GLOBAL SYSTEMS SCIENCE ORIENTATION PAPER

BACKGROUND MATERIAL

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Executive summary:

Global Systems Science develops know-how about global systems. Examples include the internet and the worldwide system of cities.. Global systems combine algorithmic machines with concepts taken from game theory and a sensitivity to narratives. Global Systems Science aims at developing systems, theories, languages and tools for computer-aided policy making. Natural targets include problems with potential global implications relating to humanity's major current challenges. It also seeks to design open processes for data collection, dialogue and civic engagement so as to assist complex policymaking and to provide greater accountability. In this way Global Systems Science will contribute to enhanced social reflectivity and improved anticipatory capabilities. It will achieve this by supporting design and effective implementation of integrated systemic tools and measures able to represent reality better while coping with accelerated global change. 'Global' in this context means much more than just 'worldwide', as it refers also to a coherent transformative vision and a perspective which explicitly aims to address the complex nature and coordination of interconnected, multi-scalar, multi-domain, multi-objective interactions of 'systems of systems'. Global Systems Science research should be open-boundary; its goals cannot be fully anticipated at the present. Being at the moment a mostly goal-searching endeavour, rather than a goal performing one, the Global Systems Science approach requires a community which, while visionary, also shows a great capacity for flexibility, openness and independence.

1 Global Challenges, Global Webs, and ICT

1.1 Introduction

‘The ATM changed banking practice but did not change how people saw themselves as human beings. The computer is said to be radical because, through its instant worldwide communications, it is changing us from locally aware beings to globally aware beings’. This remark by Peter Denning – lead author of the seminal ACM report ‘Computing as a Discipline’ – captures the reason why the evolution of computing has reached a point where it calls for and enables a science of global systems.

While most things in life can be captured by a crisp definition only in very provisional ways (try ‘time’ or ‘headache’) a very provisional definition of global systems science (GSS) may be useful here:

> *Global Systems Science develops know-how about global systems like the internet, the worldwide system of cities and many more by combining algorithmic machines with concepts from game theory and a sensitivity to narratives.*

Clearly, some comments are in order. Why algorithmic machines? Because they have become key components of most global systems, and at the same time indispensable to perceive what goes on in those systems. Why game theory concepts? Because they can be used to build bridges between the world of computation and the world of joint – often conflictual – action by human beings. Why bother about narratives? Because they can help to keep in mind that computation is but one of many facets of the human condition (see www.terrybisson.com/page6/page6.html).

In his seminal paper ‘Algorithms, Games and the Internet’, Papadimitriou claims that ‘The Internet has arguably surpassed the von Neumann computer as the most complex computational artefact (if you can call it that) of our time’. It “is unique among all computer systems in that it is built, operated, and used by a multitude of diverse economic interests, in varying relationships of collaboration and competition with each other.’ And for sure this multitude of interests cuts across nations to span the whole globe. Indeed, the internet is a paradigmatic example of a global system.

Other examples are global financial markets, the worldwide fabric of agents trying to address climate change, the global city system, the worldwide energy industry, and many more. A fundamental problem arising in all these systems is how they can self-stabilize in the face of shocks despite distributed control. The problem does not arise simply because we have not yet established centralized control over global systems, but because distributed control is what makes global systems so effective – and actually human.

The first and still by far most influential answer to that problem has been Adam Smith’s idea of the invisible hand of the market as a device coordinating large numbers of similar agents. This idea has been greatly refined by mathematical economists, building massively on the ideas on game theory first developed by von Neumann. By now, the existence of basins of attraction for the world economy as well as for subsystems thereof (like the Eurozone) can be taken for granted. Unfortunately, we know very little about the selection between different possible basins and about the speed of convergence within them (and such knowledge is badly needed to address the present turmoil of the Eurozone).

A fresh start in thinking about self-stabilisation of systems with distributed control was made by Dutch computer scientist Edsger Dijkstra. Back in 1974 he showed that in a broad class of computer networks the problem could be solved if and only if the agents were not all alike. What is more, his approach opened the door to the computational study of speed of convergence, second best solutions and much more in computer networks, including the global system known as the internet.

Meanwhile, the “fusion of algorithmic ideas with concepts and techniques from Mathematical Economics and Game Theory” advocated by Papadimitriou has turned out to be fruitful both for the study of the internet and of the world economy. Recent advances in high performance computing and big data promise many more insights. But this requires a sustained effort by a vibrant research community studying a variety of global systems in the decades to come. That is the purpose of global systems science.

1.2 Rationale

Policy-makers and society often call for evidence-based policies. But what do we exactly mean by evidence-based policy, in particular in global contexts? What type of evidence are we looking for and how can we gather it? To base policies on evidence is both urgent and a long-standing problem in policy making. The urgency has been highlighted by the financial crisis; interdependencies involving financial markets have led to contagious chain reactions to all sectors of the economy and from there to society at large, and these processes were not anticipated by policy-makers or by the simulation models their staff works with; so the question arises: can we do better, and if so, how?

Current societal challenges of climate change, food security, energy provision are all highly interconnected, and at a global scale. The number of challenges our societies have to address is often overwhelming. However, we have one thing clear: most of these global challenges have to do with science and are highly interconnected. There are cross-cutting issues across different policy sectors, and these are no longer contained within national borders. They cannot be handled by any single country or any precise policy. Consequently the nature of policy itself is actually changing. Policies are increasingly cross-cutting and cover different actors and sectors which operate at different levels, local, global, connected through a variety of social-economic networks. Therefore, evidence in this complex interconnected context is hard to obtain and hard to analyse.

One of the challenges that we face both within science and in the communication of science and getting people to participate, is that we know relatively little about the effects of any kind of innovation and of the functionality of existing institutions to deal with those innovations. These *interactions* between innovation and functionalities have been underplayed by many engineering approaches. As we produce such innovations, all functionalities in societal change, and this task is also should set out to understand.

In order to support robust decision-making and take the actions necessary in the face of global challenges, research in GSS requires advances along two dimensions: 1. To develop scientific understanding of systems based on empirical data on highly interlinked policy issues, and 2. Develop tools capable to ensure trust and dialogue between stakeholders and scientific modellers. This research will have to be complemented by a vision on how to best coordinate policies and scientific input in specific sectors to better understand the systemic effects that often lead to adverse effects on many of our policies. And we need to look for opportunities and possible solutions for society and science so as to get the GSS vision straight. In particular, the following questions are of special interest for GSS:

- What can GSS bring to understand and deal with global sustainability challenges? How can GSS identify various transition paths towards a more sustainable world society?
- When one looks at the global level one needs to couple different types of levels and systems, both temporally and spatially, all with different speed dynamics. However, we do not really know how to couple all that, but we need to think what particular tools could address these complex questions.
- What is the role of ICT in this endeavour? From the management of extreme events, there are already many ICT tools which can be used to support prevention, recovery and so on, but in GSS the challenge goes beyond this. We need to ask: How ITC can help us to know where we want to go as a society?

One of the most complex global systems is the internet in itself, and this is a global system that can help to understand other global systems. ITC has a radical impact on how society organises itself, and in particular with regard to issues of trust in models and participation of citizens. ICT connects, in an infinite variety of ways, people, knowledge, devises, business and organisations across the globe. Thereby, on the one side, ICT addresses the complexity problem, but on the other hand it also creates new complexity problems.

Thus, the ambition GSS would not possible without the ITC tools. In the use of data in global problems in our highly connected network society, while it makes it very difficult to anticipate systems-wide consequences of political decisions, policy makers still need of new cognitive tools to cope with unanticipated consequences of their own actions. Such new cognitive tools will be rooted in systems' modelling, data, and highly connected systems. Data can change mindsets. ICT is already providing us with an unprecedented amount of data on all aspects society activities and natural and technology consistencies. Can we profit from this abundance of data to get our actions and decisions in policy and society? Can we use these data and models to guide us in this maize of interconnected policy challenges?

In this situation, some preliminary questions specifically regarding ICT in the context of GSS are the following:

- What are the new capabilities relevant for GSS that ICT have enabled over the last two decades? How does it influence the ways in which science and society can tackle global challenges in novel ways?

- How can the present state of the global ICT system evolve into a situation where global players learn to act in a cooperative mode?
- How can the global ICT system become a medium of active global awareness rather than just machinery produced by a restricted elite and fostering atrophy of civic skills?
- How ITC can support social experiments, e.g. through online communities?
- How can we embed the ICT in the development of GSS?
- How much can we 'pull out' ICT from GSS when ICT is already an integral part of GSS?

1.3 A process-based document

The present report contains insights and written contributions collected as a result of a series of events that started at the First Global Systems Science Conference held in Brussels in November 2012. The overall goal of this exercise has been produce in an open plural way the first background material for an **Orientation Paper on Global Systems Science (GSS)** which can be used to support strategic science policies and capacity building in this domain. In particular, the present version contains expressed views and written contributions provided by members of the emerging international GSS community during the following conferences and events:

- First Open Global Systems Science Conference (Brussels, November 8-10, 2012)
- Towards a Sustainable Global Financial System (Potsdam, December 8-9, 2012)
- Dealing with the CO2 emergency (Phoenix, AZ, February 1-2, 2013)
- GSS workshop on Models and Data (Brussels, February 7-8, 2013)
- Urban development and GSS (Brussels, February 13-14, 2013)
- GSS – Territorial versus functional Patterns (ASU, Arizona, February 25-26, 2013)
- Narratives as Communication (Brussels 13-14, March 2013).
- Visions of GSS: Energy Futures (Brussels, 18-19 March, 2013)
- Urbanization, Resilience and Prosperity (Phoenix, AZ, April 15–19, 2013)

In addition, it includes a total of 159 contributions produced as a result of the EU – FET consultation process, 4 workshop reports on GSS carried out during 2013 and 10 additional selected posts taken from the GSS discussion blog www.global-systems-science.eu. It also builds on the work and networking activities carried out during the three-year EU project Global Systems Dynamics and Policy (www.gsdp.eu) which also run

We hope that all these effort have allowed us to identify the first range of issues that may eventually constitute a potential 'GSS ecology of questions'. Flourishing Global System Science will happen as a tension between big questions and small questions. We need a set of researchable small questions of which we can work, e.g. on the role of particular ICT on city system or medical systems, etc, and link them to a set of four or five big questions in order to get robust and valid insights on how global systems operate. All this will take time: the problems we face cannot be resolved in the short term. Openness and active collaboration between all of us here is a precondition for this to happen.

2 Policy Challenges Driving GSS: Case Studies

J. Doyne Farmer

Possible Definition of Global Systems Science: Global systems science studies the possible structural, physical and cultural transformations of the earth, environment and society. It seeks to generate, understand and study scenarios under which such transformations might occur in both qualitative and quantitative terms, with a focus on interactions, systemic effects and emergent phenomena. The methods used are interdisciplinary, including the physical, natural, social and computational sciences.

Global Challenges

The recent financial crisis has reminded us that achieving sustainable and equitable growth depends on many interdependent factors that are nonetheless strongly coupled together. A housing bubble spilled over into the banking system and triggered a global liquidity freeze, which slowed the real economy, causing unemployment, increased inequality and social unrest. This temporarily slowed growth in carbon emissions, but over the long run has probably had substantial and largely negative impacts on R&D budgets for green energy, thus slowing our needed transition to a low-carbon society. With humanity consuming estimated to consume 40% of the energy fixed by photosynthesis, the economy and the natural world have become strongly coupled and can no longer be considered separately. To fully understand almost any of the problems we face, we are automatically forced to consider all the other problems that it interacts with. For this we need global systems science.

Global systems science addresses a daunting set of problems requiring new and innovative approaches. Global systems are made up of a large number of interacting individual elements, challenging conventional thinking. They are dynamic rather than static, and probabilistic rather than deterministic. They are very difficult to predict and control, and are permeated by non-linear and network interactions amongst the component agents. The individual elements of a system are influenced directly by the behaviorof the system as a whole, and at the same time their interactions lead to the emergent behaviorat the aggregate level of the system. The 'common sense' connection between the size of an event and its consequences no longer holds. Small changes have the capacity to trigger large scale events. Such problems require the development of new methods.

Citizen science, ITC and sustainability

Vitorio Loreto

The issue of sustainability is now on top of the political and societal agenda and is considered to be of extreme importance and urgency. There is overwhelming evidence that the current organisation of our economies and societies is seriously damaging biological ecosystems and human living conditions in the very short term, with potentially catastrophic effects in the long term. People's individual actions have impacts both on the local environment (e.g. local air or water quality, noise disturbance, local biodiversity, ...) and at the global level (e.g. climate change and use of resources). Urban environments represent a crucial example. It is now estimated that over 50% of world population is living in urban areas, with a yearly growth rate of about 2%.

The need for a reorganisation of our most impacting daily activities - energy consumption, transport, housing - towards a more efficient and sustainable development model has been recently raised by the public debate on several global environmental issues. Unfortunately, the achievement of such a goal has been undermined by the difficulty of matching global/societal needs and individual needs. A lot can and must be done from the technological and policy-making perspective, for example to build passive houses, develop renewable energy, promote alternative transport modes, and so on, but it is only when people become fully aware of their actual environmental conditions and their future consequences that the much needed change of behaviorwill truly happen. In a recent statement from the head of the European Environment Agency, J. McGlade, there is a realisation that only through bottom-up actions we can deal with today's challenges: “The key to protecting and enhancing our environment is in the hands of the many, not the few... That means empowering citizens to engage actively in improving their own environment, using new observation techniques...”.

Recent progress in Information and Communication Technologies (ICT) can trigger important transitions at the individual and collective level. They imagine a scenario in which active citizens can help gathering sensible data through participatory sensing and social computation activities. The outcome of this data gathering has a twofold purpose: (i) stimulate individual and collective awareness and learning and (ii) provide relevant inputs for data analysis, modelling and decision making.

2.1 Urban Systems

For an extensive treatment of Urban Systems see also the reports from the EUNOIA meeting and of the ‘Urbanisation, Sustainability and Prosperity’ workshop (sections 7.3 and 7.4).

2.1.1. Introduction

World society is rapidly becoming an urban society, with city systems coalescing into a global urban system. The global ICT system is closely interacting with this dynamics, leading to new degrees of freedom and new challenges. Traditional centre-periphery structures are displaced by more complex patterns, the received distinction of nature and culture is put in question, and urban lifestyles are blended with the global awareness fostered by ICT.

Worldwide urbanisation is welcome for several reasons:

- since their origins, cities have been powerhouses of innovation, and innovation is badly needed to address the global challenges of our time,
- along with basic education and increasing welfare, urbanization is a key factor to achieve the necessary end of global population growth,
- cities are hotbeds of pluralism, potentially enriching the life of their inhabitants and leading to institutions shaped by empowered citizens.

Worldwide urbanization raises major challenges, however:

- innovations may well go in directions that worsen already worrying trends,
- urbanization can undermine human communities so as to lead to new forms of violence and anomie,
- health problems from circulatory diseases to cancer can be exacerbated while problems like obesity and new strands of micro-organisms reach epidemic proportions.

GSS will explore how the interaction between the global urban system and the global ICT system are changing settlement structures and lifestyles, and how policy-makers can influence their future dynamics. It will do so by relying on case studies, crowd-sourced data, simulation models, and action research.

Hence the following research questions are relevant with regard to the urbanisation and globalisation: What is the global system of cities? How is the multi-net in which different kinds of cities are linked with each other and in different ways? How different ways of structuring networks can be conceived (e.g. in a more sustainable way), for instance, by a transport systems focused and structured on demand rather than on supply – with an intensive use of ICT (e.g., Smart Cities). 3. What are the wider implications of the Information Revolution in these contexts?

Urban systems are one of the major fields of application of global systems science, for which a global perspective is necessary to be able to describe the fundamental problems and identify the different systems and subsystems involved in their resolution. Indeed, almost all problems arising to decision makers in a city or in a city network share the following characteristics:

1. They involve many different heterogeneous systems, like for example the transportation systems, the behaviorof citizens, themselves influenced by their social networks, or the energy system – those of course depending on the problem addressed.
2. These systems evolve at different time and space scale.
3. They are coupled (the dynamics of transportation systems is impacted and impacts the social behaviorof individuals) or belong to hierarchies (one system being a subsystem of another one) among which administrative (possibly overlapping) hierarchies.

These characteristics have the consequence that a “silo-like” approach, focused on one subsystem or one time/space scale cannot catch the targeted behaviorand the emergent phenomena.

2.1.2. Towards a GSS theory of urbanisation.

Sander van der Leeuw

Introduction

This white paper is a first attempt to design a research program that conceives urban dynamics and urbanization as part of the changing global system. It is based on the first two of a series of workshops held by the GSDP program in collaboration with Arizona State University. The first of these workshops was held in Tempe on November 1 and 2, 2012 under the title "Urban Networks, Sustainability, and Resilience", and brought together participants from ASU, the Santa Fe Institute, Yale University, University College London, the MIT Media and Senseable City Labs, Michigan State University, UNC-Charlotte and others. The second workshop consisted of three sessions on urban dynamics at the GSDP second annual Open Science of Global Systems meeting, in Brussels on November 8-10, 2012. It brought together scientists and practitioners from UC London (CASA), Veolia Environnement, the University of Paris I, the Santa Fe Institute, CSIC (Spain), Virginia Tech University, the Global Climate Forum, La Sapienza University, and others.

This white paper is based on the discussions held at these two workshops, but does not pretend to be a report on them. Instead, it is an attempt to set a first step towards a GSS research program on cities and urbanization. It will be refined as a result of other workshops still to be held in Brussels (by EUNOIA, February 13-14 2013) and Phoenix (by ASU, February 24-28, 2013 on Global Systems Science, and April 15-19 on 'Innovation and Urban Sustainability').

Context

Of the roughly 7 billion people on Earth, 3,5 billion (50%) live in cities, and within the current century, this is expected to rise to 80% (some 6,5 billion of the 8-9 billion people expected). The development and growth of urban systems is the most constant dynamic in human societies since about 6000 years ago, and in recent years individual cities have reached proportions that were not imaginable even fifty years ago. In effect, since the earliest towns emerged, urban systems have multiplied and grown thousandfold. Recent research attributes this to the fact that most innovations emerge in cities, so that they act as drivers for the surrounding rural society. Yet individual cities are the least sustainable and most vulnerable institutions in our societies. They are centers of wealth disparity and social insecurity, loci for sanitation and waste problems, sensitive to epidemics and other health issues; they are energy-intensive and high infrastructure maintenance, they are often noisy and polluted, etc. Cities innovate and change rapidly, but the trajectories they take are difficult to predict or to impact. They consist of many tightly entangled interactive networks of cables and tubes, streets and avenues, businesses and social groups. The huge investments in their creation and maintenance, as well as their tight integration make them high-risk systems, prone to external and internal perturbations. They are highly multi-scalar in space and time; the interaction between 'bottom up' and 'top down' is nowhere as pregnant as in cities. Hence, in recent years, urban systems have become a major topic of interest to scientists and to politicians, decision-makers of all kinds, and the general public. Though the research is done in trans–disciplinary teams, it remains essentially sectorial (focusing on water, energy, pollution, metabolism, etc.). We must change this by making an encompassing investment in Complex (Adaptive) Systems modeling of urban dynamics, aiming to deliver a coherent set of portable models of urban dynamics. To understand urban dynamics, and to effectively make decisions about cities and urban systems, such a complex systems approach is essential. But we must do more; we must view the dynamics of urban systems as part of the wider dynamics of the Earth as a complex system (hence the inclusion of this theme in a research agenda on Global Systems Science, see Dum 2012). Doing that will transform our understanding of urbanization in many different ways, among which the following are important:

1. Focus on urban systems instead of individual cities (cf. Pumain 1992). Work in Europe on Europe, the US, India and S. Africa shows that one gets a much better perspective on the long-term urban dynamics when one does not look at individual cities, but at the systems of cities (from large to small) that interact in urban systems. At the top level, the world urban system, in which Singapore, Hong Kong and other major trading cities (Shanghai, New York, London, etc.) are linked seems to be the appropriate level of urban analysis to determine the sustainability and resilience of these cities. At a level below, essentially that of continents, the same can be said for places like Paris, Berlin etc. in Europe, Philadelphia, Boston, L.A., but also Phoenix. The research shows that the resilience or sustainability of cities is to an important extent determined by competition between them at such levels, and that spatial, legal, demographic, resource and innovation differences play an important role.

