a fruitful endeavor. Given the socio-economic crises we are facing, it seems necessary and important to gain a better understanding of the systems humans have created and are creating in the future.

4 A Jointly agreed research strategy

We agree with Péter Érdi that complex systems theory offers the potential of combining concept-driven and data-driven computational social sciences. Regarding the conceptual level, we are sympathetic with Peter Allen's and Juval Portugali's note that modeling society requires us to take an evolutionary approach. We also consider evolutionary economics as promising discipline. In fact, we have elaborated in more detail on these issues in a recent paper addressing "Fundamental and Real-World Challenges in Economics" [16], which should be seen complementary to the above-mentioned Visioneer White papers.

We would like to add that, besides an evolutionary approach, an ecological systems thinking appears useful as well to reflect

- interdependencies of different human activities [17],
- symbioses and competition [18, 19],
- steady innovations, which may sometimes challenge the stability of the system [20],

and to develop suitable approaches oriented at sustainability and resilience. We particularly support the following viewpoint of Juval Portugali: "... unlike other species, human agents are subject to two evolutionary processes: the slow process of biological evolution and the fast process of cultural evolution. Social systems are, in this respect, what I suggest calling *dual complex systems*, that is, society as a whole is a complex system and each of its agents is itself a complex system too. ... In order to fully appreciate this complexity one has to look into the science that studies the complexity of human agents, namely, cognitive science ..."

As a consequence, Juval Portugali suggests the need to develop *non-classical theories of society* (where "classical theories" would represent simple, mechanistic, closed, predictable, and causal theories, as many models of social interactions in the past). We completely agree that simple, mechanistic, and predictable theories are too limited to provide a good picture of social interactions and of society, and we very much support the development of probabilistic and possibilistic models [15].

4.1 Ethical issues

One of the concluding sentences of Peter Allen that we would like to highlight because of its particular importance states: "I applaud the strong emphasis that is put on ethical issues...". For example, people care a lot about private data, when they do not meet the criteria of what is social desirable [21]. Therefore, we underline the urgency to develop privacy-respecting data mining, to create new data formats and web designs that give users back control over their data, and, more general, to carry out ethical research and develop technologies that increase possibilities for citizens to participate in the social, political and economic system. Furthermore, the proposed research activities are dedicated to promoting human well-being (see the section on "Ethical Issues" in Ref. [8]). We also imagine that a special Memorandum of Understanding should establish ethical standards in cooperations with business and other partners. Sufficient transparency and reporting should be required to ensure proper use of project results, and violations of the project goals or standards should be sanctioned.

4.2 Organizational Issues

While all comments were, overall, supportive of the suggested research program, some concerns regarding the project implementation were raised. In fact, as suggested by Bikas Chakrabarti, the envisaged project activities will have a visitor's program, a workshop program, and a dedicated publication program. While the latter is a fundamental part of the concept of the "Innovation Accelerator", all the details will be clarified during the preparatory phase of the proposed project. The research community will be involved in this process. We should underline that our proposed research project also plans to explore new alternatives and not to discourage diverse research approaches [15].

Nevertheless, we would like to point out that the quickest method of finding the way out of the forest (as Sorin Solomon puts it), is neither the individual scouts' approach nor the disciplined collective march, but a good compromise of both: the combination of individual search and orientation at successes of others (see Ref. [22]).

We would like to underline that a *pluralistic* modeling approach is part of our proposed research strategy (see Ref. [15]), i.e. we are very supportive of multiple research routes, as demanded by Peter Allen and Juval Portugali. This is also the reason why the White Papers are posing research questions rather than suggesting answers. "Hilbert workshops" are suggested to pursue a similar idea by putting a focus on posing questions rather than on trying to persuade others to use a particular approach (as conventional workshops currently do). Section 4 of White Paper 1 proposes that "Hilbert workshops would ... determine knowledge gaps, future scientic challenges and promising research routes to address them. Results of such crowd sourcing approaches should be summarized from time to time by review papers or books." At the same time, this research strategy will overcome the "lack of a 'global' effort to evolve precise points of investigation" that Bikas Chakrabarti identified as a problem of previous large-scale research attempts.

It is generally agreed that the social sciences require a substantial additional budget to accelerate scientific progress, and that there should be funds to support innovative ideas. Therefore, we generally agree with Sorin Solomon's proposal to "split the added budget in equal parts: half to the 'super-collider' knowledge accelerator and half to the independently scouting projects", although the exact share of funds can not been fixed at this point. On the one hand, core activities will be needed to establish the "Knowledge Accelerator" (or "Living Earth Platform"). These activities will be centered around leading researchers committed to the project. However, the platform of the envisaged research project will be open, allowing new scientists to board at later stages. For example, if the European Commission follows our proposal, there will be visiting grants and Marie-Curie-like stipends for talented scientists pursuing their own, project-related research, and there will be prizes for excellent research results. This latter instrument will move away from the current funding for promised results in favor of more re-funding for completed results, and the prize money could be used for free research. Details of these proposals will again be worked out during the preparatory phase of the project, involving the relevant research communities.

Work Package 3 of the afore-mentioned Coordination Action will also study role models like the CERN or the Abdus Salam International Centre for Theoretical

Physics in Trieste, as suggested by Bikas Chakrabarti. It is possible, however, that the organizational concept of the Max Planck Society (running many interconnected institutes for fundamental research in a variety of different areas) would be better suited due to the multi-centric organization of the research project.

4.3 Case studies as nucleation points

We largely agree with Peter Allen that research activities should be clustered around concrete challenges such as case studies, and that successes should be rewarded by further funding (see the discussion on research prizes and re-funding above). In fact, a major task of the envisaged project will be to integrate various Crises Observatories[1] into a Living Earth Platform finally performing global-scale data-mining and simulation. These observatories will be focused on concrete, practically relevant questions, where progress will be relatively easy to assess. Moreover, these observatories will be led by scientists who are internationally acknowledged for their pioneering work in establishing data- and simulation-centered initiatives. In other words, we know that these people have the required experience to build up Crisis Observatories, as demonstrated by their previous work.