2. Apply complex systems concepts and approaches. Recent research (e.g. Bettencourt & West 2010) has shown the power of conceiving urban systems as complex systems, in which dynamics among actors at many different levels interact to create the patterns observed. Most of the dynamics are driven bottom-up, and can be modeled in multi-level models that use agent-based modeling, network analysis and other complex adaptive systems techniques. At issue here is that urban systems combine hierarchical and market dynamics, and that the analysis therefore needs to be able to combine both. One possible approach is to decompose the urban dynamics into intersecting subsets based on the temporal dimension of their dynamics, such as has been proposed by Allen (Allen & Hoekstra 1993) and by Gunderson & Holling (2002).

3. Combining different modeling techniques. The complexity of urban dynamics makes it essential to model these to improve understanding. Many different modeling techniques are available. In creating a CAS perspective on the dynamics of the whole as well as the individual parts, we could for example combine various Agent Based Models (reflecting the 'bottom-up' component of behavior(individuals, families, companies, etc.) with Network Models reflecting the various urban infra-structure networks and the social networks processing information in the city. Differential-equation models could reflect the 'top-down' component of behavior(rules, institutions, external conditions), etc. The (multi-scale) spatial structure could be included as a set of GIS layers with transition matrices that set the conditions for changes in spatial structure.

Studies of the current sustainability predicament indicate that recent and future developments in information technology will (have to) play an essential (and growing) role in extricating our societies from that predicament. As this research agenda is to be part of the EU's Information and Communication Technology Directorate, we have paid particular attention to the future role of information technology in both the research on urban dynamics and in developing tools that will enable us to implement the results of that research in both policy-making and day-to-day adaptive management of cities. In the following pages, we have therefore divided the issues into three categories:

1. Questions to which an answer is necessary to understand fundamental urban dynamics and therefore to impact on such dynamics in the future
2. Questions relating to the potential impacts of ICT on the global urban system
3. Questions regarding ways to improve the sustainable management of the global urban system through enhanced use of ICT

1. Questions to be answered to understand fundamental urban dynamics and to im-pact on such dynamics in the future Cities are doing well – or are they?

Superficially speaking, cities seem to be doing extremely well. They constitute the most persistent characteristic of societies since about 6000 years ago. In the last few centuries they have grown to encompass an increasing proportion of the world population; all over the world rural populations have for centuries flocked to cities in an attempt to improve their material conditions, and in some parts of the world (e.g. China) government views them as a solution to many challenges and goes out of its way to build them. Recently, urban life has become the dominant mode of life worldwide, and in many countries. It sometimes seems as if urbanization cannot be stopped.

On the other hand, cities are a major source of challenges in many domains. They require major in-vestments in infrastructure that all but the wealthiest of nations cannot afford. They promote social inequality, economic misery and illnesses of various kinds. Though they may add to overall productivity, that has a high social cost. Although taken singly they may in some cases appear to be energy-efficient in the sense that living in dense cities requires less energy (mainly for transportation) than living in the countryside, we should not forget that our urban society uses about 100 times as much energy as is needed to maintain each individual alive. Altogether, cities are in effect a highly vulner-able part of our global system.

Drivers of urban dynamics.

The apparent contradiction between the ubiquity of urban life and the challenges that it poses leads us to formulate a first research question: “What is (are) the driver(s) that continue(s) to push for aggregation in cities notwithstanding these challenges?” Although at a proximate level there are of course many of these, and different ones in different situation, at a more general level there appear to be only two candidates: accumulation of energy and matter or accumulation of knowledge and information. For a long time the energy perspective dominated, and in certain sense it still does when we cite future shortages of energy as the major reason why our society might disintegrate (e.g. Patzek & Tainter, 2011). Recent work, some of it initiated as part of the ICT directorate’s IS-COM research project, seems however to indicate that the accumulation of knowledge is the ultimate driver of urbanization (Bettencourt et al. 2007; Florida 2005). This, then, raises the next major research questions: “Will a (potential) lack of energy spell the end of urbanization (and thus our cur-rent way of life) as we know it?” and “If that is not the case, what will (need to) change in the structure of our civilization to maintain its continuity, yet deal with a substantive reduction in available energy?" Of course energy is but one of the resources upon which our current mode of life depends, although it is the one that is currently most discussed. Water and food are two other ones that spring to mind. One must therefore also ask the above two questions for resources such as these (and others).

Approaching the challenge from the other side, looking at the current mode of information gathering and processing, its consequences for our current mode of life, and how the future of ICT might affect urbanization (if society does not collapse due to lack of energy), we come up with different, but related, questions. First of all "Is there a relationship between the accumulation of knowledge in urban centers and the increasing disparities in wealth, knowledge, culture and material circumstances that one observes in cities?" Then: "If that is the case, will urban growth ultimately lead to such important disequilibria (and potentially ruptures) in the coherence of our societies that this might result in chaos?" and its corollary: "What would need to change in the way we currently process information to ensure that that does not happen?"

Inside the Global Urban System.

Although we have written the last paragraphs with a clear focus on the urban part of our current global system, their significance went beyond the urban system itself, and included the whole of all of our current societies. In this section, we want to move a level down, and ask questions pertaining to the urban systems themselves. Here, again, there is currently no overarching perspective that is widely accepted as being able to explain and predict a wide range of aspects of urban dynamics and phenomena. Indeed, there seem to be two dominant approaches that complement each other – the metabolism approach and the network approach. The former looks at the material and energetic in- and outputs of cities, while the latter pays attention to the various kinds of relationships that 'weave the city together' – and is thus more involved with the structure of urban relations. For the moment, neither has made much headway in asking the fundamental question: "What constitutes a sustainable city or system of cities?" But maybe a combination of the two approaches might help us here, prompting us to ask: "What is the structure of the various networks that constitute the urban framework, and what kinds of flows are transmitted through them?" and the subsidiary questions: "How do the dynamics of the various networks impact on each other?" and "How do the network dynamics impact on and are impacted by, the urban metabolism?" The flows in question concern all resources – energy, water, food, materials, but also ideas and people – and all sources (the whole of the world trade network). Urban network science is in its early stages, and there is a lot to be done in this domain. It will be important to deal with all the various aspect of these flows, such as their nature, volume, value, frequency, local importance and effects, etc.

And in particular, it will be important to get a good sense of the structure of the networks. For the resource networks, one expects a dendritic structure (assembling resources from many places and distributing them to many other ones), whereas information networks combine elements of both hierarchical and market (distributed or heterarchical) organization in different ways that affect the resilience, and thus the sustainability, of the system. For example, Huberman & Hogg (1988) have shown that with time, the complexity of hierarchical self-organizing systems is reduced, as are their rate of evolution and their adaptability. On the other hand, it seems that very large distributed systems also have difficulty adapting due to the persistence of non-optimal strategies (Ceccato & Huberman 1988). However, the introduction of globally controlled (hierarchical) communications in market systems causes them to lose their penchant for retaining non-optimal strategies, whereas the existence of untied (heterarchical) connections in a hierarchical system increases its adaptability. Inevitably, a hybrid structure will develop which is a 'best fit' in the particular context involved.

The crucial questions here refer to the balance between these two aspects: "What determines the balance between the hierarchical and the heterarchical characteristics of an urban system's organization?" and "How does this balance impact on the urban system's adaptability, resilience and sustainability?"

Macro-regional urban dynamics. At this level, we must consider some of the differences between the very large regions that make up the current socioeconomic world, such as North America, Europe, Australia, China, India, South America, Africa, and the ways in which these differences impact the global urban system. But it should be noted that some of these regions are made up of smaller units that are only recently growing together, intensifying their interactions and their symbiosis. This is easiest seen in Europe, where over the last sixty years the various national urban systems have begun to meld into one overarching European urban system. The very concept of 'region' is thus subject to change in scale, and the urban dynamics are evolving as part of that process. That poses the questions: "How are the national urban systems, which were for a long time being kept apart by borders, being integrated into the supra-national system?", "What drives that process, and what are the variables that affect it, and are affected by it?"

The dynamics at this level are the result of the articulation between the urban system dynamics and overall trends in each area such as their demography, the nature of their economy, wealth disparities, resource availability, climate and so forth, as well as the dynamics of (political, social and cultural) institutions, etc. It is fundamental to our understanding of the current and future trajectories of these macro-regional systems that we understand the interaction between this complex set of regional trends and the urban dynamics in the area.

To an important extent, relative differences between these trends in different places are affecting the trajectory of the urban systems at the macro-regional scale. One would therefore need to ask: "How do these relative differences actually affect, and are affected by, the urban dynamics in these areas?" For example: "With population growth in China exceeding that in the US, and even more that in Europe: how do demographic differences affect the urban systems of these three macro-regions, and the interactions between them?" "How do differences in climate, landscape, spatial and economic structure, productivity, wealth level, resource availability, etc. affect the dynamics of the region's urban systems compared to other such systems?" It is essential that in these comparisons the evolutionary state of the systems is taken into account, but equally that such comparisons not be limited to economics in the traditional, macroeconomic sense, but also include a wide range of other parameters (such as, for example, energy efficiency, innovativeness, productivity, income differentials, etc.). Once a relatively detailed picture of such macro-regional differences and dynamics has been gained, one can then move onto the next lowest level, that of the local urban dynamics.

In particular, at this level, we will therefore make an effort to better understand the relationship between territorial and functional patterns as a key problem for the emerging science of global systems along the following lines:

- Territorial patterns: centre-periphery structures, energy and information gradients in nation states and empires
- Functional patterns: division of labor, industries and producer markets, system of professions, social and professional networks
- Renewables and global energy/matter flows: geopolitics and regional innovation in the global economy, the role of trade, policy and finance
- Computing and global information flows: the interactive nature of computing, hierarchical and non-hierarchical networks, money flows as information flows Local urban dynamics.

At the level of local urban dynamics, there is an immense literature that deals with virtually every aspect of urban organization, function and evolution from any imaginable perspective. It is at this level, therefore, that the articulation between the Global Systems Science perspective and extant work is at once the most poignant and interesting, and the most difficult and necessary. It is where the rubber hits the road. "Can a Global Systems Science perspective improve our understanding of what happens in individual cities?"

We think that it can. What happens at this level is the articulation between the global urban system's dynamics in its macro-regional form and the local circumstances (spatial organization, re-sources, past history) of the particular city that one is studying, and this articulation is determinant for the success and sustainability of that city. Hence, in our opinion, articulating between a coherent approach to the global urban system and the regional and local circumstances is the only way to arrive at explanations of what happens in individual cities that allows comparisons between the latter. This requires assembling a coherent model of urban dynamics. Lack of a coherent and widely accepted theory of urban dynamics has thus far hampered any efforts to create such a model. We would argue that such a model should bring together the network and the metabolism approach. Bettencourt (in press) has argued cogently that the state, structure and extent of the transport network determines many aspects of the city's dynamic. If one were to extend that approach to the communication and energy/matter flow networks, including such domains as distribution etc., as well as the social networks in the city, one would in effect be able to model the very 'urbanness' of cities – that which accounts for the close spatial proximity and entwined nature of many societal functions. Comparing urban dynamics between different cities in this light would thus have major advantages over current approaches, as it would allow us to assess the role of different forms of 'urbanness' in structuring local societies and in shaping the recurrent 'hairy' problems that occur in all cities.

2. Questions relating to the potential impacts of ICT on the global urban system.

By removing the material basis of information transmission, the ICT revolution will potentially also fundamentally change the actual urban dynamics at all levels from the global to the local. As out-lined earlier, urbanization requires both increasing information-processing capacity so as to maintain a high level of invention and innovation and a sufficient matter and energy flow to meet the needs of the individuals and the infrastructure in the city. In the pattern of urbanization that emerged over time, hub-and-spoke systems of larger and smaller cities connected by roads and transport networks between them channelled all three flows – matter, energy and information – and urban growth patterns as well as the geography of urbanism were thus determined by these flows. In the last thirty years, ICT has fundamentally changed this. Information flows are now no longer constrained by transport networks, and therefore do no longer follow the hub-and-spoke pattern that generated the urban landscape. As this process advances (it is currently only at the beginning), we might therefore see a very different urban geography. The differences will in part be determined by the geography of energy, and therefore the future of energy.

If we assume that for the next couple of hundred years our societies remain dependent on fossil fuel, this will on the one hand maintain the current spatial configuration in the western countries, which is determined by current pipelines, grids and road transportation networks for solid and liquid fossil fuel. But on the other hand, global warming will lead to important rises in sea level, and thus the disappearance of many coastal cities, requiring us to deal with the migration patterns that are inherent in that change, as well as the changes in trade patterns.

If, on the other hand, we assume that alternative fuels will indeed become a more important source of energy, this may change the urban geography because it would enable many cities to become in-dependent of the existing energy networks, generating enough solar and wind energy locally to avoid the major investments needed in the creation and upkeep of those networks. We have seen a similar change in telecommunication networks, where radio, television, web and cellphone are taking over from landline-based communication. In such continents as Africa, this is increasingly enabling changes in other domains, such as removing the need for branch offices of many companies, which thus far constituted an important component of cities. Were we to invent means to transmit energy via electromagnetic waves rather than cables, a similar change is conceivable in energy-related domains. Matter transport is less far advanced, but we are beginning to see signs of delocalisation there, too. Amazon and eBay are early examples of this, as they reduce the need of the customer to go any particular place to acquire the goods that facilitate daily life. Web ordering of household goods contributes to this as well. If one were to develop a material culture that is adapted to the increased use of 3-D printing, this development could become more and more important – even though the distribution of basic raw materials will remain dependent on the transport network.

We conclude from these examples that a number of the constraints that have led to the concentration of population in cities are likely to be relaxed in the coming century, which might in theory en-able the re-dispersal of people in the countryside. This is where other environmental factors come into play. The increasing stress on those surfaces that serve currently to provide food is likely to lead to important increases in the relative price of meat and fish (which require inordinately more energy to produce), thus pushing our food systems to become more and more geared towards vegetarian diets. That in turn could easily enable an increased use of local production in many parts of the world, further reducing the need for bulk transport (of foodstuffs).

It will be the task of Global Systems Science to begin to posit and answer the many questions that trends like those outlined will generate. From among those, we only mention a handful:

• These developments seem to indicate a shift to a more heterarchical social system, in which it is more difficult to control information flows. Such control is essential in order to maintain the coherence of societies, which is based on the alignedness of individuals around concepts, ideas and culture. This alignedness has thousands of years partially been assured by geographic constraints, but these constraints are weakening. How can ICT help us to find an alternative balance between individual diversity and societal coherence?

• Will there be other constraints that come instead of those that are weakening? No doubt. As I have argued elsewhere (van der Leeuw 2012), solutions lead to challenges, lead to solutions, lead to challenges, and so forth. Part of the task of Global Systems Science will be to look at those challenges and devise perspectives that enable us to anticipate them. One important ex-ample is the future distribution of employment. Much urban immigration is driven by the expectation of urban employment, and the above trends seem to point to delocalization of such employment. How will these two trends articulate?

• How will these trends affect the pattern and speed of innovation that is necessary to maintain people interested in our societies? Recent research closely relates innovative capacity to spatial proximity of large numbers of the 'creative class' working in institutions such as businesses that are co-located in cities. One may distinguish cities in which truly original innovation emerge from cities that specialize in recombination of existing technologies, and from cities that focus on elaboration of technologies. The spatial relationship between these cities is co-determined by the role each plays in the fabric of society. How might that change in a distributed world?

3. Questions regarding ways to improve the sustainable management of the global urban system through enhanced use of ICT

To pose the third set of questions, it is important to point to another, very different, trend: the use of Big Data to enable much closer fine-tuning of the management and organization of our current social systems and institutions, including the health and behaviorof individuals. Here we will be moving from what I'd call a 'statistical approach' to a 'personalized approach'. Currently, management of societal processes essentially depends on a statistical approach to understanding and man-aging them, in which common denominators are identified in perception, behaviorand interaction, and these lead to the creation of adaptive institutions that channel them. The precision of this approach, and hence its effectiveness, was limited by the information available, based on censuses, opinion polls and other social science tools. In the medical field information acquisition was achieved (and limited) by other tools, but the effect was the same: treatments and drugs developed to have a statistical success rate, rather than an assured individual one.

Big Data offers the possibility to acquire such data in incredible detail and in real time. Currently, certain companies in the US have data about each household according to more than 500 criteria, Sophisticated analytical methods allow pollsters to address each family with a detailed copy of their 'mental map' in mind. This capacity was one of the factors that played out in the last presidential elections in the country. Tools currently being developed that are able to simultaneously identify very large numbers of health risk factors very early will no doubt help reduce health costs in the future and may also lengthen life expectancy. These are but two examples of this general trend. Although this is only the beginning of this trend, the volume “The Human Face of Big Data” (Smolan & Erwitt, 2012) gives many examples of how the collection of massive, and very precise, data will affect our lives – whether for better or for worse depends on one’s personal attitudes, but as humans are known for their adaptive capacities, ultimately these developments seem inevitable.

Smart cities

In the domain of urbanization, this trend has recently led to the concept of the ‘Smart City’. For instance, Scientific American ran a special issue on smart cities (September 2011). Industry players such as IBM and Siemens have specific programs and practices dedicated to advancing the cause of building smart cities. Despite its intuitive appeal, we have limited knowledge within the design, planning, policy, sustainability or ICT fields about the dimensions of the concept of smart cities, and limited practical experience regarding the barriers and potential opportunities. Tentatively, one could use the following definition (DeSouza 2012): A smart city is livable, resilient, sustainable, and designed through open and collaborative governance.

De Souza (ibid) argues further that a smart city:

• is resilient, i.e. possesses the capacity, desire, and opportunity for sensing, responding to, recovering, and learning from natural and man-made disasters.

• takes a sustainable approach to the management of its economic, social, and ecological resources to ensure that they have vitality going into the future.

• infuses information for automated and human, individual and collective, decision making on optimal allocation of resources, design of systems and processes, and citizen engagement.

• enables intelligent decision making through leveraging information via technology, platforms, processes, and policies across its environments, infrastructures, systems, resources, and citizens.

• operates as a seamlessly integrated platform where information links the various infrastructures, systems, organizations, and citizens’ goals and values.

• engages citizens in planning and design of public spaces and governs use of public resources through open and collaborative governance platforms supported by information technologies that generate, and leverage, the collective intelligence of its residents.

These goals are achieved by infusing novel information flows into the city that gather information about citizen and infrastructure behaviorand disseminate information to the citizens. Smart cities use a wide assortment of information pipelines and platforms to integrate the – often disparate – physical and human sub-systems, infrastructures, and processes. By building viable connections, information flows between the various parts of the city seamlessly so as to enable real-time intelligent decision-making. Leveraging information technologies is central to the goal of developing smart cities. Technologies, especially computational and communicational systems, are vital for optimal processing of information in real time and facilitating both automated and human decision making. Hence smart cities are laden with information generation sensors, automated systems that aggregate and store data, and even tools that enable data to be transported across administrative systems. On the other hand, and maybe less evident to the ICT community, is the fact that smart cities also use information technology to involve their citizens in the decision-making and implementation of policies and other measures. This is necessary to ensure that very large cities avoid major social ruptures and political traumas. They do so by extensively using participatory platforms.

Five essential domains of development of ICT for smart cities are relevant here:

(1) Smart planning requires us to think of cities as ecosystems. Planners will be faced with the challenge of designing a new ecosystem (when faced with the challenge of creating a new city) or modifying an existing ecosystem (when retrofitting an existing city). Such infrastructure projects insert new actors, dependencies, or interactions, and require that participants renegotiate their place in the ecosystem. Many projects strand because the different stakeholders communities have not sufficiently been involved in the planning.

Successful planning for smart cities also requires looking broadly at the impact of the infrastructure on the dynamics of the economy and the geography of the region. Failure to think of such projects holistically as complex systems will result in isolation of critical stakeholders, flawed plans, and, ultimately, in poorly executed or failed projects. An excellent example of a very good plan is the model designed by Revi (20XX) for the city of Goa (India). He decomposed the econ-omy of the environment and the infrastructure of the current city, and rebuilt them with an interesting twist: rather than work from the city center outwards, he worked from the surrounding countryside and its resources inward, thus creating a much less energy-intensive and highly functional city plan.

Finally, smart planning is planning and designing for change. Planning should look beyond im-mediate completion into the life stages of planned infrastructure, based on an informed under-standing of the future of the city in order to build projects that fulfill the needs of the city that will be, not the city that was. Smart planning aims to build plans and infrastructures that are adaptable and flexible, and that have the capacity to be repurposed as conditions change.

(2) Collective Smarts. Smart cities take advantage of the talent and education that is locally available by creating and maintaining effective platforms for citizen participation in the construction of the city, encouraging their citizens to contribute constructive ideas and innovations. This is achieved by means of ICT platforms that enable co-construction of ideas among citizens. Such co-construction can happen in meetings that are organized at looking at different scenarios of the future, but could ultimately also entirely happen on-line. Another effective tool in this domain is crowd-sourcing both 'what lives in the city' and ideas that might indeed, realistically, contribute to a smarter city. Regularly monitoring of the ideas that are being discussed on the web, in social networks, etc. , enables the city government to be better in touch with what actually goes on in the city. By selecting the best from among the many ideas contributed by the urban citizenry, one could achieve a kind of "Emergence by Design" of urban innovations that respond effectively to the city's needs. In the process, transparency is much improved.

(3) Smart Infrastructures. Sensors are to be present in the physical infrastructure of a city from

intelligent traffic lights to metering technologies that regulate parking spaces. Buildings in a city also act as information sensors, tracking details such as personnel movements, energy consumption, and the flow of goods and services. In addition, citizens have multiple devices through which they interact and exchange information on their activities and whereabouts. These tools enable city managers to understand the behaviorof individual citizens, and thus help move management from the 'statistical' to the 'personalized' state. This has many ad-vantages for individual citizens as well as the urban society as a whole. And it allows the city to gain efficiencies in many domains, from resource use to transportation. Robust, nimble, and agile: smart infrastructure is the new vision of infrastructure.

(4) Smart Operations. While information is present in the many facets of a city, this information needs to be cohesively managed. Managing information across subsystems, systems, infrastructures, and organizations is critical to realizing the goals of resiliency and sustainability and to creating smart cities. The underlying structure and foundation of smart cities will be built upon the policies and design guides used by government, planners, and architects. The benefits of solid, smart city regulations will be a healthier and more fruitful life for the increasing numbers of urban dwellers. This concept of "social sustainability" also will impact those living in the cities through the presence of green spaces, walking paths, etc. For example, through the design of smart transportation systems one might be able to not only reduce the emissions for vehicle traffic, but also increase the health and well-being of citizens by promoting healthier habits like bicycling or walking to work. Economic sustainability should be present, as the city will create jobs and inform job-creation activities using information smartly.

(5) Smart Governance. Cities are administered by a collection of agencies and governing bodies, mixed and matched in singular ways depending on the local laws and cultures. Smart agencies are a vital part of the smart city fabric. These agencies leverage the power of information to conduct their operations in an optimal manner. Smart cities must be adept at multi-objective optimizing, able to pursue multiple goals, negotiating among possibly conflicting constituencies. In order to achieve this level of efficiency and responsiveness, public agencies must revolutionize their operations. Smart institutions will embrace information technologies to achieve their goals in a sustainable manner. Today we have sophisticated computing technologies, access to data of all kinds from geographic to economic with even finer granularities, and we have visualization and mapping tools that can leverage information for better decision making around megacities.
Cities also represent critical economic hubs between nation-states. As such, increasing the sophistication with which information is processed to enable smart decision-making will contribute positively to national stability and growth. Cities are resource-constrained and need to re-solve multiple, and conflicting, goals of various stakeholders who own, or have access to, these resources. Hence, there must be a movement toward information-driven, collaborative, and inclusive decision making. The fact that there is a greater chance that these spaces can recover from internal and external shocks through effective resource allocation and infrastructure management during times of distress adds to urban and national resilience. But such smart governance calls for optimal collaboration between the various stakeholders involved in ad-dressing complex challenges around the design and planning of urban spaces.

Conclusion

In this contribution to the Global Systems Science project, I have deliberately focused on questions and issues, rather than on the specifics of the many ways in which ICT is going to change urban systems, and our understanding of them. The impact of ICT is going to change so rapidly, and in so many unpredictable ways, that it seems to make little sense to outline our current vision on these in this programmatic paper. Rather, the paper aims to outline a major field of action, in which – over the coming ten years – things will change very rapidly, and out best efforts will be required to steer these changes in a constructive way.

In that process, there is a distinct role for academic research, which is to look further ahead than industry, business and politics can, and in particular to look critically at potential unintended consequences of solutions that are about to be implemented, so as to avoid that our path-dependency drives us into traps that we will have a difficult time to come out of.

2.2 Financial systems

The financial crisis of 2007 has not led to a breakdown of the world economy only because a critical minority of policy-makers – mostly central bankers – had the courage to discard the conventional wisdom of current macro-economic models and experiment with measures that defy that wisdom. In particular, the build-up of the Euro crisis could only be stopped when the president of the ECB, Mario Draghi, declared his determination to move the markets from an inferior (in his words: “bad”) towards a superior (“good”) equilibrium, rather than sticking to the conventional story of a shock that had to be absorbed by the capacity of the markets to return to their alleged single, stable equilibrium.

However, the risk of a next crisis, possibly larger in scope, is unabated, and will be a key challenge of global risk governance in the years and decades to come. GSS will help to move towards an integrated governance of global risks that takes into account the interactions between financial and other markets as well as between socio-economic dynamics at global, national and regional scales. For this purpose, GSS will develop simulation models that overcome the feature of a single stable equilibrium built into present standard models, and that will rely on well as in-depth analysis of the large data-sets necessary to monitor the complex networks of economic and other agents shaping the world economy.

This shall lead to joint learning by policy-makers and researchers about how to design and implement effective measures towards a financial sector supporting increasing employment and sustainable economic growth, e.g.:

- simple rules to limit risky dynamics of complex financial systems,
- regional experiments with innovative schemes to foster sustainable growth,
- stepwise move from the present Dollar-based state of the global monetary system towards a state where the overcoming of global poverty can take place along reasonably stable trajectories,
- …

2.2.1 ICT in economics and finance

Silvano Cincotti

The last four decades of last century have been characterized by tremendous developments in Information and Communication Technologies (ICT) and ICT have impacted all areas of our societies and have been considered the basic line to achieve innovation. Direct evidences can be found in the amazing computational capabilities that are nowadays available as well as the pervasive influence of telecommunication on everyday life (e.g., internet, smart phone, table, etc.).

In the context of the ICT revolution, a great amount of data on financial markets has been made available in the last three decades and finance has become the most quantitative social science. More recently, the crisis of 2007-2008 produced an intellectual collapse of the modern economic theory and opened a demand on how to integrate the crucial role played by the financial system into macroeconomic models and to rethink of the economy as results of interactions among those heterogeneous agents.

This opened a demand for innovative approach to modelling economy and finance and a request of contributions to other disciplines (e.g., physics, engineering, psychology, etc.) whose methods and tools can effectively contribute to the study carried on by economists and mathematicians since more than 100 years and result in significant advances and benefits.

Nowadays, this demand is further increasing mostly driven by the complexity of the techno-econo-society and ICT have the opportunity to provide efficacy and efficiency stated that we will be able to couple ICT and policy and decision making so to transform innovation into growth, feasibility into sustainability, and uncertainty into risk. To these aims, there is a need of a network of infrastructure, observatories, data repositories, services and facilities that leads to a new cross-disciplinary research community and the ICT community has the opportunity and responsibility to foster and to facilitate such synergic aggregation by providing the community with the mandatory infrastructures and tools. Two major contributions are directly expected by the ICT community:

a. repository and management of huge data in economics and finance;
b. framework and facility for analysis and computational experiments.

These enabling technologies and solutions constitute the foundation of a public facility intended for economic modelling, investigating all aspects of risk and stability, improving financial technology, and evaluating proposed regulatory and taxation changes.

The public facility should be grounded on HPC and huge computational power services and enriched by large variety of methods including data mining, process mining, computational and artificial intelligence and every other statistical physics, computer and complex science techniques and on the mathematical tools developed in network theory coupled with economic theory and econometric in order to perform a continuous monitoring and evaluation the state of the economies of countries and their various components (i.e., short term horizon). Furthermore, the public facility should also provide the framework, infrastructure and interoperability of economics and financial models to perform data-driven what-if analysis, scenario evaluations and computational experiments to inform decision makers and help develop innovative policy, market and regulation designs (i.e, mid and long term horizon). Finally, the public facility should also provide innovative solutions to collect, to store and to analyze relevant information by means of social media mining tools and web-based information markets so to constantly monitoring and managing the crucial interaction between expectations, policy and reality.

Such an arsenal of proven and novel techniques, methods, facilities and frameworks is originated by a cross-disciplinary research community of economists, social scientists, complexity scientists and computer scientists and will allow scientists and regulators as well as policy makers and the private sector to conduct realistic investigations with real economic, financial and social data devoted to prevent future crises (by making the global economy more resilient) and to explore the possibility of broad societal transitions to sustainable patterns of production and consumption.

It is worth remarking the crucial needs of a public rating institution, as the recent scandals faced by the rating societies have pointed out weakness and conflict of interests of contemporary rating system. In this respect, it can represent the European reply to the private approach that characterized current American rating system and it can also be considered a cradle for training and collaboration with the private sector to spur spin-offs and job creations in Europe in the finance and economic sectors.

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The financial system performs vital functions for the world economy. The goal of a sustainable and stable finance is of the utmost importance for global system science. Regulators and policy makers need reliable and useful visualization, modeling and simulation tools for this system. As one of the most recent approach we propose to use for such purpose the theory of Complex Networks. Very often one of more aspect of this system can be described by means of a complex graph. Typically, under the generic name of *financial networks* people indicate several different systems all related to the world of finance. Such a coarse graining is justified by the fact that in all the various situations we always find similar behaviours. We shall present here a series of examples passing from the study of stock-price correlations to the study of the web of exposures between different companies, and finally to the lending of money between banks. Indeed in every of the abovementioned systems we encounter similar mathematical structures (we always find a scale-free architecture, a scale-free distribution of centrality and betweenness). Furthermore regulators are often interested in similar basic questions. More particularly anyone wants to know which institutions are more important for the stability of the whole system, what the global impact of a local bankruptcy is, and finally how we could act on the system in order to change its properties or to recover the initial stability. The possibility to provide to regulators a set of simple indicators that can be used as a thermometer of the financial situation in order to prevent crises is one of the most challenging perspectives. For this reason more and more often scientists and research groups involve regulators in the research activity. The recent crisis has spurred a profound debate about the role of policy and regulations in financial markets. The debate has drawn the attention of researchers from many areas of science as well as of the civil society at large to the needs for new approaches to policy modelling. Overall, it has emerged as a prominent societal issue the need to build a sustainable global financial system that serves the global policy goals. In particular, many observers share the view that the current financial crisis should be seen as an opportunity to strengthen climate finance and not as an excuse to postpone the environmental objectives that were previously put forward

2.2.2 Structural Instability of Financial Systems

Guido Caldarelli, Stefano Battiston and Antoine Mandel

State of art One of the primary causes of instability is related to the failure or susceptibility to failure of multiple banks, at the same time, across the banking network. The vulnerability of the financial institution networks arises through different mechanisms such as: (i) direct mutual credit exposure between banks; (ii) interrelated exposures of banks to a general source of risk; or (iii) cascading effects from fire-sale of assets by troubled institutions (Nier et al., 2008). Today's global financial networks are more connected and hence more vulnerable to losing strategic nodes. The node failures of one network can cause node failures in another, interconnected network and may result in cascading failure of more than one network. This potential contagion effect (the collapse of one network to other key networks) is often overlooked by policy makers. The stability of the system is a key factor that needs to be addressed by Global System Science. Financial networks grow organically along with the globalization and innovation trends, and as the networks become more interdependent, the stability of the system can be compromised.

Progress To that purpose we envisage to focus on correlated exposures of banks to an emerging endogenous source of risk to analyze the effect of loss in asset value (insolvency) of one bank across the entire network. In addition to banking, we ought also study other financial networks such as currency and capital market networks as interdependent systems to capture and analyze the risks associated with the relationships among these networks. While we do not advocate reversing these natural trends of globalization and innovation, we propose steps that can be taken to improve the reliability of the financial networks and prevent cascading failures to other networks. These steps, in the form of better (not necessarily more or less) regulations, can significantly increase the stability of the overall financial system (Schinasi, 2005). Complex global networks are not likely to ever be completely reliable, but hopefully they can be made more resilient and self-correcting by reducing the interdependence between the various components and minimizing the damage from a failure of one network to the functioning of another (Cornell Info 2040-Networks, 2008).

2.2.3 Visualization of interconnection between different systems. Role of financial interlinkages.

Guido Caldarelli, Stefano Battiston and Antoine Mandel

State of art During the period March 2008 - March 2010 many US and international financial institutions received aid from the US Federal Reserve Bank (FED) through emergency loans programs, including the so-called ‘FED Discount Window’. Recently this dataset has been released thereby providing a unique and important opportunity to study the distribution of debt across institutions and across time. One of the papers based on the analysis of this dataset wanted to estimate the impact of a node on the others [Battiston et al 2012b]. This is done in order to develop novel strategies with respect to the too-big-to-fail procedure [Stern 2004].

Progress The assessment of the possible impact is done with a novel measure inspired by feedback centrality. Such quantity termed DebtRank [Battiston et al. 2012b] takes recursively into account the impact of the distress of an initial node across the whole network. More particularly DebtRank of vertex i, is a number (i.e. dollars or euros) measuring the fraction of the total economic value in the network potentially affected by the distress or the default of node i. This quantity can be used to construct a ranking, but it is not itself a particular rank of the node considered. Its computation differs from the methods based on the default cascade dynamics [Cont et al. 2010, Mistrulli 2011, Battiston et al. 2012] in which, below the threshold no impact is propagated to the neighbours. In this respect DebtRank is more similar to other feedback centrality measure that have found successful applications in many domains ranging from rankings in the world-wide-web (e.g. PageRank) to corporate control in economic networks.

DebtRank is currently used by a variety of regulators as Central Bank of England, Bank of Italy, Bank of Brazil, European Central Bank.

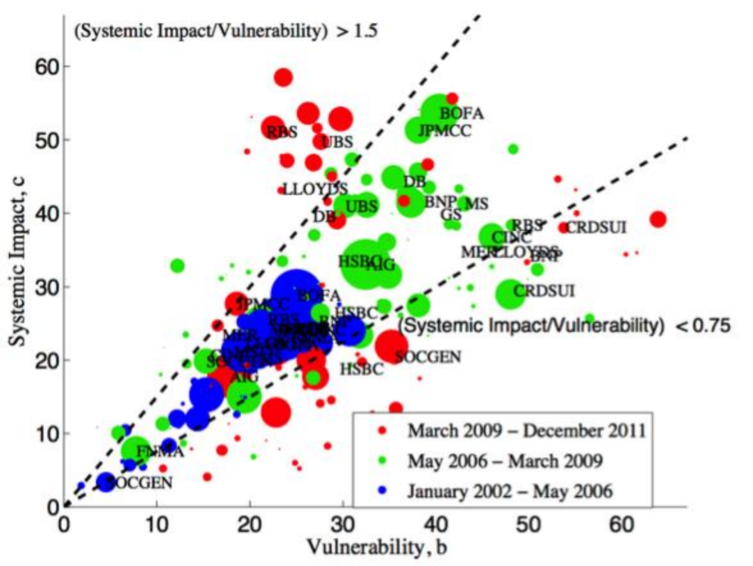

Figure 1: DebtRank-like algorithms allow to monitor over time in a 2-dimensional plot those players that have at the same time high impact on the others and high vulnerability to other players' shocks. (See Kaushik et al. 2012 for more details on the calculations). As we can see, in the intermediate period (green) a number of players were at the same time highly vulnerable and systemically important.

2.2.4 Sustainability of Welfare

Guido Caldarelli, Stefano Battiston and Antoine Mandel

State of art Every scenario simulation indicates that health spending will exert increasing pressure on the GDP in Europe. If countermeasures are not taken, we can estimate that in 2030, after a continuous trend, the increase in incidence will be between 1 and 1.5 percentage points when considering the efficient expenditure (standard), and between 1.3 and 1.8 pp if one takes into account current levels of inefficiency. Other estimates from Ecofin, OECD and the IMF (which refer to a broader scope of spending and incorporating the voice of assistance to the disabled), suggest a potential doubling of health spending to GDP over the next fifty years. Other problems emerge adding to the expenditure projections of the financing. Regionalization of welfare will worsen the situation. It is assumed that all regions contribute to the financing of the expenditure standard with a uniform percentage of GDP, equal to the share of expenditure on the standard national GDP. We construct the matrix flow redistribution so that it would activate. The mass redistribution would increase from about 10 to about 13 billion euros in 2030, challenging values, accounting for nearly 0.7% of GDP and 8 to 9% of the standard spending. Most flows would start to benefit from the North of the South

Progress To overcome the gap of efficiency and quality, it is necessary to establish clearly the standardization rules of the expenditure and the rules for its full funding. complex system representation through agent-based simulation could track the possible scenarios for regional tax leverage with the timing and for amounts consistent with healthy fiscal developments. This approach can be fruitful only involving the relationships between levels of government, the relationship between the regional and local authorities, and the cooperation with various stakeholders.

2.2.5 Network of Networks

Guido Caldarelli, Stefano Battiston and Antoine Mandel

State of the art: In complexity theory we make the assumption that a variety of economic and financial systems can be described by a graph. Economic entities and financial institutions are nodes, characterized by state variables (aka fitness) depending on their economic and financial values. Links among nodes are of multiple types, depending on the particular relationship between the institutions. Edges can be static or dynamic, and their value can possibly co-evolve with the state of the nodes. The advantage of this approach is in the simplification of the modeling and in the possibility to predict the future behavior of the system. Unfortunately the dynamics are often interconnected with the topology. Finally, the topology itself can be composed by various interacting layers. The theory of these systems has yet to be written. The simplest case is given when links are static and along them a dynamical process is going on. A typical example goes under the name of **pro-cyclicality of leverage**. Essentially, this is a positive feedback (from asset prices to fragility of banks and back to asset prices) taking place on the network formed by banks and securities. Considered alone, this network cannot be used by regulators. It is only the coupling of this network with the network of interbank credit [De Masi et al. 2006], determining magnitude and the persistence of the effects as explained in the following. Banks lend to each other, i.e., they invest in each other claims, but invest also in assets external to the interbank network (hereafter “external assets”), such as sovereign bonds. An initial negative shock on an external asset, say A1, makes more fragile a bank, say B1 that holds some units of A1. Bank B1 then sells some amount of A1 and pays back with the proceedings of the sale part of its liabilities. In so doing, bank B1 increases its robustness. However, since the sale will likely move the price of A1 further down, the other banks that hold A1 will now also feel more fragile (a case of negative externality). If in turn they start selling units of A1, this could trigger a spiral of devaluation. In this far, distress propagates only via those links that result from common investments in the same asset or asset class. However, the mechanism is exacerbated by the fact that banks may be affected by the shock on A1 also along the link of the other network, i.e., because they invested in B1 claims, which has become more fragile [Battiston et al 2012]. The current state of the art is addressing the problem only with basic mean-field approaches that neglect the network structure. We plan to investigate how the dynamics is affected by the: (i) the structure of the network bank-security, (ii) the interbank credit network and (iii) the way the two networks are connected.

Progress: To move forward on this topic we intend also to develop a link formation mechanism. We will proceed in order from the simplest standard rules [Albert et al. 2002, Caldarelli et al 2002] to more sophisticated rules, such as those based on spectral properties of the graph [König et al. 2011-2012]. A challenge here is that there is a formation rule for each type of link and thus the space of parameters grows very fast. This makes it harder to characterize the general properties of the system. Another challenge is that it could turn out that it is important that link formation rules take into account the number or quality of the links in both networks. For instance, the decision of a bank, B1, to invest in a certain set of external assets may depend also on the assets held by the banks connected to B1 on the credit network. Indeed, the output of this task is expected to contribute on the theoretical understanding of the topological structures emerging from the interplay of two or more interdependent rules for link formation. We also plan to investigate how the evolution of links in a multi-level network may lead to interactions at different scales in the structural dimension. The result of recent and on-going investigations suggest to conjecture that the link formation rules at the firm level could lead to the self-organized formation of super-nodes [Vitali et al. 2011], which then influence the dynamics at the firm level.

J. Doyne Farmer

In his opening address to the ECB Central Banking Conference on 18 November 2010, the ECB President, Jean-Claude Trichet said that “in the face of the crisis, we felt abandoned by conventional tools”, and went on to call for the development of complex systems based approaches to augment existing ways of understanding the economy. While traditional methods in economics are very useful for some purposes, there is an urgent need for additional work that properly addresses the financial system as a system, rather than a set of disjoint parts.