4.3.1 Success Stories of Complexity Science

We would like to illustrate the successful application of complexity science just by one example, in this case the previous work performed by the team of one of us (DH):

– Based on an application of the "slower-is-faster effect", the supply chain management of etching devices in Infineon Technology's semiconductor production was considerably improved, increasing the throughput by 30% [23].
– In a project for the ddg Traffic Data GmbH, it was possible to reduce the delay times of traffic jam detection and to improve its accuracy by a factor of two each. The novel approach was based on the integration of real-time infrared detector measurements with floating car data and real-time fluid-dynamic traffic simulations, which also contained an on-line calibration module. The software was subsequently used by the company T-Traffic to monitor traffic on Germany's freeways, and it still seems to be in operation.
– In a collaboration with Volkswagen, a new automatic cruise control system was developed, which can improve the collective traffic performance (i.e. increase the traffic flow and its stability). The system is based on adaptive car-following strategies and inter-vehicle communication [24,25] and has been successfully tested in real traffic as well as on special test tracks.
– A completely new, fully decentralized traffic light control based on concepts of self-organized coordination and self-control has been patented in Japan, Germany, and other European countries. A pilot study is currently being performed in the city of Dresden, Germany.
– An agent-based software to easily assess the logistic performance of production plants, using self-organization concepts, has been developed in collaboration with SCA Packaging. The software is now being used by the spin-off ACM Managing Complexity GmbH.
– A pedestrian software for multi-modal traffic, crowd and evacuation simulations has been developed, based on the social force model of pedestrian motion. The

[1] For financial and economic instabilities, for social instabilities, wars and conflicts, for crime and corruption, for health risks, for large-scale environmental changes, etc.

software is commercially distributed on an international scale by the PTV AG through their VISSIM simulation package. This software has in the meantime supported the planning of the Formula One Grand Prix in Abu Dhabi, the North Melbourne Station, and various arenas and mass events all over the world.
- A video analysis software based on sophisticated pattern recognition approaches was developed in order to help prevent critical conditions in pedestrian crowds [26]. The spin-off company Crowd Vision Ltd. is now selling this software world-wide.
- The biggest success was probably the scientific development of novel concepts for the organization of the pilgrimage in and around Mecca in the context of the construction of the New Jamarat Bridge, a 1 billion Dollar investment. The concept required us to take hundreds of factors as well as many religious, political, historical, cultural, financial, and ethical constraints into account. The series of unfortunate crowd disasters in previous years has been stopped by a combination of various measures, and a safe Hajj was celebrated in 2007 (1427H) despite difficult circumstances, particularly with more or less the same capacities during that year, but with 25% more pilgrims than expected. These measures included: counting and monitoring crowds through newly developed video analysis tools, the implementation of a scheduling program for pilgrim groups, re-routing strategies for crowded situations and contingency plans for possible incidents, an awareness program and also an improved information system, which had to guide millions of pilgrims speaking about 200 different languages [27,28]. The insights gained in this project also help to explain crowd disasters in other places and to reduce the likelihood of future ones by careful application of the lessons learnt.

Several of the above innovations have been awarded by research prizes (eight altogether, several of them based on national or international competitions [29]). They have also been covered by international media reports [30]. We should mention, however, that none of the above projects has been supported by the EU. Following Peter Allen's remark, it would be appropriate to reward such successes and those of many more colleagues by research funds (see Refs. [31] for more success stories; the EU project ASSYST is currently working on a new compilation). The reader can easily imagine how much could be achieved, if Europe would focus the power of 100 or more research teams through a flagship project. It is also the uniqueness of case studies pointed out by Peter Allen, which ultimately requires the EU to grow a large community of complexity scientists.

5 We can do better

We would also like to address some critical comments, as they were articulated by Peter Allen, possibly as a result of frustrating experiences in encounters between science, business, and politics. The scepticism seems to suggest that, no matter how nice the solutions of scientists will be, the powerful and mighty will do what they want.

Based on our own experience, we do not share this pessimistic view. There are at least three ways of creating successful interactions between science, business and politics:

1. The *interactive approach* makes sure that there is a continuous dialogue between the different stakeholders and that the expectations on all sides are sufficiently clear and mutually fitting. The proposed project, for example, will develop new platforms for participatory decision-making.
2. The *powerplay approach* follows the rules of business and politics, using all instruments from concerted action over lobbying up to the use of the public media.

In fact, the web2.0 offers social media such as twitter and facebook and thereby facilitates coordinated activities, which empower people who have previously been excluded from political participation.
3. The *contingency plan approach* explores alternative solutions for future crises and is prepared for the moment when decision-makers run out of reasonable options and need help.

Given the large public spending deficits of most Western countries as a result of the financial crisis, the latter case will become more and more common. New solutions will be needed and sought after. We also believe that the scientific and technological ability to explore and illustrate the implications of different policies (including their long-term and side effects) will have an impact on decision-making, particularly where the complexity of the system exceeds the limits of our intuition and imagination. Furthermore, we point out that the envisaged project will explore new institutional and system designs, including collective decision mechanisms leading to better outcomes (e.g. avoiding undesirable herding effects). Finally, it will sooner or later become possible to measure the impact of decisions on individual and social well-being. This will be a precondition for limiting selfishness and increasing fairness (basically in the same way, as possibilities to quantify environmental impacts enabled people to protect their environment more efficiently.)