Techniques used in global systems science are quite different from those used in conventional economic theory, with its emphasis on optimization. They include data mining, network analysis, systems dynamics, agent based modeling, and non-linear dynamics. An important challenge for GSS is to explore the (in)stability and resilience of global financial markets focussing on issues of agent heterogeneity, network effects, spreading of information, market psychology, social learning, and expectations. At the same time, many instabilities in financial markets are driven by nonlinear instabilities that are inherently mechanical or that derive from market structure. (Good examples are nonlinear instabilities driven by derivatives). GSS will use a variety of approaches to understand the nonlinear feedbacks that exist in markets more comprehensively, explore their interactions with each other, and in particular to model their interactions with human decision making.

There are many questions that can be addressed by GSS: What are the causes of extreme events and crises? What preventive measures should be taken? If a crisis does occur, how should it be managed from a GSS perspective? What is the role of financial innovation? How can institutional design and market regulation contribute to the stability and resilience of global financial markets? It is now widely believed that modern markets have become much more vulnerable to sudden changes as a result of the development of automatic trading algorithms. The latter, for example, often incorporate stop loss instructions to sell when a price descends to a certain level. If many algorithms have the same thresholds this can lead to a cascade of sales as in May 2010 on the NYSE. This interaction between modern technology and market dynamics will play an essential role in the way GSS models understand financial markets. Recent work in network theory and agent-based modeling has begun to address some of the systemic problems in finance, but such work has so far only scratched the surface of what is possible, and most of the important work still lies ahead.

The network view of finance and economics. Finance and economics provide a rich set of networks to consider, in which the nodes can be many things. Examples that have already received considerable attention include interbank lending, international trade, corporate ownership, and input-output relationships in production. There nonetheless remain many more relationships to be studied, and in particular the interactions between these different systems remain poorly understood.

The vision of the economy as a system of evolving coupled networks provides a completely different policy perspective. A key feature is that the behaviorof the economy at the aggregate level emerges from the interactions, both of the individuals within each network and of the networks themselves.

Traditional policy recommendations are based on the reactions of individual nodes (people, firms, institutions) to changes in policy. The network approach opens up the possibility of identifying and targeting key nodes within the system, thereby potentially increasing the effectiveness of policy. It further makes it possible for policy makers to influence the way in which the structure of the network evolves. So, for example, the Basel agreements have focused upon controlling and improving the viability of individual institutions rather than on the ways in which they are connected and hence the viability and resilience of the system as a whole. A classic example of the failure of this approach was that of Dexia, a Belgian bank which had to be rescued by government intervention only 3 months after having passed the official stress tests without any problem. A global systems science network analysis can yield insights into the systemic banks in the financial network, which must be preserved from falling. These latter considerations have only recently come to the fore. This point has been heavily emphasized by the Bank of England, but despite the establishment of the European Systemic Risk board there has been little reaction in terms of macroeconomic modelling to this issue.

The current crisis has shown once more the importance of the feedback between the macro economy and worldwide financial markets. The global economy is a multi-scale complex system and a multi-disciplinary approach is necessary to study its functioning. In particular, interactions and feedbacks between financial markets and the macro economy need to be studied to understand crises and improve their early detection and to develop new complexity based economic policy.

2.3 Sustainable Economies

J. Doyne Farmer

The problem of protecting both current and future generations is manifest when considering the supply of food, water and energy, and understanding how we can maintain a high standard of living for the whole world without depleting natural resources and destroying biodiversity. How do we avoid or at least mitigate these key social, economic and security-related problems? These extremely difficult problems require trans-disciplinary teams and are naturally addressed by GSS.

At present the state of the art for understanding the dynamic aspects of sustainability is system dynamics modeling, as used in the original Club of Rome study, Limits to Growth. Such models have certainly been useful in providing an understanding of the relationships between key components of earth systems. GSS will expand considerably the analytical techniques which are applied to such systems, beyond that of ordinary differential equations by using tools such as network theory, complex systems theory, multi-agent simulations, multi-level models, experiments and participatory platforms. We also take into account explicitly spatial and network effects, as well as heterogeneity of agents and randomness.

Economic growth. At the same time that modern economic growth theory embraces technological progress as the agent of change underlying growth, it has traditionally dealt with it in a very simple way. In a typical economic growth theory a technology is a black box embodied by a very simple production function. In contrast, it is clear that to understand the patterns of technological progress one needs to look inside the black box and carefully model its constituents and their interactions with each other. Technologies are recursively built out of other technologies, and technological change happens in an evolutionary manner: Existing technologies are recombined and only occasionally are genuinely new technologies created.

Furthermore, technologies form a web of overlapping and interacting physical parts and conceptual processes, so that one should think in terms of the global ecosystem of technologies rather than individual technologies. Progress in one technology is automatically transmitted to all the technologies for which it is a component, or to which it is related. Improvements in semi-conductor manufacture, for example, have made a substantial contribution in driving down the cost of photovoltaic modules. Global systems science could contribute by giving us a better understanding of technological improvement, by treating the process of improvement as a networked phenomenon that is driven by the physical interaction of technologies as well as the social drivers underlying supply and demand. A program in this area would include the economic, environmental and social consequences of technological development. Moving in this direction, recent work in the complex systems community models the way in which the components of a technology depend on each other, and shows that using simple models for technological improvement, the rate of technological change and its diffusion depend on the interconnectivity and separability of the technology.

Constructing technology investment portfolios

Most decisions about technological investment are made using subjective criteria. GSS offers the possibility to develop more systematic methods for allocating technological investments. To do this, however, we first need to solve some basic problems presented by technology investment that are not present in traditional financial investments. This problem present several interesting features that make it well suited for being addressed by GSS.

In traditional portfolio theory in finance the behaviorof outcomes -- the returns on the investments -- are assumed to be independent of the investments themselves. This makes it possible to convert the problem of computing portfolios weights into a simple problem in variational calculus. Technology investments violate this property in a dramatic way. As it well know, increasing production tends to drive down costs, through learning and economies of scale, and indeed the central purpose of R&D is to find cheaper and better solutions. This enormously complicates the portfolio problem: Rather than being a static optimization problem, it is now a dynamic optimization problem. Investment influences returns: The more one invests, the more costs drop. Treating this problem involves understand a complex nonlinear stochastic dynamical system.

Traditional portfolio theory in finance pushes strongly toward diversification as a means of reducing risk. For technology portfolios, however, this is not necessarily the case. In the absence of uncertainty in the outcomes, one should simply pick the best technology and invest everything in it, as this will generate the best outcome. However, the fact that the future of any given technology is uncertain changes this, and means that one needs to invest in multiple technologies to hedge one’s bets. Nonetheless, one should not diversify too much: If investments are spread too thinly across too many technologies, little or no progress will happen. From a qualitative point of view it is necessary to make a compromise. It becomes necessary to make a compromise between diversification and concentration. From a quantitative view, however, this problem remains poorly understood.

GSS can contribute to this by funding work on this essential problem. Such work has the potential to improve public planning. This applies to the ICT program, as such methods could potentially be used to improve ICT funding.

Data for GSS in economics.

The economy generates vast amounts of data that are currently not being gathered and recorded in an integrated manner, and which can provide much deeper insight into the workings of the economy than existing data sources. Most current data collection in economics is geared for econometric and DSGE models, which only require aggregate data such as GDP, unemployment, etc. Network modeling and agent-based modeling, in contrast, are best done with finer grained data, such as information about the choices of individual householders. Information about the heterogeneity of behavioris essential. Agent-based models can potentially make use of many different types of information, as described below.

Ultimately the economy is about the transformation of physical materials into manufactured goods, and the organizing of human activity into services. On a longer timescale, data concerning products, technologies and firms should be recorded so that we can understand more directly how the economy transforms human activity into material goods, information and services. (Here we define "technology" in a very broad way, to include everything from electronics to new financial instruments to changes in the legal system).

Inequality.

Where does inequality come from? The core model of modern economics, general equilibrium theory, does not enable us to say anything about the distribution of income. The issue of inequality cannot even be addressed in the standard representative agent model in macroeconomics. Is inequality an inherent feature of complex systems with heterogeneous agents? But inequality is not just a matter of the distributions of income and wealth. A major concern of policy makers about, say, outcomes in health care or education across hospitals and schools is that such outcomes are "unequal'' or "inequitable'' in the key sense that they differ at any point in time.

Distributional properties have an important impact on aggregate economic outcomes; for instance, it is well-known that the effectiveness of tax-cut policies aimed at sustaining consumption demand depends on the income distribution of tax payers. Other distributional issues are probably still undervalued in economics, as for instance the distribution of debt among and within the different sectors of the economy: public, corporate and households.

Policy makers face the problem of predicting and controlling the distribution of wealth. What are the best strategies to achieve a more egalitarian society? Agent-based models naturally take into account the distribution of economic variables at individual levels and therefore can be valuable tools for policy design. A particularly important question is that of intergenerational inequality. To what extent should we make changes now to protect future generations?

2.4 Climate Change

In a different way, the challenge of integrated risk governance and multiple equilibria (more technically: basins of attraction) is relevant for global climate policy, too. Attempts to reduce global emissions stressing the dangers of climate change to justify moderate reductions in economic growth have led to gridlock in international negotiations, globally and to some extent even within the EU.

GSS will support global climate policy by investigating possible co-benefits of climate policy, ranging from reduced health impacts by air pollution to accelerated productivity growth by new directions and volumes of investment. In part, this will require models with a similar architecture from those required to address global financial risks, in part it will require even greater emphasis on interactions between different policy fields like environment, energy, employment, health and foreign policy as well as time and spatial scales.

As with the financial crisis, GSS research shall lead to joint learning by policy-makers and researchers about how to design and implement effective measures towards climate policies supporting mutually reinforcing goals as the following:

- showing by examples that increased economic well-being is possible with systematically decreasing emissions,

- generalizing these examples up to the point where emissions decrease globally, too,
- turning measures to adapt to adverse climate change into experiences of social learning that strengthen resilience while reducing emissions
- prepare for the need to take CO2 back from the atmosphere, especially once global poverty will have been overcome

2.4.1 Climate mitigation modelling

Doyne Farmer

What are the optimal strategies to deal with climate change and its consequences, and how much will such strategies cost? Current climate mitigation models assume general equilibrium. Production decisions maximize the utility of a representative agent, a typical person who exemplifies the average worker and consumer. Such models assume full employment and assume that firms have no unused inventories -- everything that is produced is consumed. Since by assumption industries operate at full capacity there is no need to stimulate demand. Such models count the costs of converting to new technologies without giving any weight to the economic stimulus that such conversions might generate, i.e. they do not allow for the possibility that developing new technologies might put people who are otherwise unemployed to work, and thus stimulate demand and make the economy operate at a higher capacity. Perhaps even more important, they typically make highly questionable assumptions about technological progress. Such models have never been back-tested against historical data and their predictive accuracy is highly questionable.

Global systems science has the potential to develop an alternative type of climate mitigation model. By constructing the model at the level of individual agents we have far more historical data that can be used to calibrate the model. By making use of results from behavioural economics we do not need to assume that agents are rational -- we can instead use decision rules that have been calibrated against the behaviorof real people. By collecting and calibrating against an extensive database on technological change, it is possible to deploy more realistic models of technological progress. Most importantly, we do not have to assume that the economy is in equilibrium. It is possible to study the effects of stimulus for new technologies, modeling the consequences of putting more people to work and making progress in new technologies, e.g. possible revolutionary transformations to a green energy economy.

2.4.2 Climate Finance

Guido Caldarelli, Stefano Battiston and Antoine Mandel

As the amounts of funds involved in climate finance increase (the EU and other developed countries pledged jointly to mobilize $100 billion a year by 2020 from public and private sources), the interactions between the climate and the global financial system grow in numbers and in intensity. For example, crucial linkages might form between the climate financial system and the concept of an international commodity reserve currency, as recently revived by the governorate of the Central Bank of China: “To replace the current system, Mr Zhou suggested expanding the role of Special Drawing

Rights (SDR), which were introduced by the IMF in 1969 to support the Bretton Woods fixed exchange rate regime but became less relevant once that collapsed in the 1970s. … China's proposal would expand the basket of currencies forming the basis of SDR valuation to all major economies and set up a settlement system between SDRs and other currencies so they could be used in international trade and financial transactions" (see Anderlini 2009, Bergsten 2009). What is relevant here is, firstly, that the basket would of course include climate and weather sensitive commodities. Secondly, and more importantly, carbon permits themselves might at some point be considered as one of the commodities backing-up the currency. If this were the case, the dynamics of the carbon price would become key, not only to the financing of climate change mitigation and adaptation, but also to the stability of the international monetary system. More generally, considering the central role of international financial institutions in the stability of the global financial system and their major commitment towards climate finance we can expect that the climate finance system will be soon and massively connected to the global financial system. Hence both systems will likely have major influence on each other dynamics.

The interactions between the climate and the global financial system grow in numbers and in intensity. Using the expertise built on both these systems, GSS should be able to identify on the one hand ideal points of contact and intermediary actors between the two systems and on the other hand zones of fragility where shocks might propagate from one system to the other. These insights will in particular be of interest on the one hand for public financing institutions in search of leverage for their climate finance and on the other hand for financial regulators that will increasingly have to monitor the climate finance system as it grows in importance.

Work on the linkages between the climate financial system and global finance will also provide key inputs to the macro-economic analysis of climate policies. As a matter of fact, the GSS community could be consulting in the coming years for a range of policy bodies in Europe and Asia (following, in particular, the reports in Jaeger et al. 2009, Tabara et al. 2012). In particular, the linkage of carbon markets with the concept of international reserve currency will, if implemented, drastically change the approach to the economic assessment of international agreements on climate change mitigation.

In addition to policy-makers, the outputs of GSS in this area ought to be communicated and discussed with stakeholders active in the field of climate finance with whom GCF has been working for several years. Those include agents such as: Munich Climate Insurance Initiative (founded by MunRe); the KfW Carlon Fund and related sustainability activities; Re-define, an international think-tank who recently published a study on "Funding the green new deal" (Kapoor et al. 2012); and the newly established Carlo Foundation, an independent rating agency for sustainable financial products.

2.4.3 Mapping the climate network relevant for policy

State of the art: For the "fast start finance" 2010-2012 period strong commitments were made and delivered on. However, a major difficulty turned out to be to spend the money both quickly and effectively. This difficulty demonstrates the need for a better understanding of the interactions between the different actors and instruments involved in climate finance. There is also a problematic tension between on the one hand the complexity that is inherent to most financial innovations and the other hand the high level of transparency that is needed in order to sustain international agreements.

Progress: As of today, climate finance projects are assessed individually, in isolation. The only risk considered as global is the one associated with the carbon price. In other words, there is no systemic view on the climate finance system although a few actors play a crucial role and face highly correlated risks.

Insights about complex financial networks show it is crucial to introduce a systemic perspective in climate finance. Deeper insights into the dynamics of the complex climate financial system shall be provided by developing maps of its network structure and models of the actions and interactions of the agents involved. In particular, leveraging on the work carried out on new- generation agent-based models and financial network models (Battiston et al. 2012a), network models can be developed to assess the systemic importance of actors in the climate finance arena. Algorithms have to be developed in order to analyze the impact of a negative shock on one actor to its counterparties, in a framework where commitments are not (only) financial, but also environmental. In similar models, the propagation of positive shocks, e.g. the decision to make a new investment in climate projects, shall also be investigated in order to develop methods to identify empirically where investment capacities with maximal impact are located in the network.

Such models and methods could contribute substantially to the design of a broader and more efficient climate finance system. They will be of a particular interest for public institutions involved in climate finance such as multilateral development banks or the European Commission which has provided around €3.7 billion in climate since 2002. Increasing the transparency of the climate finance system will also be an extremely valuable input for those in charge of its monitoring such as the Monitoring Unit of the DG Climate Action of the European Commission.

2.5 Health

2.5.1. Global Health and ICT

Manfred Laubichler

Health is a global challenge and a global problem. Health or well-being is also fundamentally a property of complex and ultimately global systems. The global dimension applies to individual health as well as to the health of populations, ecosystems or economies. Any understanding of health requires a complex adaptive systems (CAS) perspective that also includes values (social, economical, cultural, personal) and epistemologies (how do we know what we know, what are criteria of evidence, etc.)

Health Challenges as Part of Global Systems Science and Complex Adaptive Systems Science

All health challenges lie at the intersection of several global systems. These include various biological, ecological, social, technological, and economical systems. As part of a tightly interconnected world processes at all levels intersect--although exactly how is in many cases not fully understood. But what we do know is that there are multiple complex interactions that play out at different spatial and temporal scales and involve various feed-back and feed-forward loops. Most research has been focused on small or local intersections and has missed important dimensions that are only visible at a global scale. We are currently collecting data that will allow us to understand some of these connections and causal links (the big data challenge). But these data will only be meaningful, if we have a corresponding conceptual and theoretical framework that frames challenges, such as health as a truly global systems problem. To establish such a framework and test it in the context of specific health challenges at all levels of organization is one of the goals of global systems science.

A global systems perspective applies to all dimensions of health

- **Individual health:** While traditional biomedicine is exploring genomic, physiological and behavioural components of health as complex adaptive systems it is becoming increasingly clear that global systems dynamics play a major role in determining individual health outcomes. Examples include shifts in the distribution of infectious disease agents due to global climate change, exposure to new diseases and environmental pollutants due to climate change and global economic activities, increased risks to the food supply, etc.

- **Population Health**: Many health issues also affect populations. And in today's world the population structure has reached a global scale. The ongoing danger of pandemics, the effects of demographic changes and the patterns of global migrations all affect health at the population level.

- **Ecosystem Health:** Another important aspect of global health is the state of the supporting ecosystems. These provide a variety of ecosystems services that are increasingly threatened by various aspects of globalization. Ongoing changes to ecosystems will, through various links and connections of integrated complex systems, affect all other dimensions of health. A global systems science perspective is essential to study, understand, and manage health at all levels.

Evolutionary Dimensions of Global Health

Evolutionary dynamics are a central part of global systems and complex adaptive systems approaches to global health. All system respond to external and internal challenges, either by regulatory dynamics that maintain an adaptive equilibrium or by transformative dynamics that change the system state, either in an adaptive or chaotic way. Currently many of our complex global systems are operating far away from their equilibrium points and are observing positive or feed-forward feedbacks that make it increasingly difficult to predict their behavior (not unlike the financial system). In order to maintain or manage global health challenges we there fore need a better understanding of the dynamical properties of closely connected global systems.

ICT Dimensions of Global Health

Approaching health as a global systems problem is only possible if it is done in the context of big data and new forms of information and computing technology. Current trends in monitoring systems level properties and markers of systems health need to be expanded and most importantly these various data streams need to be integrated in real time to allow for adequate representations of system states in order to enable informed decision making. Global systems health is thus at its core also a computing challenge. This includes present and future as well as historical data (which increasingly become available). The historical dimension is especially valuable, as it will also allow us to study the effects of phase transitions in systems behavior. Complex systems change their dynamics when they go through scale dependent phase transitions. It is therefore crucial to get access to as many case studies of such phase traditions as possible. Health data, financial data as well as data about the history of science are among those that allow us to study the consequences of phase transitions in complex and now global systems.

Phase Transitions in Knowledge Systems

One foundational question in the context of globalization is what happens to knowledge systems after they pass through patterns of expansion finally reaching a truly global dimension. How are the dynamics of these systems affected by such transitions? What are the consequences for our understanding of such systems as well for their governance and organization? Western science as a specific type of a knowledge system has continuously expanded since its inception in its modern form during the period of the scientific revolution. It has passed form a mainly local organization with well established patterns of communication in the 16th and 17th century to a period of national organization during the 18th and 19th century (including its role within European colonial expansion), a period of mainly transatlantic interactions in the early 20th century (amplified by the exodus of Jewish scientists from Germany and neighboring countries) to finally a truly Global enterprise. Western science has thus experienced a number of phase transitions, all of which are very well documented in the historical record of science. It is thus a prime case study for exploring the consequences of transitions in scale. To do that, we need to analyze the history and current practices of science as a big data problem, analyzing a rich and vast documented historical record with novel computational approaches that allow us to identify patterns and processes and their transformations in the context of transitions in scale. To this end we will apply concepts from evolutionary theory and the theory of complex adaptive systems to the analysis of the historical patterns and processes of in the development of Western science. Treating science and it history as a case study for global systems science has two distinct advantages: (1) science is a complex social system with a long and well documented history and analyzing science can thus lead to important insights into global systems dynamics and (2) effective governance of current global science is one of the main challenges of our global society as we depend on getting the right kind of results from investing increasingly scarce resources.