5.1 Possibilities and limitations of attempts to predict techno-socio-economic dynamics

We agree that limits of predictability [32] are an issue in complex systems, particularly socio-economic systems. However, it is currently not known where these limits are and what they depend on (see also Sec. 5.1.2). Due to their principal importance, these limits and conditions need to be scientifically explored (as well as, by the way, the limits of manageability of socio-economic systems). Section 4.2.3 of Refs. [33] partially addresses these issues. It gives examples for social laws and for long-term, short-term and no predictability in time. It also discusses different methods to improve the system performance in all these different cases. Moreover, Section 4.2.2 [33] explains, based on results of a laboratory experiment, how information systems can be designed such that social adaptation does not invalidate model predictions. This strongly questions the generality of Peter Allen's claim that "the reflexivity of agents means that they will change their behaviour according to the outcomes predicted by any model, which will invalidate its predictions."

Furthermore, Ref. [15] argues that forecasting capability is not a good measure for the usefulness of models, but testable model implications are. While in socio-economic systems it is often not possible to determine the exact time when something will happen, in many cases it is still feasible to say what events are likely to happen and in what sequence (see Fig. 1 and Ref. [33] for details). Putting it differently, the envisaged project does not claim to come up with precise forecasts of the future, but it will be able to explore *possible* futures [33] and to detect warning signs of certain kinds of systemic instabilities or systemic shifts (such as critical fluctuations). For example, it will be able to answer, which political scenarios will cause less conflict in the Middle East, and similarly relevant and challenging questions.

5.1.1 It's not a mission impossible

From our point of view, the following problems do not form fundamental obstacles for modeling socio-economic systems:

- *Selfishness, power, unfairness, etc.:* These are typical model ingredients (or outcomes) of many game theoretic models [35]. It should also be feasible to develop models of corruption.
- *Collective behavior:* Many researchers study models for it and (start to) compare them with empirical or experimental data. Herding effects are well-known and often a result of a lack of orientation (for example, due to information overload). This can also explain financial bubbles at stock markets [36].
- *Social conflict:* Recent models can describe empirical data of conflicts increasingly well [37].
- *Noise effects* (randomness, or fluctuations): They are an ingredient of many models and do not fully eliminate predictability (when the analysis focuses on probability distributions). Moderate noise may even have positive effects on social systems [38,39]. (Usually, there is an optimal level of noise.)
- *Adaptiveness:* The rules governing social dynamics may be subject to change, but such changes can, in principle, be incorporated in models, even though they are hard to anticipate (but one may simulate and explore many possible, "parallel" worlds through scenario analyses).

The following "ingredients" of social systems reduce the level of predictability, but they can still be reflected by agent-based models:

- There is usually a large *heterogeneity* regarding the preferences and values of people [40,41]. This implies that one faces statistical issues related to small numbers of entities. As a consequence, the variability may be large and the predictability small, but only in situations where the system behavior can be significantly influenced by individual players. This tends to be the case for political and other entrepreneurs, whose behavior may have singular macroscopic impacts, if the system architecture allows. Yet, even leaders of powerful countries or CEOs of big companies have limited decision power (see Sec. 5.1.2). When the people, staff or customers oppose their decisions, their influence can melt away quickly, as various recent and historical examples have shown. Despite large differences in the histories of countries, there are global economic and political trends that impact them sooner or later as a result of the exchange of goods and ideas and the competition between systems.
- *Creativity, innovation, novelty, and surprise* are common features of social systems, which deserve further exploration. However, it is not impossible to mimic such features by combining random variations with evolutionary algorithms. Based on the previous argument, it is likely that these features become systemic only rarely, when the system shows critical behavior [42]. For example, innovations are more likely to occur, when there is a pressure for innovation and, importantly, and more likely to spread when the time is ripe for them.
- *Reflexivity* is a problem insofar as it often tends to be individualistic, i.e. world views of different people may diverge, and this may trigger different behavior in people. Similarly, economic models considers *expectations* as driving forces of human activity [43], and these may largely vary from one individual to another one, depending on the respective previous experiences, etc. Again, this creates mainly a problem of small numbers, while individual perceptions may be modeled by individual, experience-dependent filters.
- *Emotions* such as likes, dislikes, jealousy, etc. influence the behavior of people. While we still lack a fully satisfactory mathematical theory of emotions at the moment, emotions are largely responsive and stereotypical [44], and there is some progress in modeling them [45] as well as in the data-driven analysis of collective emotions [46–48]. Moreover, there is empirical evidence that people use *fast and frugal* heuristics most of the time, when decisions must be taken in a complex

world [49,50]. Furthermore, modern research fields such as behavioral or cognitive economics [51–53] and behavioral finance [54,55] are trying to shed new light on laws of "irrational" behaviors of people. Some research labs specifically focus on the computational modeling of emotions [56], and there are even new decision theories, which explain a number of cognitive biases, which have questioned models of rational decision-making before [57]. Today, one can even buy agent-based software that mimics emotional features of human characters and responses to emotions [58]. In fact, why should it not be possible to reflect features such as subjectivity, reflexivity, and cognitive complexity by agents with a small simulated brain and an experience-based individual learning dynamics?

Many of these points have been considered in different places of the Visioneer White Papers and in Ref. [16]. They qualify the proposed project as a project addressing grand fundamental challenges, thereby meeting the criterion of high risk research demanded from flagship projects. The models that can be explored with agent-based simulations will certainly be able to overcome limitations of current mainstream models based on the paradigm of the "homo economicus" as a "perfect egoist" [16]. This approach fits well into reflections of Jean-Claude Trichet on the nature of monetary policy non-standard measures and finance theory during his opening address at the European Central Banking Conference in Frankfurt on November 18, 2010, where he stated: "... we have to think about how to characterise the homo economicus at the heart of any model. The atomistic, optimising agents underlying existing models do not capture behaviour during a crisis period. We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. We need to entertain alternative motivations for economic choices. Behavioural economics draws on psychology to explain decisions made in crisis circumstances. Agent-based modelling dispenses with the optimisation assumption and allows for more complex interactions between agents. Such approaches are worthy of our attention."