An additional contribution is expected here from Alessandro Vespignani

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See also Appendix 4.1 on 'Global Contagions Over Co-evolving Networks: A Genuine GSS Challenge' by Christopher L. Barrett, Devdatt Dubhashi, Madhav V. Marathe in section 3.1.2

2.6 Energy

The global energy system is entering its biggest transition since the first oil crisis four decades ago. In those days, oil prices left the remarkably stable basin of attraction in which they had moved since the initial learning-by-doing made cheap oil available more than a century ago. Presently, the debate about climate change, the fast rising demand by emerging economies, the decision to phase out nuclear in one of the premier engineering countries of the world, the learning-by-doing in the field of renewables and the development of fracking techniques are profoundly changing the global energy landscape.

As usual in those situations, people tend to claim reliable knowledge in areas where informed guesses are all that is possible. Developing such guesses – scenarios, possibility spaces, subjective probability and more – in a transparent and systematically improvable way is an important task for global systems science. Collecting evidence for successes and failures of policy interventions is a second one. The results can be sobering, but that may well be exactly what is needed.

J. Doyne Farmer,

Possible problems to which GSS can contribute for energy include:

Infrastructure. Energy production and consumption involves a complex set of physical and economic processes, with social, environmental and financial impacts. Understanding the consequences of possible policies in regulating and supporting energy infrastructure should be a primary activity of GSS. To be explicit, the stages of energy production include the following stages:

- *Resource extraction*. The majority of current energy generation occurs by extracting fossil fuels. Renewal energy generation still involves resource extraction, including sun, wind or tidal energy. The nature of the extraction phase has far-reaching environmental consequences, but also economic consequences (price) and social consequences (e.g. jobs). The nature of extraction dictates many aspects of the rest of the infrastructure given below.
- *Production of energy generating capability*. Getting the ability to produce energy requires infrastructure in and of itself. Constructing an oil refinery involves extracting other resources, such as steel and other building materials, depends on construction methods, etc. Oil refining requires a deep knowledge of chemistry. Similar considerations apply to solar energy and other renewables. This is embodied in the sustainability literature by life cycle analysis, which takes all the stages of production into account. GSS can play a key role in broadening life cycle analysis to include all the other components in this list, including social as well as economic consequences.

- *Storage* is a key problem that must be solved in order to make the transition to renewable energy. This is primarily a technological problem, but as with all of the above, any proposed solution has side-effects on broader levels that must be properly taken into account. Storage solutions must be well-integrated into the vision of a smart grid.
- *Transportation*. Fossil fuels must be transported to their end-use location.
- *Transmission*. Electricity must be transmitted from its point of generation (unless generation is performed on-site).
- *Distribution*. It must be distributed from local stations to the consumer.
- *Consumption.* Understanding consumption is at the core of the problems to be solved. The energy system is designed to satisfy human needs. Having a good understanding of consumption is essential -- we cannot design energy infrastructure without understanding what people want and people will respond to policy alternatives. This is particularly true because patterns of usage have major impacts on efficiency.

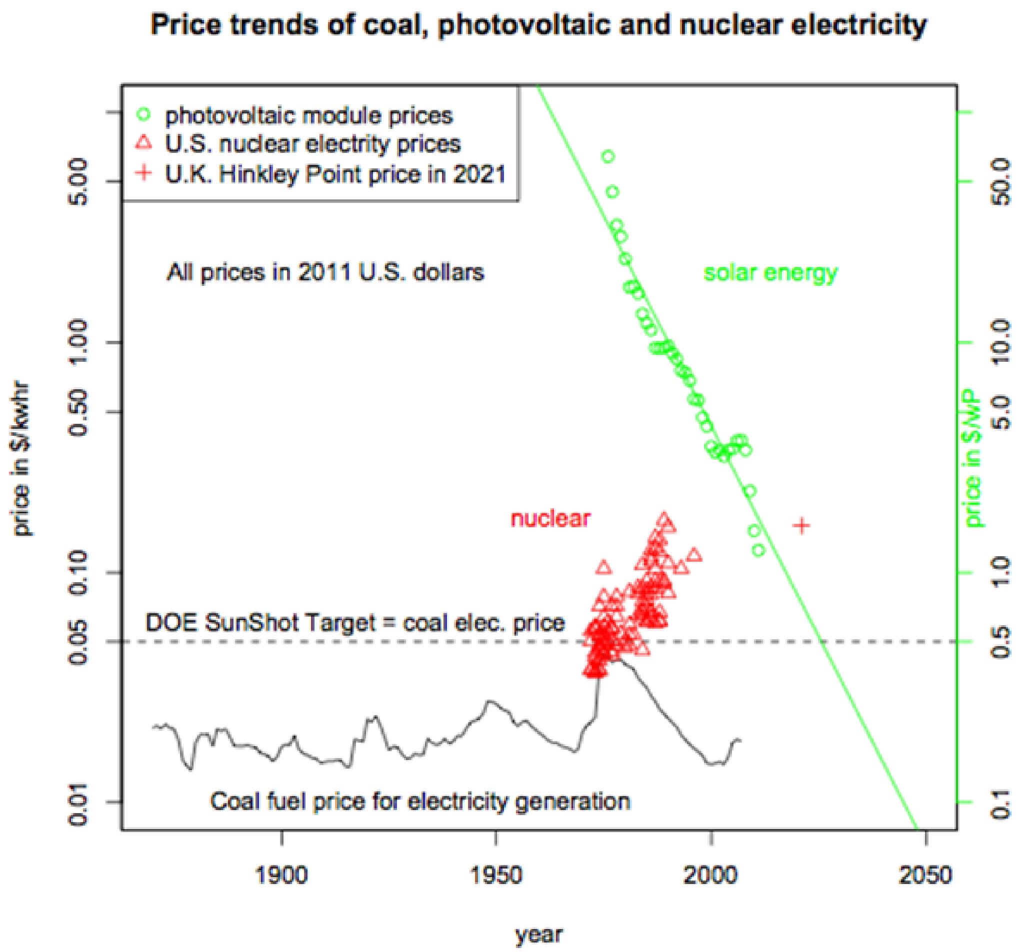
It is essential to have a holistic model of the entire energy infrastructure that addresses the interactions between its components. This requires global systems science.

Understanding the process of technological improvement is essential for planning future energy systems.

To understand how to mitigate the effects of global warming and plan investments intelligently we are forced to make forecasts about the likely rate of improvement of different technologies. We must find energy production technologies that minimize environmental impacts with the lowest possible cost. The best approach for climate mitigation depends sensitively on assumptions about the rates at which different technologies improve. Our choices of technologies dramatically influence all aspects of energy infrastructure; for example, the characteristics of the grid that we will need in the future will be very different if we massively adopt nuclear power than they will if we adopt solar energy. To plan our research and development in energy technologies it is not sufficient to "leave technology to technologists", which leads to bad planning. Expert forecasts regarding technological improvement have typically been wrong due to a combination of siloed thinking, industry bias and the advocacy of special interests. Note that we are not claiming that we should advise technologists in the lab, but rather that we should take global systems science into account when making investments and in extrapolating the future course of technological improvement for planning purposes.

The different nature of technological dynamics is illustrated in the following figure 2 which compares the cost efficiency of generating electricity with coal, nuclear power and photovoltaic solar as a function of time. We show the coal fuel price, which makes up about 40% of electricity cost from 1860 to present, and compare it to the price of electricity from U.S. nuclear energy (measured in terms of the time when a plant comes online), and the price of photovoltaic solar energy modules, measured in terms of dollars per watt of peak power. As a reference we show a horizontal dashed black line, which is the goal adopted by the U.S. department of energy as the price at which solar modules begin to become competitive with coal. The key point that emerges from this figure is that the historical time dynamics of different energy sources are quite different. In particular, the price of coal has remained roughly constant over the 150 years it has existed, the price of nuclear power has actually increased[1], while PV solar energy has dropped by almost a factor of 3000 since it was introduced in 1957 (we show only data since 1976 here). If we assume these trends will continue the consequences for public investment are dramatic: While solar is only marginally cheaper than nuclear at present, it is likely to be dramatically cheaper in the future, and indeed a simple trend extrapolation shows that if present trends continue, by 2050 it will be five times cheaper than coal.

Figure 2



Failure to take such trends into account could lead to poor decisions regarding our public energy investments. And of course, these choices impact everything else: This suggests that we will need to make a dramatic change in infrastructure in order to make the needed transitions.

1 Evolving safety regulations have unquestionably had a large effect on nuclear energy prices; in particular the Three Mile Island and Chernobyl disasters occurred during this period.

This example illustrates the need for better methods for planning not just energy investments, but technological investments in general. This is treated in the section on sustainable economics.

2.6.1 Energy infrastructures and GSS

Emile Chappin & Paulien Herder

Energy infrastructures form the core backbones of our society and enable our society to prosper. In order to maintain our way of life, the need for an affordable, secure and clean energy supply is widely acknowledged. Europe imports around 90% of its fossil fuels, which makes it heavily dependent on limited resources and geopolitical forces. Solving the problem of sustained energy system security is crucial for Europe.

Solutions for ensuring energy supply in the next decades need to be found in technology, policy, institutions and behaviour. Increasing interdependence between electricity, natural gas, heat, biogas and other energy infrastructure networks may result in more volatile and unexpected system and market behaviour. Policies for balancing, managing international interconnections, supporting renewables, trading greenhouse gas emissions, curbing congestion and maintaining generation adequacy differ between countries and are interdependent. We need to develop an integrative systems approach that accounts for such interdependencies. Renewable energy technologies, smart grids, energy markets and regulation, and emission trading schemes have sparked massive research efforts all over Europe. An integrated engineering systems perspective, in particular a systems-of-systems view across sectors and national borders, linked with policy and economics is necessary.

A new generation of analytical, modelling and simulation tools should enable us to study innovation, strategy and policy making and explore the evolutionary pathways and the operational dynamics of these complex systems in relation with technical, economic and social conditions.

2.6.2 Energy: Centralisation versus Decentralisation

Catalina Spataru, UCL Energy Institute

By the end of the post-war period, electricity production in Europe has been driven towards centralisation with the development of large scale power plants. The fact that the electricity system in Europe is going nowadays through a transformation process can initiate a new era in the energy sector. As Europe is experiencing a period of deep modifications in the energy sector, energy efficiency, reliability and decrease of greenhouse gas emissions are the first priorities for a more sustainable energy strategy. However, the EU legislative does not adequately specify the questions posed by a decentralised approach with many unknowns unknown. Starting with the definition for decentralized energy as given by DTI [1]: “power generation that is connected to the low voltage distribution network at 132 kV and below”, we can say that the benefits of a decentralized energy could be at low level, so that can contribute towards establishing distributed generation as a main source of electricity or as a backup producer, with decentralised energy being generated in smaller power plants. As a result, it can reduce the environmental footprint of producing energy, compared to centralised systems, where transmission requires an enormous footprint for lines to transport power at high voltage (MGx). Currently, 93% of electricity worldwide is supplied through centralised generation and distribution [2].

Currently through the use of centralised electricity generation stations, around 65% of the energy is lost before it even reaches consumers. If we could use this waste heat, it could contribute to improve energy supply security and tackle climate change.

Although, as already stated before, there are many advantages to adopt a decentralization way, currently investments continue to focus on centralised technologies especially in electricity. Part of the reason why this is happening is the structure of electricity and gas markets and the way in which they are regulated, but also the fact that many industry and policy makers support the convenience of centralised energy systems. Furthermore, there are more practical barriers and technical problems, as the distribution networks have to be reinforced and to some extent redesigned to deal with new capacities. Also, price competitiveness is very important in order to establish an efficient distributed generation in terms of both performance and cost. Subsequently, regulatory barriers require extensive work to modify the rigid regulatory environment the distributed generators have to face.

With distributed generation and storage, energy consumers have the possibility to become producers of electricity. Therefore a decentralisation system has several advantages over a centralised system, such as: avoid network losses, reduce transmission and distribution costs, requires less backup capacity due to the fact that many small generators are less likely to suffer a major impact from the outage of a single generator, can be tailored to local conditions; can be installed much faster than a centralised system. In global terms, decentralized energy could revolutionise the lives of billions of people who currently lack access to basic clean, affordable energy services.

However, despite the many benefits there are still significant barriers and at European level it depends on national circumstances. Currently, decentralisation has already started to made a strong appearance in the European energy market, in 50% of Denmark's electricity and almost 40% in Netherlands with widespread in many other countries, including Sweden, Germany, Austria, Finland, Italy, Spain. Realistically centralised power stations will need restructuring over the next years to be able to cope with high uptake of renewables and move to a decentralised system. To do that, the best way is to adopt a transition pathway to a hybrid centralised- decentralised mix system which will be highly lightly to work through slowly progression. Governments need to improve policy and remove regulatory barriers to uptake a more decentralised approach to energy system. Also important is to increase the accuracy of forecasting need, possible energy storage of energy excess production and reduce cost of recent technological innovation. However, applied globally, decentralisation could be a promising social transformation and industrial revolution.

[1] Department of Trade and Industry 2006. The Energy Challenge: Energy Review Report. London: The Stationery Office

[2] Decentralising power: An energy revolution for the 21st century, www.greenpeace.org.uk

2.6.3 Energy Resource Dynamics and Immediate Issues

William J. Nuttall

Even without the looming challenge of anthropogenic climate change, energy is a complex business. For most, but sadly still very far from all, Europeans it is many decades since energy was simply a matter of keeping warm. Even in the nineteenth century the supply chains and industrial investments to source Europe's energy were far from straightforward. Today however the energy business is truly a GSS. Of all the energy resources arguably only crude oil is a genuine market commodity traded in liquid and transparent markets. Natural gas is still shrouded in a cloak of contractual secrecy and renewable and nuclear power are entangled with politics. The most strongly growing fuel in the global energy mix is coal despite the climate change problems it brings[2]

One of the odd truths of the current energy system is that one international oil and gas company allocates a cost of $40 per Tonne to CO2 emissions in its investment appraisals(http://www.bloomberg.com/news/2012-12-06/shell-says-europe-needs-120-a-ton-co2-to-rival-coal-wind-1-.html), while the carbon price in the European Union, so proud of its green credentials, languishes at one tenth that level. Such odd realities are a sign of a GSS at work.

In the last few years the retail distribution of petroleum has seen examples of fuel panics which reveal interesting GSS characteristics[3]

The technique of system dynamics has long been applied to problems of energy resources depletion[4].The Electricity Policy Research Group at Cambridge University has built upon this tradition in recent years. Much of that work is now in collaboration with The Open University.

Much consideration is rightly given to renewable energy for its potential contribution to a low carbon future. The attributes of renewable for energy security are similarly important are very well suited to GSS analysis. Much of that analysis remains to be done. One immediate issue is the possible risk of cascading grid disconnection of distributed renewable generators in the face of detected erosion of grid power quality. See the work of Martinez de Alegrıa et al[5]. Such cascading failure could be similar to a cascading failure in the banking sector, as considered in section 2.2. Despite these risks renewable energy avoids the supply chain risks long associated with fossil fuel energy security.

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[2] http://www.iea.org/newsroomandevents/pressreleases/2012/december/name,34908,en.html

[3] Upton and Nuttall: http://www.eprg.group.cam.ac.uk/wp-content/uploads/2013/04/1305-PDF.pdf.

[4] http://www.systemdynamics.org/conferences/1989/proceed/parallel%20sessions%20pdf/naill423.pdf

[5] http://www.ewp.rpi.edu/hartford/users/papers/engr/ernesto/farrew2/Project/research/7E440736d01.pdf). Other considerations relate to the risk of disconnection in the face of extreme weather (http://www.risoe.dtu.dk/rispubl/reports/ris-r-1714.pdf

In summary even before the emergence of a low-carbon distributed and smart energy system there are many important issues faced by both the energy industry and policy makers which are usefully amenable to analysis using GSS methods.

2.6.4. Global energy trade flows, modelling and economic networks

1. Global energy trade flows and the economy

Franziska Schuetze

In 2011, annual revenues of the three largest energy corporations such as Royal Dutch Shell, Exxon and Chevron were in the range of US$ 470bn, US$ 433bn, US$ 236bn respectively (Global Energy company rankings: http://top250.platts.com/Top250Rankings/2012/Region/Industry). Seeing that this is as large as the GDP of Portugal (US$ 237bn), Argentina (US$ 446bn), Norway (US$ 485bn) in the same year, one can assume that energy trade flows have a significant impact on the global economy as a whole.

GSS can engage in mapping and understanding the global flows of energy: including fuels/raw materials used as energy source, as well as trade flows of generated electricity. Resulting from this information, we can ask how the energy sector influences the global economy?

How would a shift in trade flows or price shocks influence the economic activities in the network of countries and corporations involved, e.g.:

- How does the shale gas boom in the US influence global trade (quantities and prices) of oil, gas and coal. Does it shift electricity generation practices globally?
- How vulnerable is the "real" economy? How do oil/gas/coal price shocks influence the industry and therefore the entire economy globally?
- Can a shock in the energy sector cause a global crisis to a similar extend as the financial sector?

More advances tools and models are needed to assess global scenarios of this kind.

2) Energy & electricity modeling

In the area of energy modeling especially when assessing electricity costs, there is a need to go above and beyond single technology considerations, where usually LCOE (leveled cost of electricity) or capex (capital expenditure) of several technologies are compared to each other.

Instead, **energy costs need to be analyzed from a system cost perspective**, including more than one electricity generation technology (not a single technology vs. another) and including system costs such as energy storage, transportation as well as demand side management (next to generation costs).

If for example a generation or storage technology is expensive from a capex and LCOE perspective, but highly relevant from a system perspective and will only run several hours per year, it will not increase the overall system costs significantly but will add value to the system.

Parameters that become important then are technological lifetime, load and capacity factor, flexibility, storage capacity, as well as cost sensitivity with respect to changes in variable costs such as fuel costs and CO2 costs.

Even if an electricity system is optimized in terms of total system costs, the following question remains: **Does the system need to be organized in a centralized fashion?**

GSS can develop tools to assess differences in efficiency and costs of a decentralized energy system versus a centrally organized energy system.

Linking energy system considerations to ***climate change and sustainability research*** is equally important. Here GSS can shed more light on questions such as:

- **Multiple equilibria:**

The question of multiple equilibria is relevant for the energy system as well. The current energy system (in any country) is not without alternatives, therefore the question is which alternative systems (equilibria) are possible and how can a transformation to such an equilibrium take place.

If the aim of an energy system is to provide supply security at minimal cost for society (system costs plus externalities), there are several possible equilibria, however with different levels of externalities. Assessing and choosing for a possible energy systems should include considerations in climate and environmental policy as well.

- **Externalities:**

The amount of externalities, such as CO2 emissions throughout the entire value chain, environmental degradation, contamination, food security, loss of biodiversity, long-term risks of fuel extraction and waste disposal need to be assessed more carefully and taken into account.

- **Risk assessment:**

There are short-term risks (emerging during the operation time of the plant) and long-term risks (risks that go beyond the operation time of the plant). The assessment of these risks seem to differ very strongly between countries and are heavily influenced by political goals and political decision making. Private companies internalize the benefits of using energy technologies with high long-term risk, but often the long-term risks are transferred to the nations and therefore society. The involved risks are only shifted in space and time but not reduced or eliminated. Lobbying power of energy corporations certainly plays an important role here.

Energy corporations are not wiling to take the long-term risks due to the short-termism of todays financial and investment cycles. The challenge is to find governance mechanisms that make corporations take over a larger part of these risks collectively (disaster fund /resource extraction fund or similar) and therefore take over more responsibility for long-term consequences of their operations.

However, there are no unified measures used to assess these kinds of long-term risks. The challenge is to establish a more objective and more holistic risk assessment at a global scale, which will put a price tag (a range of potential costs) to specific technologies and practices.

3) Market design and policy interventions at a global scale

Information about energy market design and policies implemented in the energy sector is highly dispersed and partially not transparent:

- First, how is the energy market organized/set-up in countries worldwide: Which markets are liberalized, which are centralized, what are the resulting wholesale and retail prices, how transparent are the costs for the consumer? How can we obtain more transparency in OTC transactions?
- Second, which countries have implemented which policies (e.g feed-in-tariffs, quota systems, etc.) with which effects?

A more systematic monitoring and information sharing system is needed to increase learning at a global scale.