5.1.2 Increasing predictability by a micro-macro link and social norms

Another difficult, but solvable challenge results from the current lack of a micro-macro link, i.e. a theory that connects the individual, micro-level behavior with the aggregate, systemic behavior on the macro-level, and the feedback of the macro-behavior on the micro-level. Such a micro-macro link is needed to understand (first-order and second-order) emergence and multi-scale behavior in socio-economic systems. In fact, as has been found in physics, closing the loop by considering feedback effects in the system can increase the predictability of models for complex systems, particularly in non-equilibrium situations. This is, because nonlinear interactions of many system elements reduce the relevant degrees of freedom. For example, the flow of a gas containing thousands of billions of molecules may be characterized well just by a density equation, a velocity equation, and an equation for thermal conductivity.

It would indeed be too pessimistic and even wrong to assume that the human element just creates unpredictability and chaos. Humans have rather invented a whole set of instruments to make social interactions (more) predictable, which includes laws, contracts, social norms, traditions, and cultural values. In some sense, social norms (particularly internalized ones) may be compared with a "remote control" for people. They let individuals do certain things even if they do not like to do them and abstain from other behaviors even if they like to show them. Social norms may, therefore, be seen as scaffolding of society and analogous to roads in traffic systems. Some researchers even call them the cement of society [59]. Nevertheless, there are no measurable physical forces behind social norms – everything is mediated via our cognitive system. This makes them hard to measure, and in fact, people are not even aware of most norms. Nevertheless, a large fraction of our behavior is determined by them. In fact, the behavior of individuals in homogeneous peer groups like communes are pretty predictable [60]. What makes things difficult from a modeling perspective is that people in *heterogeneous* environments have learned different norms and follow different values, depending on their respective background, education, and experience. However, in homogeneous social environments, e.g. certain peer groups, communes or villages, a large fraction of public activity is quite regulated and predictable.

5.1.3 Social uncertainty principle and non-classical social theories

All the above arguments do not mean that we underestimate the difficulty of making scientific breakthroughs in the modeling of techno-socio-economic systems, but some promising advances have recently been made with agent-based computational models, which shed new light on self-organization processes in social systems and emergent phenomena [61–63]. Some people compare the nature of the afore-mentioned non-classical behavior of social systems with quantum mechanics, where an "uncertainty principle" prevents the prediction of the exact course of an individual particle. They wonder, why it should not be possible to develop a non-classical theory of complex techno-socio-economic systems. Finding such a theory (and one that is more realistic than the theory of the "homo economicus" (the "perfect egoist") will be hard, but progress is promoted by the availability of new data sources.

Indeed, understanding the forces that keep societies together and how to manage them in a sustainable way belongs to the greatest unsolved scientific challenges of our century. However, given suitable model assumptions, the special features of social systems mentioned in Sec. 5.1.1 can all be mimicked by agent-based models, and their implications can be tested through scenario analyses in multi-level computer simulations [33]. The development of realistic hypotheses and the verification of the models, however, requires suitable empirical and experimental data. The relevance of social data mining and social super-computing follows from this (and the large number of possible scenarios).

5.2 Paradigm shifts in computational social science and real-time forecasts

Following the advent of computers, the natural and engineering sciences have enormously progressed. Computer simulations have been used to facilitate and understand interactions of physical particles and make sense of astronomical observations, to describe many chemical properties *ab initio*, and to design energy-efficient aircrafts and safer cars. It would be very surprising, if computers would not be able to make significant contributions to a better understanding of social and economic systems as well. In fact, computer models can naturally complement classical research methods in the socio-economic sciences. For example, they allow one to test whether mechanisms and theories proposed to explain certain observed phenomena are sufficient to understand the respective empirical evidence, or whether there are gaps or inconsistencies in our understanding. Morever, they allow one to investigate conditions, for which analytical solutions cannot be found, and therefore to go beyond the idealizations and approximations of many rigorous models. The study of realistic models and parameter ranges is often not possible without the use of numerical analyses.

Computers are also central for the process of turning data into knowledge. The transition from data-poor to data-rich social sciences will facilitate not only the calibration, but also the verification and improvement of models, and furthermore data-driven modeling. The corresponding research path has, for example, been recently taken in the area of pedestrian and crowd modeling [64,65], and it is likely to succeed in other areas as well. Furthermore, reality mining will be able to provide data in real time, allowing one to integrate measurement and simulation, or to perform on-line calibration. Furthermore, it facilitates a better predictability (in particular the timely determination of advance warning signs) and the avoidance of destabilizing delays and inappropriate measures taken in response to delayed information (delays are a major problem in the efficiency of disaster response management and mitigation). In this connection, a recent breakthrough is Google Flu Trends [66], which managed to establish a real-time analysis based on particular Google searches. A recent publication even topped this: Using particular properties of the spreading dynamics in networks, the authors have shown how to reach a two-week forecast based on "health sensors" [67]. Such successes were totally inconceivable only 2 years ago.

5.3 Fundamental aspects of predictability and scientific paradigm shifts

The idea that techno-socio-economic systems would behave in a completely unpredictable way is exaggerated and misleading. Would it be true, then politics, management, and advertisements would not make any sense. In fact, recent empirical work has revealed regularities in human behavior [68–71] and in human history [72]. For example, a recent "thermodynamic" theory formulates conditions under which hierarchical systems turn into democracies [73,74]. Moreover, *prediction markets* have established themselves as a useful forecasting tool that outperforms classical market analyses and opinion polls [75]. It is also well-known that the position in a social interaction network determines the level of influence and a number of other features [76]. Furthermore, social interactions in space are quite well predictable, including crowd behavior and vehicle traffic [65,77]. Finally, forecasts regarding the exploitation of natural resources seem to be more reliable than expected [78].