4) Innovation and technological development

From a sustainability perspective, technological development in the energy sector need to take into account the negative environmental and social impact throughout the value chain. Different solutions need to be assessed in a more holistic way. Questions arising from that are:

- What do learning curves for different technologies depend on? How can they be accelerated? Which role does energy policy and industrial policy play?
- How can we make sure that new energy technologies focus on sustainability and become value–adding for the environment and society?
- What is the role and the responsibility of engineers in this respect? (Analog to the question on the responsibility of bankers and traders in the financial sector)

5) Connections between the different layers and networks

Decisions have influences (often unintended) on other sectors (cross-sector) and other countries (cross-country) and vice versa:

- Interconnections between the transport sector, industry, energy sector, housing/building sector, the financial sector and so forth become increasingly important. E.g. How can the financial system support and hinder technological development? How does energy policies influence climate policies?

- Decisions about the market organization of the energy market in one country have an influence on neighboring countries and trade partners. Countries should be more aware of and take into account the influence their decisions have on other countries (especially in the EU context) and coordinate policies in this respect.

2.7 Global Sustainability

Sander van der Leeuw

These contributions have been extracted from the GSS blog: http://blog.global-systems-science.eu/

2.7.1 Environmental change, globalization and ITC

March 5, 2013

Models and our understanding the dynamics of the Earth system

Our understanding of climate change is due to thirty-odd years of research that combined empirical observations (ice-core analysis; monitoring of (ant)arctic ice sheets and glaciers, average annual temperatures, etc.) into models of the atmospheric dynamics, including incident radiation, CO_2, NO_2 and other gas concentrations in the atmosphere, etc. In that enterprise, modern computing plays an essential role – without it we would not have been able to combine the various sources of information into a *dynamic* theory that was able to explain what is happening. The results have been the basis for the reports of the Intergovernmental Panel for Climate Change, and have thus drawn worldwide attention to the topic. An important aspect of this work is the modeling without which we would not have been able to gain a glimpse of what might be happening in the future.

From an ICT perspective, it is noteworthy that this research as in fact used some of the biggest computers on Earth, and has led to the development of very sophisticated mathematical and empirical modeling software in centers such as the National Center for Atmospheric Research in the USA and the Hadley center in the UK.

Worldwide, projects such as the AIMES component of the International Geosphere-Biosphere Program (and its predecessors) have over the last ten to twelve years begun an ambitious attempt to include other flows and dynamics of the Earth system in these models.

The relevance of this effort is attested in the prominence more recently accorded to the concept of 'planetary boundaries' – the idea that there are a number of other, interrelated, domains where human activity has pushed the natural dynamics of the Earth system to the point that equilibria that have persisted since the beginning of the Holocene are likely to be fundamentally undermined (Rockström et al, 2009). Some of these domains are ocean acidification and sea level rise, freshwater use, chemical pollution of the terrestrial ecosystem, biodiversity and ecosystem services, etc. The result could be that rapid changes in each of these domains would start interacting with each other, and tip the Earth system as a whole out of its current basin of attraction.

The models and data used to derive the understanding of these other planetary boundaries has thus far been developed in an ad-hoc and sectorial fashion, so that the potential interactions between these phenomena are far from clear. *Efforts are needed to remedy this, by building models that can integrate the dynamics of the various sectors. This in itself will be a major challenge in the ICT domain, not so much concerning hardware as in developing the software to achieve this.*

In the context of the restructured 'Future Earth' program, which will succeed the existing Global Environmental Change Programs of the International Scientific Union (ICSU), and is co-funded by a range of national and international funding agencies, scientists across the world are now beginning to set the next step: including human social dynamics in these models. This requires a change of scale. Whereas atmospheric and hydrospheric dynamics can in first approximation be modeled at the global scale, that is not the case for the societal dynamics. These differ economically, technologically, culturally and institutionally so much across the globe that the scale at which they are first explored is necessarily regional.

All this poses number of important challenges to ICT:

- *The downscaling of the atmospheric and hydrospheric models to the regional (or even sub-regional or local) scale,*
- *The up-scaling of ecological and other environmental models to the regional scale*
- *The development of models of societal dynamics in all their complexity in real space-time.*
- *As these models cannot be built top-down, underpinning any such efforts will require massive data collection and monitoring, by a wide range of means, in different environments and among different societies.*
- *Two kinds of data can be distinguished: behavioural data and perceptual data.*
- *The former can generally be captured by a wide range of sensors*
- *The latter can only be gathered by direct interaction with the people concerned, in experimental or other situations, or through crowdsourcing*
    - *Finally, this will require a massive intellectual effort to compatibly bring together information that has been assembled in different contexts, by different disciplines, and with approaches rooted in different epistemologies.*

Not only do we believe that these challenges can be met, we would argue that meeting them is a question of survival for our mode of life. If we do not meet them, the environment will change and find a new set of equilibria, but there is an important risk that our societies will not in time be able to achieve the resilience necessary to deal which these changes.

Transforming our culture to integrate the challenges

The potential consequences of climate and environmental change have been known for decades, whether due to human activity or not, but very little has been done about them thus far. This is a classic 'collective action' challenge – how do we mobilize sufficient interest, and create the necessary sense of urgency, to trigger collective action. It is complicated by the fact that the change in culture and mindset required is massive, and by the fact that there is no 'fixed point' outside our cultures to leverage against. Under this heading, we distinguish between action and the research needed to focus that action effectively.

Research

We argue that in this domain our next step is to *identify the core themes that can energize the transition to a sustainable society* and the role ICT can play in that project. Though much Global Environmental Change research to date has been focused on understanding the dynamics that drove our world to the present predicament, much less effort has been devoted to thinking about ways to get us out of it. Moreover, the social sciences have thus far insufficiently been involved because the challenges defined by the research community were not formulated as social science challenges. Preparing and guiding the sustainability transition, however, is essentially *a social science challenge*, even though many other disciplines are involved in determining the context for that transition.
The core question we must ask is: *'Why is it that so much knowledge and publicity about sustainability at so many levels has led to so little action?'* That question has a number of different components at various levels, going from the cognitive to the cultural, to the institutional, which we will not elaborate here:

- *The path-dependency of our societies*
- *The difficulties of preparing for and dealing with major catastrophes,*
- *The difficulty of anticipating unintended consequences,*
- *The role of technology in our society and our (over-) confidence in it,*
- *The difficulty of anticipating how societal dynamics will impact on our life, etc*.

We are not arguing that there are immediate answers to these challenges; nor that we see a clear path for an ICT contribution to them. There is certainly the space and the opportunity for such a contribution, but implementing it must go hand in hand with some important developments in theory development, and the exact implementation will depend on how this shapes up.
Next we must ask a series of questions about the *nature of the transition that we wish to effectuate*:

- *Should we aim for a rapid 'quantum jump' transition or for a slow and incremental one?*
- *Should this be driven 'bottom up' or 'top down' or maybe 'sandwiched' between the two?*
- *How do we upscale the 'bottom up' elements and downscale the 'top down' approaches so that they are adapted to local circumstances?*

Once we have done this, we must raise the issue of *how to instantiate this transition*? That, again, gives rise to a host of questions:

- *How would we frame normative goals? There is a troika around values, economics and institutions, but is that enough?*
- *How would we "create an ethic of stewardship" or a "feeling of community"?*
- *How would we confront cultural and social value differences? One cannot impose any cross-cultural specific practice because of such differences.*

- *Would one use tools integrating persuasion, dialogue, policy debate, culture and custom?*
- *How can we identify innovative and exciting accelerators of change?*
- *Could we build positive, plausible scenarios for transition to a sustainable society that could provide a framework for future research.*
- *Would we need to explore how to deconstruct institutions?*
- *What strategies for avoidance, adaptation, and transformation are effective at large scales?*

All of these questions involve studying the structure and dynamics of alternative futures, and therefore involve a much more systematic exploration of models and scenarios, in which ICT will play an essential role. *We have thus far not systematically harnessed the power of computing to the exploration of multiple societal futures*. As a result, most of our reactions to potential societal futures are underdetermined by our observations, and over-determined by responses derived from past situations, which are in- and of themselves path-dependent and inadequate. That needs to change, and that requires re-thinking how we use ICT with respect to global environmental change, *moving from learning* ***from*** *the past to learning* ***for*** *the future* (van der Leeuw et al., 2011).

Action issues

Action needs to happen at all levels of society, and in the following few lines, we can only highlight a few areas. All of them can hugely profit from ICT developments, because these will enable better data-driven decision-making, but such developments have to go hand in hand with a study of their potential impact on society, including their unintended consequences.

We need to improve how governments, at all levels, create and manage different policies and other tools that promote sustainability. The difficulty is in combining the ethical and environmental dimensions with the economic and social ones, and in identifying the tradeoffs and making the correct decisions about them. Clearly, this cannot happen in a uniform way across the globe – but ICT tools can be developed that look at trade-offs scientifically and rationally, and thus facilitate decision-making, and these can be propagated as 'best practices'. An approach that may further this goal is to improve the connection between government and civil society using ICT to effectuate "emergence by design", combining data mining of movements and ideas emerging in civil society with a top-down selection process that moves us in the right direction.

The most likely response from the business community would be to commandeer the sustainability movement so that it may be at worst controlled, and at best turned to a profit. This is clearly evident in "green-washing", and is one reason for the wide, and biased, publicity regarding the term sustainability. Business "brands" the movement as its own, takes charge of it, takes the wind out of it, makes it harmless, and if possible even makes some money off of it. Can this tendency be transformed into a serious attempt at promoting sustainability? There is reluctance to pursue this thread because it is admittedly cynical, but it is also the way of the real world. If we are to move in the right direction, involving business as best we can is an urgent task.

The economics of "rational behaviour" are a problem within each culture, but particularly within our own. Standard economic definitions of rationality pose individuals as self-interested utility maximizers. There is nothing irrational about ignoring a call to sustainability if it leads to a reduction in utility (i.e. well-being, wealth, etc.). The rational choice is to carry on with business as usual, thus the social dilemma and collective action problem embodied by the prisoners' dilemma. It is clear from behavioural economics that the standard neo-classical definition of rationality is inadequate. Its major inadequacy is its failure to consider relative standing and interdependent preferences.

We must engage our societies' full innovative capacity in the task at hand. We must find ways to both focus that capacity and to accelerate it. The unbridled innovation of the last few centuries, driven by the desire to create value for our economies, is to an important extent responsible for our current predicament. We need to re-focus innovation by always taking its potential environmental consequences into account, and we need to develop pathways to accelerate such sustainability-focused innovation, removing bottlenecks and barriers. We are not very good at either of these, and have to rapidly develop the know-how to improve that situation.

Action tools

What might be some of the avenues by which we could approach these challenges? An important tool is, of course, *education*. We teach in general along principles that date back at least half a century, if not more (in certain disciplines). One important innovation would be the systematic introduction of ICT-based models in education from a very early age, as this trains people to think in alternative solutions, and therefore stimulates both critical thinking, and searching for multiple solutions. The tools are available in the gaming industry, but the teaching profession has so far not made adequate use of them.

Another important tool would be the *systematic introduction of art and creativity* in schooling throughout life, as this favors multi-dimensional and intuitive thinking as opposed to current linear, rational thinking. Here, the ICT multimedia industry has wonderful tools to help this kind of development. Moreover, by combining such tools into a kind of interactive and personalized online teaching that is very different from the kind that most schools and universities in the US practice today, it will be possible to reach a vastly larger population with these ideas and tools at low cost, and that kind of leverage would in itself be an important positive factor in achieving a transition to a sustainability culture.

One could argue that a major factor in the non-emergence of a collective movement towards a sustainability culture has been the *failure of the scientific community to adopt effective communication strategies.* The messaging has been in terms of a more or less uniform 'scientific truth', and people who did not understand that message in the form presented were not addressed. This opened the way for powerful lobbies to sow doubt in many people's minds about the veracity of the scientific message, whereas in other cases, the message was simply ignored because of a fundamental disbelief in science.

Network ICT, coupled with 'big' social data availability about the population of North America, for example, now offers the possibility to craft messages that address the core issues for a multitude of subsets of the population, and thus adapting the message to many different world views beyond the rationalist scientific one. In order to exploit those possibilities, it would be interesting to combine the ‘big data’ social databases – some of which characterize each individual according to up to 500 traits – with extensive data mining among the discussions going on in the social media. That should enable us at low cost to gather the information necessary to craft appropriate messages to all sectors of the population.

Crafting these narratives will be an activity in its own right, using all means of communication but also extensive creativity. It will have to be based on substantive knowledge of how sustainability issues are perceived, and how that perception changes under the impact of education and communication. For this purpose, one could develop other kinds of ICT tools, which dynamically integrate environmental change scenarios with regional economic and societal dynamics in order to help stakeholders understand how environmental change is going to impact their businesses and themselves personally. From the interaction between such tools and the stakeholders consulting them one can learn the latter’s perception of the issues concerned, and monitor how that changes over time.

The third major topic in this series is that of *engagement in the transition to sustainability*. Without such engagement, the desired mindset change will be much slower to emerge. Hence, the crucial issue is: how do we optimally engage our societies in this transformation?

2.7.2 A social planetary boundary

March 26, 2013

Much of the current public discussion at all levels of society is about a perceived ‘crisis’ in domains as different as natural resources, ecosystem services, our economy, our financial system and the security of our societies. That is, of course, true if one looks at each of these through disciplinary or sectorial eyes. But from a holistic perspective we see all these, together, as manifestations of one underlying crisis, notably *a temporary incapacity of our society to process all the information needed to deal with the dynamics in which it finds itself*. The fact that we do not have the answers to deal with all these issues, whether individually or collectively, is due to a lack of knowledge and understanding about the nature of the challenges and the means to deal with them, as well as a lack of sufficient communication and alignment within our societies to take collective action together.

What has driven our socio-environmental system to this point? In their 2009 *Nature* paper on *‘Planetary Boundaries’*, Rockström et al. argue that the current environmental crisis is the result of anthropogenic activities that have driven, and are still driving the Earth system out of balance. But that paper does not address how anthropogenic activities have also driven the human component of the Earth system out of balance. *The most striking imbalance that anthropogenic action has created in the societal domain is the huge difference in wealth between rich and poor.* In the security community it has raised the question whether this is a social ‘planetary boundary’, and how close we are to transgressing it.

Before answering that question we need to discern the dynamic behind it, and this involves a few paragraphs of theoretical language. In its most basic formulation, humans process matter, energy and information to live. As individuals, they sustain themselves by processing matter and energy, and to avail themselves of these commodities they process information. As information is not subject to the laws of conservation (but the other two are), it is the only one of the three basic commodities that can be shared among individuals. Shared information processing is what keeps a society together – shared knowledge, shared values, shared customs, shared institutions, shared culture. Sharing enables a group of people to meet challenges that exceed the power of single individuals to solve. It thus makes the members of a group 'better off' than they would be on their own, and among societies the one that offers more advantages ('value') than others will prosper and grow. Ensuring that a society keeps offering such advantages is the role of innovation.

For most of human history, inventions by individuals were only transformed into innovations at the societal level if (a) there was a need felt for them (a problem that they could help solve) and (b) there were enough free energy and matter ('wealth') available to implement them. These two conditions severely limited the innovative capacity of ancient societies, and thus the steepness of the value gradient between them and the outside world. We could summarize this by stating that *for most of human history innovation was 'demand-driven' and 'energy-constrained'.* The pace of societal change was limited by these two factors, and so was the value differential between the society's 'insiders' and 'outsiders'.

But this changed fundamentally from around 1800 with the introduction of ways to massively use fossil energy and the 'industrial revolution' it enabled. That change is a fundamental factor in understanding the current sustainability predicament. As the energy constraint was relaxed, *the last two centuries have seen a shift from 'demand-driven' to 'supply-driven' innovation,* in which information processing has replaced energy as the main constraint and marketing has enabled innovators to create demand for their products. This has fostered the emergence of education as a fundamental societal need, caused the exponential growth of (and our dependency on) the fossil energy industry, and ultimately the current globalization driven by multinationals and trade. But it has also hugely increased the value and wealth differential between the core and the periphery of the system, and thereby reduced the chances that outsiders become insiders, leading to the perception that the wealth discrepancy may well be the fundamental societal 'planetary boundary'.

Over time, the dominance of the information constraint has led to the fact that, presently, information, wealth and power are concentrated in a very small elite worldwide. This is due to the fact that those with the most information at hand, and thus the greatest information-processing capacity, have an advantage over others in controlling the trajectory of society, and thus also in extracting energy and matter fro0m the whole system, accumulating wealth. It thus explains much of the (growing) current imbalance between rich and poor in the world, as well as the environmental problems that we are actually facing, which has come to the point that it seems more and more difficult to maintain this extractive system in a stable state.

As wealth differentials reflect differences in information-processing capacity, they are therefore likely to be hugely affected by the information revolution, which is in the process of levelling the information-processing capacity differential. Rather than accumulation, spreading of information is likely to become the main driver of the economy, and the tool to create wealth. This will favor an *inversion from the current, predominantly extraction-to-waste economy* (in terms of raw materials, but also human capital) that has reached its limits, *into an economy of opportunity creation and spreading wealth*. Only by increasing the value, education and wealth of the underprivileged can our societies continue to enjoy the high standard of living they currently have.

Currently, we observe two seemingly contradictory trends – a levelling off of wealth disparities between nations, as the BRICS countries become wealthier, and at the same time a steepening of the wealth disparities within countries. This is the statistical effect of the rich becoming richer in the developing countries, while within these, as well as in the developed countries, the contrast between rich and poor becomes starker. The 'opportunity economy' needs to, and will, tackle that growing disparity by spreading information and thus reducing the steepness of the information gradient, and the wealth gradient with it.

We can distinguish two main kinds of processes that work in this direction. The first enable the development of local knowledge, or the expansion of local wealth creation, whereas the second aim for direct information transfer from the developed to the developing world.

Examples of the first abound, and have been spreading for fifty years under the impact of NGO's that quickly saw that providing local populations in poor countries with western knowledge or infrastructure often did not have as immediate an effect as helping local populations use their existing talents. Developing the local recycling economies of the developing world is a good example. These use materials such as empty oil drums and crates, used tires and the like to create pipelines, furniture and baskets. They are a fundamental part of the local economy, providing jobs, spreading or accumulating knowledge, and reducing waste. Giving them access to world markets has been one way to promote them, as in the case of the South African production of decorative baskets from telephone wire. But another way to promote them has been the spread of microcredit to provide for the initial investments needed for such enterprises to emerge. This has been so successful that more recently it has spread to poor areas in the developed world, such as parts of New York City.

Examples of the second are the facilitation of distant access to information from many different sources that was initiated by the search engines (Yahoo, Google, etc.), and then led to the development of specialized online encyclopaedias such as Wikipedia that not only assemble but also synthesize information. It is now entering a different stage with the emergence of the Massive Open Online Courses (MOOCs) driven by major universities such as MIT and Stanford. These enable anyone to study free of charge anywhere in the world. They are currently experimental, but likely to spread if ways are found to return to the educating institution a small percentage of the proceeds ultimately generated by the people thus educated. They are part of the 'online revolution', which in the next thirty years will fundamentally transform the worldwide education landscape at all levels.

In addition, there are many e-based tools that, even though they do not deliberately aim to educate, have very important educational components. These range from blogs to social networks to games that promote certain learning skills. In this domain, we may expect many more innovations that contribute to the transformation of the information-processing landscape.

We conclude that we have to take the hypothesis seriously that one of the main impacts of the information revolution will be a redistribution of knowledge and information-processing capacity that will fundamentally undermine the current structure of our societies, businesses and governments because information can no longer be kept from spreading.

In our vision that will inevitably end the very regime of wealth inequality that is about to lead to major social disruptions due to the fact that the extraction of resources (including natural resources, wealth and labor) from the periphery around the core of society which currently controls the information processing system has gone to the point that such extraction is more and more costly and damaging. From an energy perspective, the concentration has come to the point, for example, that whereas individuals need about 100 watts to comfortably survive, in the US, the per capita energy consumption is about 11,000 watts. At the same time the RoI for energy has gone from the neighbourhood of 100 to around 10. For many other natural resources, the same is happening (though maybe less drastically). For extraction of human capital there are no such clear figures, but the lack of trust in the current governance system in many parts of the world and the wealth imbalance that has grown over the last few centuries point in the same direction. This has, for example, been noted by the security establishments of the US and UK, for example. In public reports, they predict that many social systems in the developing world have been so fragilized by this process, that their survival will seriously be endangered by the consequences of climate change.