Due to the variability of human behavior, forecasting *individual* behavior will remain hard or impossible. However, this is anyway not a goal of the envisaged project. We are rather interested in exploring the possible macroscopic dynamics of techno-socio-economic systems, which results from the many non-linear interactions in them. Such macroscopic behavior still requires probabilistic approaches, but provides better perspectives for a scientific description, as discussed above.

It is very important to realize that despite the probabilistic behavior of a system that naturally limits its predictability, this has not prevented the development of useful models in other areas: Quantum systems, turbulent flows, and chaotically behaving systems are all characterized by limited predictability, but nevertheless they have been much better understood with mathematical and computational approaches. In fact, once the laws of quantum mechanics had been revealed through a difficult process requiring good intuition and a lot of experimental data, this created a major paradigm shift in science. Today, quantum theory has evolved into a most powerful and useful tool, that has led to numerous technical breakthroughs (laser, semiconductors, novel nanomaterials...) even though the very foundations and limits of the theory are still not fully understood.

6 Bringing quantitative and qualitative research together

Some of Juval Portugali's comments indicate scepticism regarding a narrow "positivist approach" *á la* "social physics" or "social engineering", which so far has not fulfilled the expectations in it, paving the way for "critical (social) theory". By pointing out that "science is a double edge sword", he is underlining the "dark side of technology", which has not only helped to solve problems, but also "reinforced and magnified" other problems. Hitherto 'unsolvable' social problems would be "rooted ... in the very socio-political structure of society" and the fact that "a lot of science ... were first designed for military purposes ... and only at a later stage were 'released' to be applied to civil purposes". Therefore, he concludes that "more/better knowledge is not a guarantee for a better society" and that complexity theories tell us that "pressing social issues will not be solved by the power of technology alone". Nevertheless, Juval Portugali also underlines that "Complexity theories of society evolved in the last two and a half decades ... [and] can ... be seen ... as the second attempt to develop a science of society – this time ... on the basis of two strong and interrelated foundations: the new theories of complexity and the progress made in information and communication technologies." They would "suggest new forms of human behavior, communication, governance and planning." In this connection, he points out that one should not underestimate "the important role of the qualitative ... the quantitative should go hand in hand with the qualitative."

We actually agree with all the above points and are fully aware of them, as we will elaborate in the following:

– References [15] and [16] discuss a number of different research traditions and, underlining their complementary value, even if the approaches and implications may sometimes be incompatible. These papers also discuss the potentials and limitations of a "social physics" approach. "Social engineering" is not proposed by us. We promote participatory decision-making and explicitly point out that the concept of "control" is not appropriate for social systems. The novel, complexity-inspired concept of guided self-organization appears to be better suited [79]. Nevertheless, there is no doubt that different societies have different social institutions, and that they promote different social outcomes. In fact, politicians and business people are changing institutional designs all the time. This is, for example, demonstrated by the development of the European Union or of financial markets. There is also a new systems debate that compares Western and Eastern societies in the light of the fast economic growth of the latter. If one considers the "very socio-political structure of society" as the root cause of apparently unsolvable social problems, as Juval Portugali does, it is only consequent to ask for systemic weaknesses and for alternatives. In fact, we consider this as part of the scientific challenge. Therefore, our research addresses public goods problems [80] as well as deficiencies of collective decision-making processes [81] and markets [39,82]. Based on complexity science, we have also discussed common fallacies behind some of today's attempts to govern social systems [79,82].
– The first Visioneer White Paper states that "many of the grand challenges mankind is facing in the 21st century are either of socio-economic nature or involve human factors in a substantial way... Many of these challenges cannot be solved by technology alone, but require us to understand the collective social dynamics as roots of these problems and key to their solution." In fact, problems such as wars and financial crises are recurrent phenomena and involve both, problems of individual and collective decision-making. Problems like these require clearly a non-equilibrium and complex systems perspective. While World War II can be analyzed from a variety of different viewpoints, it is likely that such events result from the buildup of stress in the system. For example, previous wars and a financial crisis have created conditions that allowed extremist positions to spread among the population, a problem that appears to be quite typical. Furthermore, while the recent revolutions in Tunesia and Egypt have apparently been triggered by high food prices, they would not have been possible without collective social behavior as it was facilitated by new ICT systems such as twitter and facebook.

- The concern that scientific and technological innovation may be used by the military before it becomes available for civil purposes is probably shared by many people. In fact, it stresses the need to perform a project like the envisaged one under public sponsorship and democratic control, before single countries or companies take over control. The public must know what can be done with today's and future technologies and data. Without such knowledge, politics will not be able to assess potential dangers and take decisions required to protect fundamental human rights like privacy, pluralism ("socio-diversity") and the freedom of decision-making.
- The "double edge" of science and innovation has been discussed in Ref. [83]. This work shows that, in order to avoid finite-time singularities due to an ever-accelerating innovation dynamics, one would have to avoid super-exponential growth processes by inhibitive, regulartory feedback processes. The first Visioneer White paper (and also the second one) make it quite clear that the unreflected and uncontrolled development of new ICT systems can have quite harmful side effects for society. This implies that innovation by itself is not necessarily a good thing, but it should be guided by the goal of increasing human well-being in a sustainable way. Therefore, we are strongly committed to paying particular attention to such issues (see Sec. 4.1).
- Regarding what can or cannot be scientifically achieved, one cannot argue from a historical perspective *á la* "attempts to describe social systems in a quantitative way have always failed in the past". Such projections from the past in the future do not prove anything. In fact, science has again and again managed to solve hundreds of years old mathematical, physical, medical, and technical problems, and the same actually applies to socio-economic systems (take the invention of social networking and eGovernance tools, or insurance, for example). In the social sciences, many promising research directions have not been systematically explored, yet. For example, there are very few applications of complexity and systems theory, or of evolutionary and ecological concepts to governance and economics so far. Finding new solutions requires to leave old paths and to think out of the box. For example, there are promising recent attempts to model social structure and dynamics mathematically as results of self-organization or spontaneous emergence, based on the non-linear interaction of heterogeneous individuals in space and time, considering social networks and fluctuations [61–63].