If we are to avoid such a major and uncontrolled restructuration of our current societies, the question in front of us is thus: *How do we play into these insights in a way that contributes to also reduce the environmental impact that our societies currently have?* The core of the answer is in our opinion a long-term policy of stimulating and harnessing demand. But rather than do so by heavy advertising directed at the same populations that businesses have for so long depended on, they have to identify new pools of demand, so that we can once again grow the economy based on demand-driven innovation.

Identifying that demand begins, of course, close to home, in our western societies, by identifying existing pools of demand that have thus far been ignored, such as in the New America Foundation's effort to develop new demand in construction and agriculture in the US by restructuring the economy around construction in existing urban cores of housing and offices that are low-energy (including refitting), and promoting novel strategies to increase sustainable agriculture in the Midwest.

In the developed societies, much larger (and more durable) pools of demand can be generated by *improving the education of the general population*, as has been done in, for example, Finland and other Scandinavian countries. Education is good for business, and business would do well to heed that and invest in it – whether directly or indirectly (through taxation and government spending). Better-educated people are more likely to be upwardly mobile, to gain more and thus to generate more demand, and they are also more likely to stimulate invention and innovation, thus enhancing the total value space of the societies involved. They stimulate the economy on the supply as well as the demand side. In due time, this will close the income gap and strengthen the middle classes, thus reducing the risk of fracture in our societies.

Hence, western business should not leave the education and development of the middle classes in Africa and elsewhere to others, such as China and India. There are huge markets to be conquered once the goal is long-term rather than short term, and the strategy is not to 'westernize' and stimulate the consumption of western goods and the creation of western-style infrastructure, but the discovery and encouragement of ways in which the populations involved can develop their own kinds of culture, society and – ultimately – demand. Collaboration between governments (both western and local), NGO's and businesses is essential to achieve this. NGO's in particular have developed a wide and deep knowledge of the other cultures in which they are active, and can point the way.

Education is clearly not the only way forward. *Improving access to the basic commodities necessary for a healthy life* will increase life expectancy, and thus contribute in its own way to creating new demand, both in our own societies and elsewhere. Investment in freshwater access, locally generated energy, access to healthcare, improved transportation and communication all increase not only life expectancy, but also economic activity, interaction, information processing and innovation in all parts of the world. Much is being done in this respect, again mostly in collaborations between governments, foundations and NGOs, but business should come to see more widely that it is in its own long-term advantage to upscale and spread these efforts by investing in them. In particular, there seems to be a growing disinterest in doing this in the health and education areas in some western countries, where this is in principle the easiest to achieve. There again, business can and should make important investments.

In first instance, such efforts would reduce infant mortality, and thus create a wave of young, energetic people aiming to enter the labor market in many places where the jobs are not available to cater to them. *Investment in job creation* – by fostering small and medium sized businesses *and creating a legal and institutional climate in which business activity is regulated and protected* are thus other tasks that need urgently to be undertaken and invested in. Large international companies could for example take a number of small and medium-sized companies in developing countries under their wing, develop collaborations, and ultimately profit from their growth (driven by local markets). Governments could use their experience to invest in designing and creating the legal and institutional frameworks necessary. In particular this might concern a revision of intellectual property rights, in view of the fact that communication is becoming so pervasive that the current legal frameworks are obsolete.

All this is predicated on two major assumptions. Firstly, that we can change the way in which we innovate. Since the industrial revolution, our western societies have essentially, and increasingly, innovated in every which way there was immediate profit to be gained. Business is now engaged in a race for the invention of more and more material goods at a rhythm never reached, and this speed find its parallel in the short-termism of the financialized economy. This has led to a situation in which society clamors for innovation to lead us out of the current sustainability predicament (greenhouse gases, ocean acidification, waste and other problems), while forgetting that two centuries of indiscriminate innovation have brought us to this point. Western science, because of its reductionist tendencies, has not been able to study the process of innovation scientifically, which of course concerns the emergence of novelties. It has therefore conceived of invention as a 'black box' ('creativity'), and concerned itself mostly with the conditions under which it happens, and its results. But from a complex adaptive systems perspective, it seems that we might now get a better idea of how inventions emerge, and how they are introduced into society so that they innovate. Business has much more experience with that process, and it would be in business' direct long-term self-interest to use that experience to focus on directing invention and innovation towards domains that combine generating new demand with a reduction in resources needed and waste produced. This may well include an important component of re-purposing of existing technologies and processes.

The other major condition *sine qua non* for an approach like this to be successful is finding and harnessing the important, long-term, funding stream needed. Currently, the vast majority of wealth is invested in, and draws its profits from, short-term financial speculation rather than investment in production for any market. Taking a proportion of that wealth and investing it for the long term in the domains mentioned above is a necessity if we want to make the transition towards an 'opportunity economy' of the kind proposed here. This will require a joint effort of government, business and visionary elements of the financial world to build a different, stable long-term socio-economic structure that engenders widespread trust. Until that has been achieved, the temptation to invest in short-term speculative values will persist.

3 Enabling Knowledge Technologies

3.1 Scientific Evidence – Models, Data and Computation

3.1.1 GSS models.

The following section provides some first ideas regarding possible GSS models characteristics, components and structures:

Michel Morvan and Eric Boix

The systems targeted by global systems science share common characteristics that make them "complex systems":

1. They are composed of different *heterogeneous* parts.
2. They include *hierarchies*, that is that some parts of your systems are themselves composed of subsystems, that can themselves be composed of subsystems, etc.
3. The different parts of the systems (heterogeneous or not, hierarchical or not) are *coupled* together, which means that the behaviorof one part depends of the situation of the other part.
4. The different parts of the systems represent *different space scales* and/or evolve at *different time scales*.

This intrinsic complexity makes unreachable the hope to "solve" them and therefore, modelling and simulation are a fundamental tool to tackle them. Being able to provide ICT tools, and in particular complex systems modelling and simulation tools, that allow:

i. to describe them as they are, without unnecessary simplification;
ii. to run sets of simulation and be able to show meaningful indicators from them;
iii. and therefore to think the problems in their globality and to test scenarios to identify global trends is clearly of great importance.

Steven Bishop

An open modelling platform is needed that will support a variety of users with widely different analytical and ICT skills, ranging from data scientists to policy makers and ordinary citizens, empowering them with the ability to define, manage, integrate and synthesize data models, computational models, and visualization models, aimed at carrying out simulations and what-if explorations of society.

Novel technology is needed that will provide the right abstractions for scientists to define new models from scratch and compose new, more complex models from existing models. The scientists will be able to link models to other models, to data sources, and to experiments that enable what-if analytics and help validate these models. In addition to the structure of a model (e.g., a set of mathematical formulae), scientists must be able to define the model interfaces (e.g., parameters of the model and their semantics) and rules that specify the assumptions of the model and how it can be composed.

New techniques are needed to integrate different types of models - ODEs from dynamical systems, PDEs and agent based models - as well as ways to aggregate results from these models at different scales. Along the lines of integrated assessment models. Link individual models into a system framework which will allow for qualitative analysis and assessment which are most suited to policy decision making.

3.1.1.1 Agent Based Models

Doyne Farmer

Agent-based models (ABMs) are a natural tool for simulating social systems. In comparison to econometric models or the DSGE models of mainstream economics, which are formulated in terms of aggregate quantities, agent-based modelling is done at a microscopic level. Agent-based models operate at the level of individuals, who can be householders, decision makers at firms, or government regulators. Agent-based models make use of computer power to represent as many different agents as are needed. They do not rely on complex mathematical derivations or closed form solutions. This makes it easy to implement nonlinear behaviorwithout restrictions on the degree of realism. The use of agent-based models makes it possible to build an economy from the bottom up, incorporating as much realism as is needed in each of the individual components.

In recent years behavioural economists have made great strides in understanding how real people behave in economic contexts. Agent-based modelling works hand-in-hand with behavioural economics, incorporating its insights to model the decision-making of agents, and using the power of the computer to simulate their behaviorin complex interacting coupled networks, to keep track of their interactions through their consumption, production, budgets, borrowing, lending, flows of goods and services, investment, trading, etc.

Perhaps the greatest strength of the ABM approach is that it is possible to realistically model institutions, such as households, firms or banks. One can build in as much realism as is needed. Indeed a key challenge can be to keep things simple enough to keep the models tractable and understandable.

Another great virtue of ABM is the ease with which it is possible to perform regulatory studies. Regulatory rules are easily incorporated into computer programs, even when they are complex, and they are easily modified to test different policy regimes. It is also possible to study counterfactual situations in order to determine cause and effect relationships. So, for example, in a recent ABM model of the housing market, it was trivial to ask, “What would have happened to the Washington DC housing market if lending policy had remained unchanged during the first decade of the 21st century?”. (The answer was that the housing bubble would have almost entirely been suppressed).
In economics agent-based modelling has so far been used primarily as a qualitative tool. GSS will take ABM in economics to the next stage, making much more realistic and quantitatively accurate models. This should occur in several ways. The limiting factor in any ABM is the realism of the decision making rules of the agents. GSS can improve ABMs by funding work that makes it possible to calibrate better

decision rules. This can be done in several ways, for example through (1) social experiments, in which real people are put in situations where they must make decisions and their responses are measured; (2) gathering micro-data about how real people behave; (3) collecting data from game situations that mimic real-world situations; (4) Pushing on ABM researchers to make their models more quantitative. Once this is done ABMs have the potential to become a central decision making tool in economics.

Zofia Lukszo, Igor Nikolic and Gerard P.J. Dijkema;

When investigating global large-scale socio-technical systems it is clear that both the real-time performance and long-term evolution are shaped by a myriad of actors, with none of them being in position to control the whole system. Moreover, the ensuing interactions and interdependencies entail new, unknown and possibly unacceptable risks, which add an extra dimension to the system's complexity.

Rather than focusing on specific system components or subsystems, our efforts should be aimed at understanding and steering the structure and behaviorof the system as a whole. The system representation should not be confined to technological aspects but should also address the social dimension, seeking to capture the behaviorof different actors in decision-making, in competing or in co-operating and negotiating. The concept of agent-based systems, composed of multiple interacting actors and physical elements, is a promising modelling approach that can simulate how system behavioremerges from the behaviorof actors at the bottom level.

With the assumption that we can indeed capture the behaviorof real actors, Agent-Based Models allow us to observe how the technical and social subsystems of large-scale systems co-evolve, and which overall system behaviormight emerge from their ongoing interactions, at multiple system levels and time scales. The importance of these simulations is that they can also help to answer the question of what a “better” system might be. Systems can be improved in a variety of ways, the appreciation of which is strongly dependent on the perspective of the decision maker. Generally speaking, in the day-to-day operation, improvement is concerned with system performance, including efficiency and effectiveness. Over a longer time frame, systems also need to be robust and resilient. They need to be responsive, flexible and adaptable, too. Negative external effects manifest themselves on a variety of spatial and time scales. Socio-economic effects ripple through intensively interconnected social systems, financial markets, international supply chains, geopolitics etc. Hence, we must accept the fact that there are no easy, isolated solutions or quick fixes; there is much to be learned. Agent-Based Models contribute to the process of learning and thereby to finding more complex answers.

Agent-Based Modelling is a category of advanced modelling and simulation tools particulary relevant for cross-sectoral and inter-disciplinary research on complex global systems exhibiting both technical and social (multi-actor) complexity. In Agent-Based Modelling, an agent is the software representation of some entity that completes an action or takes a decision, by which it effectively interacts with its environment. At the highest level of granularity, an agent may represent a single decision maker, e.g. a consumer. Beyond this level of granularity, an agent may represent an organisation, for example an electric utility company deciding to build a new nuclear plant or a government deciding on new policy and policy instruments. The agent pardigm aligns with the concept of systems composed of multiple interacting social entities and technical subsystems. The system behavioris the overall observable sum of the agents' actions and state changes. It is an emergent property caused by the interaction of the internal, local and environmental states and the decision rules.

Agent-Based Modelling and Simulation is the premier candidate with which to model socio-technical global systems and explore how structural and behavioural change enfold ensuing from the interactions between agents within and between the social and the technical subsystems. Agent-Based Models thus allow us to complete rich ex-ante analyses of the possible outcomes of different parameter settings, e.g. different policies and elucidating system characteristics before creating the real system. This is particularly advantageous when systems are developed over the course of years of decades, or when the risk associated with incorrect operational decisions are large, e.g. in terms of loss capital or even lives.

The use of Agent-Based Modelling and Simulation has been explored by many researchers from the Energy and Industry Section at the Technology, Policy and Management Department of the Delft University of Technology, the Netherlands. In previous and on-going studies at the TU Delft, the Agent-based modelling and simulation platform has evolved so that new simulation models can re-use building blocks from previous studies. An Agent-Based Model allows one to simulate the operation, dynamics, evolution and growth of a system and therefore help us to understand a system's complexity.

3.1.1.2 Social Simulation & computational social science

Ciro Cattuto

The approach to monitoring, measuring, and dealing with collective phenomena in social systems has been rapidly evolving under the pressure of two main drivers: 1) the end of linear thinking brought forth by the maturity of complex system science applied to socio-technical systems, and 2) the ability to monitor and quantify human behaviours at unprecedented levels of resolution and scale, unleashed by the planetary-scale adoption of the World Wide Web, mobile communication technologies, e-commerce systems, and on-line social networks. The latter technologies and platforms, in particular, are just starting to display their full transformative power on society. Historically speaking, the current level of interconnectedness of society is a sudden event with no precedents, and its inception is forcing change in the way organizations think about society and deal with societal phenomena, both in the public and in the private sectors.

Data-driven computational models are increasingly emerging as the new appropriate tools to face the study of complex social phenomena, whose phenomenology is no longer established only by controlled experiments on small communities, but with increasing importance by data-mining larger and larger collections of digital traces of human behaviorat the organizational, urban o geographic scale.

The discourse on hyper-connected ICT-mediated social systems, however, has been primarily focused on the transformative power that these processes have had or are having on known social processes, and to a lesser extent on the novel types of social phenomena that may emerge because of the new connectedness of individuals. Such new connectedness occurs at the spatial scale of entire countries and at the temporal scale of seconds. In specific domains, such as finance and marketing, the emergence of a new phenomenology has been acknowledged already. Marketing had to come to terms with a new dynamics of popularity that is driven by social media, on-line social networks, bottom-up generation and amplification of memes, networked customer communities as new actors, and adversarial information diffusion campaigns.

This is a process that is still unfolding: smartphones and wearable devices are tearing down the digital-physical barrier, creating simultaneously the ability to digitally track the state, location, and preferences of a large number of individuals, and at the same time enormously empowering the capability of those people to be networked, to be informed in a timely fashion, and to act accordingly, both at the individual and at the collective scale. The full societal potential of citizens empowered by smartphones, wearable sensors, augmented-reality devices, and all sorts of real-time participatory platforms is still dawning. Several efforts are starting to recruit these emerging capabilities to develop new societal functions such as citizen science, participatory surveillance of diseases, participatory mapping of pollution, games with a purpose, and so on. These efforts are however largely engineered in a top-down fashion, by designing incentives at the microscopic level, by leveraging mass media, or by deploying them in specific and compelling contexts like an emergency situation. As the barrier between the digital and the physical vanishes, the door is open for the emergence of yet to be seen social phenomena that may effectively create new “actors” organizations and governments will have to deal with, both in the digital and physical spaces. An early example of this is Anonymous, whose nature and behaviordefy simple interpretations, and whose actions – nevertheless – have been shown capable of global outreach. Other examples include the social uprising mediated by social media that was observed during the recent Egyptian political crisis. Whereas the exact role of social media such as Twitter has not been fully assessed yet, it is clear that real-time connectivity enables crowds and communities with previously unseen capabilities of coordination and collective action. The most recent example is the self-organized manhunt that emerged in the popular on-line social network Reddit during the aftermath of the Boston bombings and resulted in very negative consequences for innocent parties.

The above scenarios call for new insights into emerging social phenomena in hyper-connected social systems, that can properly account for complex factors and processes such as information diffusion driven by the combination of mass-media, word of mouth and social media, the emergence and role of influencers, the bursty focusing on collective attention on specific issues, organizations or individuals. Assessing the degree of controllability or manipulability of ICT-enabled social systems, for example, by coordinated injection of misinformation by influencers, is also an important fundamental challenge that needs to be tackled in order to guarantee the safety of citizens and the correct operation of democratic institutions. Reasoning about these global challenges calls for extensive data-driven social simulation and has a potentially strong impact on the relevant institutional stakeholders and the corresponding policy frameworks. This is an effort that encompasses research areas such as agent-based methods for social simulation or socio-physics, because it needs to be strongly data-driven, it needs to provide interpretation keys that are transparent to policy makers, and it needs to be validated at scale during real-world scenarios unfolding in real time. In summary, the global systems science vision applied to social systems points to data-driven investigation that take the move from computational social science and focus on decision making and risk management of social phenomena at the global scale.

3.1.1.3 Formal Languages

David Pearce

We describe several aspects of Global Systems Science where logic and logic-based languages can play a key role in the construction, description, comparison and presentation of theories and reasoning about them.

1. *Logic-based policy languages*.

Several aspects of GSS are “human-centred”, not or not merely in the sense that humans are the objects of study (though they may well be), but very broadly speaking in the sense that scientific inquiry is guided by human concerns and socially relevant challenges. One further aspect of this is the idea that policies and policy makers must somehow be integrated within system models, and that the link to policy and decision makers must be itself a part of the scientific enterprise.

We may think of a policy as a principle or rule to guide decisions. It can be seen as either a statement of intent or a commitment. However, a policy does not usually compel or prohibit actions by itself. Policies may be specified as procedures or protocols and can be adopted by organisations, groups or individuals. Since policies are rules they may be expressed in a rule-like, logical language. Reasoning with policies involves reasoning about defaults, exceptions, norms and typicality. That is, the type of reasoning required is non-monotonic. It is often important to compare two or more policies in a logical manner, for instance to examine whether one policy is stronger than another, subsumes another or is equivalent to another, under specified circumstances. These are logical concepts and can be reconstructed and studied with logical methods. Several other logical questions arise naturally. For example, we may ask whether a set of policy rules is consistent either locally or in a specific, broader context. Or, given some informal specification of a policy we may ask whether a set of formal rules correctly characterises it.

Languages like Answer Set Programming (ASP, see eg Gerbser et al (2012)), and other non-monotonic reasoning systems, are well suited to represent defaults, typicalities and exceptions and to deal with non-determinism. They can also formalize different kinds of abduction and they are already applied in reconstructing policies, e.g. in the area of security (see eg Bonatti (2011)). They can be combined with ontology languages and other logics for reconstructing knowledge (databases, KBS etc.). In GSS, logic languages can play a similar role in expressing and reasoning about policies. In addition to connecting with traditional knowledge bases, these languages would have to link to the mathematical models used in the GSS applications in question. In principle this should not be a barrier, however. In the case of ASP, for example, as there are several techniques for interfacing with external knowledge sources. Some of these techniques are implemented and already used for instance in business applications (see eg http://www.kr.tuwien.ac.at/research/systems/dlvhex/index.html).

Languages of an ASP kind can therefore integrate policy rules and knowledge sources within a single computational system. An important feature of this approach to computation is that it is problem-oriented and model-based (in the sense of logical models): it directly presents solutions to practical problems based on logical models (answer sets) that embody the solution in a direct manner. Moreover, in typical applications the problems in question may involve diagnosis, explanation, planning, actions and temporal reasoning, in other words many problems of a kind that can be relevant for policies and decision making in a GSS context. For example it means that actions and plans can be integral features of the computational system that combines GS knowledge with policies.

2. *Logic-based languages for specification and verification*.

One of challenges for GSS expressed in the GSDP project is the need for efficient and transparent means for specification and for the effective verification of computational models. Logic-based languages such as logic and constraint logic programming and newer variants such as ASP are well-equipped in this respect and are well-suited to deal with specifications and verificational aspects. Experience suggests that these and other related challenges may be addressed by designing domain-specific languages that may be used, for instance, for implementing socio-economic and agent-based models. One of the options explored in GSDP is to focus on languages based on dependent type theory, itself derived from a logical approach known as constructive type theory (CTT). DSLs may be valuable not only as a programming environment for implementing mathematical models, but also for the science-policy interface discussed above. Within what we may broadly call the theory of action, logicians have studied many kinds of speech acts and developed logical formalisms that may be highly relevant here. Moreover aspects of social ontology and the structure of institutional concepts are already being logically reconstructed and implemented in socially-oriented, logic-based languages. Such high-level languages that deal with institutional and social relations of empowerment, permission, obligation and trust may provide an ideal, logical-based approach to DSLs for the GSS-policy interface.