  The classical approach of working in disciplinary silos is obviously not appropriate to address systemic questions. One facet of this is that we need to combine quantitative and qualitative approaches, as demanded by Juval Portugali. However, while the qualitative tradition in the social sciences is strong and well established, the complementary quantitative, mathematical direction is just successfully emerging and needs particular support, at least for some time. There is no doubt that certain methods, which have been successfully applied in other sciences, have not been used, taken up or even noticed yet in the social sciences, as pointed out in the Visioneer White Papers. Getting access to data that are required to study the complexity of social interactions (such as MIT's social sensor projects [84]) or the development of agent-based computer models that allow us to understand longstanding puzzles in the social sciences are noteworthy progresses. Recently, scientists have also found new ways of measuring human well-being and societal progress, which are better than the gross national product. Overall, with geographic information systems (GIS) and other recent technologies, we are getting a much better picture of society. Projects such as George Clooney's "Preventive Crisis Diplomacy in the 21st Century" [85] or the Open Data initiatives in the UK and USA [86–88] express the hope that already observation itself could make a difference by reducing conflict and corruption and creating more fairness and justice in the world. Moreover, supporting a better awareness of the impacts of decisions that people take is one goal of the envisaged project. This will allow people to avoid mistakes and undesired side effects. It will also give victims of unfairness more power to fight for their rights and for compensation. Another project goal is to provide participatory platforms to facilitate a better social, economic and political participation.

- We have already made considerable effort to bring together researchers focusing on qualitative and quantitative methods. In fact, a long series of workshops has successfully built a number of bridges to overcome the gaps between previously disconnected research approaches. We are deeply convinced that scientists of different disciplines can profit and learn from each other through multi-disciplinary interactions. The envisaged project will foster further activities along these lines. The project believes that integrating ICT, Complexity Science and the Social Sciences will create synergy effects and a paradigm shift that facilitates a symbiotic co-evolution of ICT and society. Furthermore, we think that, besides providing critical, responsive reflection, the qualitative approach can make, also proactively, many substantial, constructive contributions in a number of fields, for example:
- *Qualitative reasoning* is the basis of all mathematical or computational modeling attempts. It is required to provide an intuition of the fundamental mechanisms underlying the techno-socio-economic-environmental phenomena under investigation. That is, all quantitative modeling requires good qualitative analysis to build on.
- Besides quantitative measurement, *technology impact assessment* clearly requires a qualitative reflection of the effects that engineered systems have on individuals and society. Rather than doing such an assessment when a new technology is already widespread, one should make attempts to assess potentials and dangers of new technologies already in their nascent state, as an integral part of the project. Particular attention will be paid to ethical issues.
- Through *Hilbert Workshops*, quantiatively and qualitatively oriented researchers will discuss together the state-of-the-art and identify crucial open problems and possible solution approaches. We believe that, in general, identifying relevant research questions is fundamental for the scientific success of science. In particular, such joint Think Tanks may help to understand the social mechanisms that drive the evolution and spreading of innovations, norms, technologies, products etc. and scientific challenges related to the questions how to manage complexity or to create systems which find a better balance between top-down and bottom-up processes, between centralized and decentral approaches, or between conflicting interests.
- Such Think Tanks may also come up with new ideas for *socio-inspired technologies* or the development of *techno-social systems*, which combine technology with social competence and human knowledge (such as Wikipedia, prediction markets, recommender systems, or the semantic web). The envisaged project will, for example, develop new *co-creation tools*. It will build virtual and real *Participatory Platforms* involving large numbers of people to envisage, populate and test possible futures [33]. In the very simplest case, this method could be applied to explore alternative designs of a city center, railway station, airport or shopping mall, but it could also be used to assess new market designs, decision rules, etc. In other words, humans will be able to try out alternative futures and choose more consciously between them. This is particularly important, as decision-makers in complex systems are often confronted with new, counter-intuitive and hardly imaginable situations. Another example of a novel techno-social system is the *"multi-national adapter"* or *"multi-cultural guide"* [89,90], which will help people with different values, preferences and backgrounds to make each other understandable. It could be imagined as a device that does not only translate in real-time one language into

another one, if activated, but can also make the individual reasoning and expectations better comprehensible to one another. In this way, it will be a great help for individuals to deal with people they would not understand today.
– The previously mentioned techno-social systems cannot be imagined without *qualitative contents*. Everything that is not based on abstracted social mechanisms, but on concrete opinions, their evolution, interaction, contents, meanings, interpretations, expectations, etc. require important contributions of the qualitative social sciences and humanities.

Given the large potential for collaborations between qualitatively and quantitatively oriented approaches in the above mentioned and further fields, it is time to overcome disciplinary boundaries [15]. They seem to make less and less sense.

7 Urgency of the envisaged project

The problems that humanity is currently facing are so serious and big that any reasonable effort must be made to overcome them. For example, in a letter of George Soros, dated March 17, 2010, eleven well-known economists and econophysicists concluded: "The financial crisis has not only created huge financial losses. It has damaged the economic system to an extent that several countries are at the verge of bankruptcy, and social systems have become dangerously vulnerable. The problems we have seen may just be the beginning of a larger crisis. The situation may totally get out of control, endangering social peace and cultural achievements."

It is only logical that Peter Allen concludes: "I would also stress the urgency of applying complexity science to human systems..." Similarly, Sorin Solomon states: "I am all for investing (even many billions) in finding the way out of the current troubles of humanity...". It is obvious that the social sciences need more funding in order to get into a position to catch up with the pace of newly emerging societal problems or even anticipate (some of) them. Joshua Epstein of John Hopkins University formulated the need to act even more clearly by saying: "The world is facing epochal changes and crises. Simulating the coupled techno-socio-economic-environmental dynamics on a planetary scale is therefore a project we can't afford *not* to do." It is our *responsibility* to explore what we can achieve with new with scientific and ICT breakthroughs that this opportunity offers us. Last but not least, as president of New York's prestigious Columbia University, Lee C. Bollinger stated [91]: "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."

It must be stressed that the public investments into the flagship programs would be cheap as compared to the cost of the financial crises (actually, less than 0.1% of the damage caused by it). They would also be much smaller than the investments made into other research fields. For example, the European Fusion Reactor ITER will require about 1.5 billion EUR per year over 10 years (about half of which is provided by the EU). NASA invested 18.7 billion dollars into space science in 2010 alone, and ESA's investments on the European side amounted to 3.75 billion EUR. The CERN required 1.1 billion CHF in 2010 (which is currently equivalent to approximately 0.9 billion EUR). Furthermore, the EU invested about 1.1 billion EUR into nanotechnology from 2007 to 2008. The US Human Genome Project, finally, was funded with approximately 0.9 billion dollar in 2003. Of course, the investments in all these cases extended over long time periods, typically over 10 years (or more).

There are also other reasons why public money needs to be invested into this project now: First, the global competition for the pole position in this area has already started. Second, it should be ensured that inventions along the vision of the proposed project will benefit humanity and not just a privileged minority. In principle, a project of the proposed scale could be performed by certain multi-national companies or the military of a country. However, a project that performs global-scale simulations of societies and economics may have potential impacts on the future of humanity. It should therefore be transparent and publicly supervised, and it needs to rest on a thorough ethical foundation to ensure that the balance in the world is not impaired. Consquently, one must make sure that a trusted public institution like the European Union will be first and set the standards.

Appendix

Short Summary of FuturICT

The ultimate goal of the FuturICT flagship project is to understand and manage complex, global, socially interactive systems, with a focus on sustainability and resilience. Revealing the hidden laws and processes underlying societies probably constitutes the most pressing scientific grand challenge of our century and is equally important for the development of novel robust, trustworthy and adaptive information and communication technologies (ICT), based on socially inspired paradigms.

We think that integrating ICT, Complexity Science and the Social Sciences will create a paradigm shift, facilitating a symbiotic co-evolution of ICT and society. Data from our complex globe-spanning ICT system will be leveraged to develop models of techno-socio-economic systems. In turn, insights from these models will inform the development of a new generation of socially adaptive, self-organized ICT systems.

FuturICT as a whole will act as a Knowledge Accelerator, turning massive data into knowledge and technological progress. In this way, FuturICT will create the scientific methods and ICT platforms needed to address planetary-scale challenges and opportunities in the 21st century. Specifically, FuturICT will build a sophisticated simulation, visualization and participation platform, called the Living Earth Platform. This platform will power Crisis Observatories, to detect and mitigate crises, and Participatory Platforms, to support the decision-making of policy-makers, business people and citizens, and to facilitate a better social, economic and political participation.

FuturICT will involve a range of social sciences from social psychology over sociology and political sciences up to economics, to mention just a few. The cognitive and behavioral sciences ranging from psychology up to behavioral economics and biology are obviously relevant for FuturICT. Furthermore, within the scope of this project, research activities will cover qualitative approaches and ethical issues as well.

FuturICT's Paradigm shifts in the area of information and communication technologies (ICT)

It must be underlined that the activities envisioned by FuturICT flagship will not be restricted to studying socio-economic challenges by using information and communication technologies (ICT) as a tool. The FuturICT vision will also have fundamental transformational effect on ICT and Computer Science. At the core of the proposed approach is a shift towards a wholistic, complexity science driven view of ICT as as a dynamic, globe spanning system, composed of billions of entities interacting over multiple spatial and temporal scales, interweaved with society in a multitude of ways across different functional and structural layers. Such a shift will lead to three core developments:

Social Awareness. As ICT technology will help build complex models and predictions related to global social phenomena and structures, the information produced by such models will become an integral part of the system. This will facilitate social awareness, which is a natural extension of the current paradigm of context awareness [92]. Thus, for example, we envisage the development of global ICT systems generating real-time representations of phenomena such as socio-demographic change, financial and economic instability, the emergence of conflict, mobility patterns, health trends, etc.

Social Adaptation. One of the most profound ICT developments in the recent years has been the transition from explicit to implicit, situation-driven interaction [93]. Thus, instead of waiting for detailed, explicit commands from the user, systems increasingly analyze the environment and autonomously take appropriate actions. Examples range from simple location-sensitive mobile applications to cars that can autonomously react to the situation on the road. Building on the concept of social awareness we foresee a transition from a single device reacting to its immediate environment to a dynamic, globe-spanning system reacting to complex social phenomena and collective behaviors on different temporal and spatial scales. Thus, the global ICT system shall be able to adapt to social needs, react to unforeseen events and prevent or mitigate systemic crises. The actions that the system will be able to take will range from reshuffling of resources (e.g information sources, bandwidth, distributed computing resources) to enable better monitoring and management of an emerging crisis or the mediation in and between communities. They will be directed by human-formulated goals and implemented by bottom up, self-organized processes leveraging the systems' social awareness and ability to model complex social phenomena.

Socially Inspired, Bottom Up Self-Organization. Developing future ICT systems within the above framework faces very similar challenges as organizing a well-functioning society, including issues like coordination, cooperation, adaptability, interaction, networking, group or community formation, collective (aggregate) behavior, exchange, integration, differentiation, conflict resolution, stability, resilience, trust, deviance (malicious behavior), (cyber)crime, (cyber)war, innovation, and culture. It is made even more complicated by the fact that the a socially aware and adaptive system can not be viewed as an isolated technical entity. Instead, one must consider the co-evolutionary dynamics of ICT and society at different scales and interaction levels. This leads to a new science of the co-evolution of society and ICT. The use of models and methods resulting from this science has the potential to enhance the flexibility, adaptiveness, reliability, and trustworthiness of complex ICT systems. It represents a novel, socially inspired approach to self-organization in computing.

Considering the fact that Facebook, which exploits the idea of social networking, is now one of the most valuable companies in the world (with an estimated value of 50 billion dollars), highlights the economic potential of socially inspired ICT in an impressive way. However, the much broader scientific vision outlined above requires one to gain a fundamental understanding of the way socially interactive systems work in a sustainable way, which is one of the major scientific puzzles of our times. As already stated by Norbert Wiener: "... Communication is the cement that makes organisations" and, thereby, is a basis of society. As a consequence, it will be necessary to develop a *"social information theory"*, as has been pointed out in the Visioneer White Papers.

Towards the above broad and fundamental paradigm shift, significant advances in a broad range of ICT areas will be stipulated. Classical optimization and control approaches must be replaced by approaches to manage complexity that respect the special character and requirements of techno-socio-economic systems. A new trusted

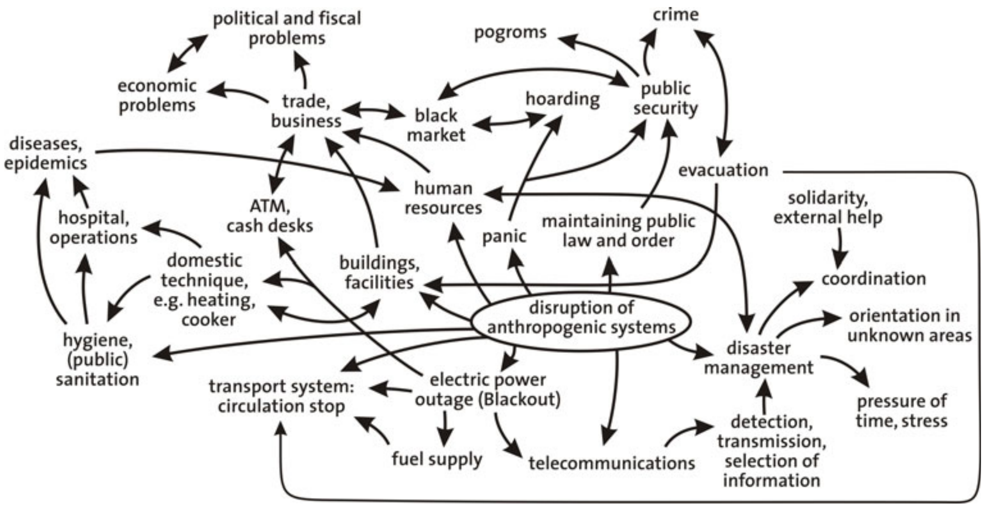

Fig. 1. Illustration of cascading effects in socio-economic systems, which may be triggered by the disruption (over-critical perturbation) of an anthropogenic system (after Ref. [34]). A more detailed picture can be given for specific disasters. Note that the largest financial damage of most disasters is caused by such cascading effects, i.e. the systemic impact of an over-critical perturbation.

web architecture and data management is needed, which give users back control over their data and protects privacy and intellectual property rights. ICT systems must also be designed in ways that maintain socio-diversity and avoid undesirable collective behaviors such as herding effects, which requires to re-think today's recommender systems and mass communication concepts. Machine Learning, Pattern Recognition and Data Mining will all be challenged to extract high-level information from the data present in the system, given the amount, diversity, and dynamic nature of the data sources, the need for distributed bottom-up processing and the extremely large semantic gap that needs to be bridged. There will be a need to develop data-foraging, establishing methods to fill gaps in data required for the models. Similarly, Semantic Technology and Artificial Intelligence in general will have to develop new methods to bridge the gap between high-level goals and corresponding low-level system requirements. High performance computing research will have to develop new types of systems going beyond the focus on linear-algebra-centric problems, moving towards interactive rather then batch supercomputing. At the interface of Agent Technology, Distributed Systems in general, Computer Networks, Control Theory and Complexity Theory, new control mechanisms and models driven by the bottom-up socially inspired paradigm will have to be found. Furthermore, writing applications for the new kind of ICT will require novel concepts in Software Engineering and Data Management, and Digital Libraries. To involve a large ICT community and get access to many interesting datasets, it will also be necessary to build an open modeling and data platform with the possibility to provide commercial incentives and participation. Finally, presenting the data and making the system transparent to the user will require major advances in Visualization Technology, Visual Analytics, and Human Computer Interaction.

In summary, a major ambition of projects like FuturICT is to trigger a scientific paradigm shift by bringing the currently fragmented fields of ICT, complexity science and the social sciences together in a research and development feedback cycle aimed at promoting the beneficial co-evolution of social and information systems (see Fig. 1). A new generation of cooperative, self-organized ICT systems will be developed, which in turn will facilitate a novel data-centered, but theoretically informed scientific approach to global techno-socio-economic systems and vice versa.

A further feedback loop must be created to establish an efficient research cycle involving empirical and experimental studies, data analyses, model building, computer simulations, knowledge extraction, visualization, and systems design. It is important to underline that our proposed project is not aiming at "blind" data mining without theoretical foundations or "naive" super-computing that is not theoretically rooted. Our proposed project is rather oriented at a combination of theoretical, data-oriented (also experimental) and computational research, as this is expected to be the most powerful research approach.

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