3. *Logical concepts for modularity*.

A related issue raised by the GSDP project is how to improve comparability and modularity of models. Agent-based models have been singled out in particular, however modularity is a key issue in any large knowledge building enterprise. It forms part of a wider problem of how to formulate and analyse inter-theoretic relations and it is especially acute in areas that cross different domains where theories and models are combined from different disciplines. The concepts and tools of intertheory relations are typically logical ones and they are used in many knowledge-rich, computational areas such as Answer Set Programming, the construction, matching and merging of ontologies, in agreement technologies, and so forth. Key logical notions include separability, reduction, equivalence, modularity, translation, interpretability, synonymy and others. A crucial problem in GSS is that global challenges may involve multiple, interacting networks some of which use similar concepts but possibly defined, measured or characterised in different ways. This raises logical questions about whether translation from one conceptual framework to another is feasible, or whether data analyzed within one framework can be re-used within another. In general there remain many open issues about how information can be reliably extracted from multiple interacting networks, each with its own set of concepts and data types.

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3.1.2 Big Data for GSS

The Role of Big data and High Performance Computing in the Global System Science Program

Christopher L. Barrett, Ralph Dum, Devdatt Dubhashi, Madhav V. Marathe

1 Introduction

In today's world, human behaviour, social networks, and civil infrastructures are closely intertwined. Coupled social, technical, informational and organizational systems or STIOs do not stand-alone. They consist of many interacting physical, technological, and human or societal components and are spatially distributed, managed by different federal, state, or commercial entities and operate at multiple time scales. Examples of such systems include regional transportation systems, regional electric power markets and grids, the Internet, ad-hoc telecommunication, communication and computing systems, content delivery networks, social networks, search networks and public health services. What all of these systems have in common is that they are networked individual agents or components interact only with a specified set of components. The links in such networks can be physically real or a matter of convention such as those imposed by law or social norms, depending on the specific system being represented. Thus coupled STIO networks consist of one or more social networks interacting with underlying technological and physical networks.

Our focus here is on global system science, defined provisionally (cite) as follows: *Global Systems Science develops know-how about global systems like the Internet, the worldwide system of cities and many more by combining algorithmic machines with concepts from game theory and a sensitivity to narratives.*

In other words, global systems can be viewed naturally as global-scale coupled STIO networks. It is important to note that global systems as defined not only have a global footprint, but also comprise of multiple systems that span the social, political, geographical and technological domains. Today's Internet and interconnected cities constitute excellent examples of global systems. In addition, systems built on top of these systems constitute examples of global systems as well. We will give two important examples that illustrate the key aspects. The first is system of systems that includes a global multi-modal transport network that connects cities and comprising of airline networks, road networks, waterways, a logistical system built on top of the transport network and aids the flow of individuals, goods and information and business networks that build on top of these networks and support trade and commerce between individuals, organizations and countries.

A second example is hierarchy of networks built on top of the Internet that really comprises of the routers and cables that are connected together to move digital information across the globe. Content management and distribution networks such as the one built by Akamai ride on the top of the basic Internet and allow efficient, mirroring, caching and distribution of content. On top of this, we have the World wide web that comprises of billions or even trillions of web-pages that are linked together using hyperlinks. Services such as Google, Bing, etc, provide services over the WWW. We then have networks such as Facebook, Myspace, Twitter, Foursquare and Linkedin that provide services to support online social networks. We also have informatic platforms such as Ebay, Amazon etc. that have built various forms of commerce over the lower layers. Finally, we have systems such as Amazon Turks etc, that provide online labour markets. The two examples amply illustrate the key components of GSS: global reach and system of systems.

The system of systems are not necessarily hierarchical, but are connected in complex ways themselves.

In this white paper, we focus on the role of Big Data and High Performance Computing in developing the science and engineering of global systems. We will primarily focus on a synergistic view in which the need for developing the scientific and engineering principles of global systems presents new challenges for Big Data and HPC. Conversely, the availability of Big data and HPC fundamentally change the form and shape of scientific investigations pertaining to the study of global systems. This close interplay between the three topics is the primary focus of the white paper. It is important to note that BigData and HPC are enabling and transformative technologies; furthermore they are evolving and are shaped by new and emerging applications in various spheres of life.

2 BigData

Michael Jordan starts his presidential address to the Bayesian Society [4] with the words: "The era of Big Data is upon us.". In their new book Big Data: A Revolution that will transform the way we live, work and think, Mayer–Scönberger and Cukier write:

The benefits to society will be myriad as big data becomes part of the solution to pressing global problems like addressing climate change, eradicating disease and fostering good governance and economic development.

See also McKinsey's report Big data: The next frontier for innovation, competition, and productivity. Large data problems now come from many disciplines. Examples are NEON (National Ecological Observatory Network), a project of the National Science Foundation, and GBIF (Global Biodiversity Information Facility), an international effort to digitize all information about all living species (estimated number: between 2 and 10 million).

The intelligence community has been dealing with big data questions for some time; the Department of Homeland Security tries to do so. The financial sector grapples with huge amounts of data. Just about every U.S. federal agency that funds science currently supports at least one major national initiative on data. Announcing a $ 200 million R&D initiative in big data in March 2012, the White

House described the program as a way to enhance ”our ability to extract knowledge and insights from large and complex collections of digital data.”

Defining aspects of “Big Data” As enunciated by Fred Roberts, Director Emeritus of DIMACS and member of the SIAM Committee on Science Policy at a recent meeting[6], “Big Data” refers to a combination of the following aspects:

Volume: The size of data being generated from various sources is today estimated in thousands of exabytes [6]

Velocity: Much of this data is generated dynamically and often needs to be processed in real time.

Heterogeneity: Data is of different types - text, audio, video etc.

Unstructured: It is unstructured unlike traditional relational databases.

Complexity: Data is complex and multi-dimensional.
Store Query Search: How do you store, query, and search data when there’s so much of it?

Security Privacy: How can you trust the data you have? How do you define “trust”? Social media data is an example – can Twitter and Facebook data be considered accurate?

Analytics You would like to make inferences and hypotheses from large amounts of data. How do you do that?

Big data technologies: Technologies associated with big data can be classified into: (i) storage and computing technologies, (ii) data management technologies, (iii) data and visual analytics, and (iv) data representation methods. The emerging and popular technologies for each of the components is discussed in the Appendix.

3 High Performance Computing

Computing technologies are undergoing a rapid change to support the emergence of Big Data and the continual need to develop realistic complex models, business applications in physical, social and economics domains, e.g. oil exploration, algorithmic trading, online social media, etc. Peta-scale systems have already established a foothold. In the US National laboratories and select NSF funded HPC centers e.g. NCSA have already acquired and tested computing systems providing sustained peta-scale performance. The next big goal is Exascale computing. Blue prints and road maps for this have already been prepared. Exascale computing provides three orders of magnitude performance improvement over peta-scale systems. It is widely expected that technological, physical considerations will lead to Exascale systems that are likely to quite different than peta-scale systems. First, each node will have between a thousand and million cores. An important concept being

[6] http://www.siam.org/news/news.php?id=2059

investigated is that of co-design. Finally, probabilistic and fault tolerant computing paradigms will become an essential feature – see [9] for a detailed discussion on this topic.

At the other end of the spectrum are clouds, grids and other loosely-coupled computing and data management architectures. A new emerging trend is mobile cloud, cloud-like environments composed of millions of mobile computing and communication devices such as cell-phones. Companies such as Apple, Google and Amazon provide services now that allow user a pervasive access to data and services using such environments.

A third emerging trend are embedded sensors. They exists in cars, cell phones and virtually all of the appliances and gadgets. These sensors are becoming smarter and many of them are hooked to the web via a radio device. They also possess a fair amount of computing power. For e.g. today's smart phones are much more than a phone but sensing and a computing device.

3.1 Putting this together

When you take all of these trends together, one starts to see that Wieser's pervasive and ubiquitous computing vision is turning into a reality. Pervasive computing that allows anytime, anywhere and anydevice computing and communication.

These advances imply that we as humans are creating a socially-embedded cyber physical computing, communication and information system – this is a network of smart devices embedded in the society and in the physical world.

This has two highly important ramifications:

1. First, humans are an integral part of the global computing and information processing network; not only they consume the services but are in fact computing themselves and providing the computed results to other humans. In other words, we are moving towards a natural and artificial computing and information ecology. Crowdsourcing is an example of this phenomenon.
2. Second, Big Data is now an integral part of this vision and in fact we think a better term is Big Information or Big Knowledge. These pervasive socially-embedded systems will produce enormous amounts of data and information, that will be constantly processed refined and analyzed. This trend towards social sensing and computing will lead to an exponential growth in the amount of data that is created and will need to be processed.

3.2 The Role of HPC and Big-Data in Supporting GSS and Policy Making

Point 1: Scaling and effective Utilization of Supercomputing resources: *Scaling to large machines and large instances so as to complete the computations in a reasonable amount of time is necessary and now feasible.*

Supercomputing resources will be critical for modeling global scale systems at detailed spatial, temporal and individual level. A simple back of the envelope calculation suggests that an individual-based representation of such global scale networks will to have 109 agents, with 1011 edges. Structural analysis of these networks as well as dynamics over such networks motivates the use of current and emerging Supercompuing resources. Developing models that can effectively use Supercomputing platforms is challenging. The networks are highly irregular, dynamic and co-evolving. The emerging peta-scale and the future exa-scale computing platforms will have 1 Million - 100 Million+ cores. See [9, 11] for further details.

As an example of recent progress, we just completed a paper to Supercomputing that shows for the first time how social simulations (we did this for epidemics in the paper) can be mapped onto machines with over 300; 000 cores. This is the largest open machine in the US at NCSA. We can now run a single run of epidemic simulation (200 days) for entire US in about 5 minutes. The network has 300 million nodes and 15 Billion+ edges. Scaling such as this will become critical as we move to developing detailed models for GSS. The scaling we are getting to process structural properties (not dynamics) is even better. Our goal is to have models that scale to 10 Billion node networks in about three years. This will get us ready for addressing the important questions raised in the GSS program and support real-time policy making.

Point 2: HPC-enabled methods for immersive user interaction: *Social, behavioural and economic scientists have traditionally not used HPC resources to solve the computational problems arising in their domain. We thus need effective ways for them to use and interact these models without becoming computing experts.*

The overwhelming use of HPC resources thus far has been to study physical problems. Social, behavioural, economic (SBE) sciences have traditionally not used HPC resources in this work. Use of HPC resources by SBE scientists thus requires development of easy to use visual interactive technologies. Several groups have begun to develop such technologies. There are several issues pertaining to this: (i) system response, (ii) simplicity of the UI, (iii) ability to navigate vast amounts of data and information in a meaningful way. The work falls under a broad emerging area called Web Science. It combines traditional areas of data and visual analytics with distributed computing systems. As an example, In a recent article Dean and Barroso [10] have persuasively argued that Software techniques that tolerate latency variability are vital to building responsive large-scale Web services. In [22] the authors argue that systems that respond to user actions quickly (within 100ms) feel more fluid and natural to users than those that take longer. This is only aspect of building such systems.

Point 3: HPC-enabled methods for data analytics: *The kinds of models that we would like to develop for the GSS should be driven by a combination of data and appropriate theories. Data here is meant to refer to classical use of data but also procedural information in the form of laws, behaviours and policies, as well as networked relationships that capture interactions, causality and dependencies. HPC methods are therefore needed to process these data sets to prepare them for ingestion by dynamic models. The resulting data all of which is really a part of the synthetic information should also be processed to identify important patterns, trends, anomalies, etc.*

HPC hardware and methods for this are often quite different than the traditional clusters used to run large models. A recent trend is the concept of data intensive supercomputing. The new model of computation differs from traditional models of computing in that producing, analyzing, processing and curating data are integral parts of the computation. Big Data is a related concept and focuses on related concepts, including analytics and reasoning. We have recently proposed the concept of ”network centric computing” that extends these ideas. It melds the traditional data and compute intensive approaches and also highlights the role of networked data. In network intensive computing, HPC resources are used to compute about and over networks; moreover the computation requires significant amount of data to synthesize the networks as well as significant computing to process these networks. See [21, 1, 4].

Point 4: Massively Distributed Data collection and Computing*: Crowdsourcing, pervasive availability of devices and sensor systems all point to the need for a different notion of HPC. In this view we are talking about highly distributed, fault tolerant, spatially distributed, bursty data and computation. To support citizen politics and decision making as well as real-time data gathering, this form of computing will become all the more important in the coming years.*

Crowdsourcing of computation can occur at various levels – from simple collection and dissemination of information and data to active computation in which humans are a part of a distributed computing process; see See [13, 14, 15] for additional information. Crowdsourcing has played an important role in policy making and citizen science already. The role of social media and crowd-sourced methods was evident most notably during the recent social revolutions in the middle east under the rubric of Arab Spring. Some (non-exhaustive) examples include:

1. Citizen science projects e.g. the ornithology http://www2.dnr.cornell.edu/citizenscience/dickinson/Citizen_Science.html; and astrophysics projects, http://www.galaxyzoo.org/ and Foldit http://fold.it/portal/;

2. Public participation in planning and civics: crowd-sourcing grassroots anti-corruption drives e.g. http://www.ipaidabribe.com/, Brabham [21], Aitamurto et al. [18, 17];

3. Online labour markets e.g. Amazon Turks.

Crowdsourcing and technologies to support can play an integral role in the overall GSS program: (i) they can provide an important source of near real-time information, (ii) they can be involved in active computation process and (iii) the technologies can be very useful in framing and assessment of policies. Developing such technologies is an ongoing research direction. The continual progress in socially-embedded cyber physical computing, communicating and information systems (SECPCI) will present new challenges and opportunities. We list some of the important topical areas below:

1. Distributed and Real-time Decision Making

1. Real-time data driven decision making. The availability of data at very fine scales (temporal, spatial, social) is prompting individuals, groups and organizations to develop real-time decision making abilities. This includes, rapid changes in how resources are brought to bear

on a problem, interventions that are analyzed and enacted to reduce the severity of the problem, etc. Of course the time scales at which policy making has been done in the past is quite different. But one already seems glimpses of this. Examples include response to market crashes, pandemics, natural disasters, etc. Of course this creates a tension between the expectation of the public at large and businesses, governments and institutions. Decision making in such setting is always done with incomplete information and the system is co-evolving with the decisions. Thus appropriateness of decisions will be questioned; e.g. was the response to H1N1 pandemic too slow or too fast, was the response too aggressive, was the response to the volcanic eruption over Finland too slow, etc. Global System science will need to address how to make faster decisions, how to analyze the massive amounts of data and study the possible counter factual and how to convey these decisions to the public.

2. Empowering citizens to be decision makers. An important outcome of SECPCI is that individuals, small communities and organizations can participate in the entire decision making process in a manner that was not possible earlier. This changes the dynamics of global systems which were traditionally managed by centralized and hierarchical authorities. GSS will need to address and develop protocols and information sharing schemes for networked decision making. This includes methods for allowing individuals to convey their preferences, thoughts, votes and ideas to traditional decision makers. It also includes the need for methods to make information related to the event available to individual decision makers; creating online tools for them to effectively interact with other individuals.

2. Exascale-enabled global systems modeling

1. Supporting real-time and distributed decision making will require the development of innovative computational techniques to simulate global system of systems. Dynamical processes over networks that represent such systems of systems are hard to simulate. The networks are irregular, time-varying and extremely large. Moreover, the dynamical processes are such that renormalization techniques do not seem to be possible to obtain dimensionality reduction. As a result explicit interaction-based simulations over networks with 107□11 nodes and 109□14 edges remains a challenge.
2. Another challenge pertains to developing interactive simulations – simulations that can ingest incoming data and also provide the analyst an opportunity to try out new decisions based on the information available from the model as well as the real world. Interactivity implies that simulations such as these should be able to start and stop.
3. Sensitivity analysis and Uncertainty quantification over these inherently stochastic systems presents another challenge for HPC and Big Data. It requires new research in adaptive and sequential designs and ability to manage multiple replicates effectively over large computing systems.

(References in Section 8)

4 Appendix

4.1 Global Contagions Over Co-evolving Networks: A Genuine GSS Challenge

Contagion is used here broadly to mean transmitted phenomena such as diseases, opinions, fads, trends, norms, packet diffusion, worm propagation in computer networks, database replication in sensor networks, spread of social movements, and influence among peers to purchase music videos or go to movies [28, 34, 31, 30, 39, 34, 29, 26]. The spread of contagions across a national population is a well known complex problem, and includes: (i) pandemics, such as H1N1 and swine influenza outbreaks in recent years, in which the spread of the flu virus is often modelled by stochastic processes, such as the SIR process [36, 35, 33], (ii) spread of information on online social media, such as Twitter and Facebook [37], which are often modelled by stochastic and threshold based models [41], and (iii) the 2003 blackout in Northeastern U.S., and the cascading effects on traffic, communication, and other infrastructures that cost $6 billion [32]. A key observation from numerous studies shows that the underlying network structure has a significant impact on the dynamics [38, 42], and as in the case of the 2003 blackout, this could span multiple networks [27].

1. Often the size and scale of these systems is extremely large (e.g., pandemic planning at a global scale requires models with 6 billion agents). Further, the networks are highly unstructured and the computations involve complicated dependencies, leading to high communication cost and making standard techniques of load balancing and synchronization ineffective.
2. Individuals are not identical – this implies that models of individual behavioural representation cannot be identical. Behaviordepends on individual demographic attributes and the interactions with neighbours [28, 40].
3. The contagion, the underlying interaction network (consisting of both human and technical elements), the public policies and the individual agent behaviours co-evolve making it nearly impossible to apply standard model reduction techniques that are successfully used to study physical systems. For instance, in the case of epidemics, as the disease spreads, people cut down their interactions, thereby sparsifying the network, which in turns slows the disease dynamics.
4. Finally, in many cases as we discuss below, we are faced with modeling multiple networks that are coupled, with possibly multiple contagions evolving in each network.

Policy making for these large complex systems involves very large counter-factual experiments. Moreover, the time to solution is important as well. This makes the problems challenging from a computational perspective. From a policy perspective, global scale contagion processes pose very interesting challenges. Two important examples: (i) allocating/sharing scarce pharmaceutical resource among countries to control the pandemic, social distancing measures such as reduced travel, and overuse of antibiotics and resurgence of certain diseases such as TB in a number of developing nations; (ii) cyber-attacks, cyber espionage and
more broadly use of the Internet to promote, control and manipulate individuals and resources in another country.

4.2. Big data Technologies

1. Storage and computing technologies:

   A NoSQL database provides a mechanism for storage and retrieval of data that use looser consistency models than traditional relational databases in order to achieve horizontal scaling and higher availability. NoSQL database systems are often highly optimized for retrieval and appending operations and often offer little functionality beyond record storage (e.g. keyvalue stores). The reduced run-time flexibility compared to full SQL systems is compensated by marked gains in scalability and performance for certain data models.There are a large number of such technologies today, for example Apache Cassandra, Hbase and Google's BigTable.

   Cloud Computing :The ubiquitous availability of high-capacity networks, low-cost computers and storage devices as well as the widespread adoption of hardware virtualization, service-oriented architecture, autonomic, and utility computing have led to a tremendous growth in cloud computing. There is increasing momentum to shift to an approach that takes the computation to the data rather than the reverse. Amazon's EC2 is a popular commercial service, there are also increasing open cloud initiatives.

   Domain Specific Languages Another approach to scaling up methods to big data using the power of modern heterogeneous computer architecture is represented by Stanford's Pervasive Parallelism laboratory[7] through domain-specific languages (DSLs). The idea is to use a layered system based on DSLs, a common parallel compiler and runtime infrastructure, and an underlying architecture that provides efficient mechanisms for communication, synchronization, and performance monitoring.

   Google has introduced a scalable infrastructure, named Pregel, to mine a wide range of graphs. In Pregel, programs are expressed as a sequence of iterations. In each iteration, a vertex can, independently of other vertices, receive messages sent to it in the previous iteration, send messages to other vertices, modify its own and its outgoing edges' states, and mutate the graph's topology.

   GraphLab[8] *is* a graph-based, high performance, distributed computation framework written in C++. While GraphLab was originally developed for Machine Learning tasks, it has found great success at a broad range of other data-mining tasks. It has an optimized C++ execution engine that leverages extensive multi-threading and asynchronous IO, allows access to r data directly from HDFS and has a suit of powerful Machine Learning toolkits.

   Apache Mahout[9] is an Apache project to produce free implementations of distributed or otherwise scalable machine learning algorithms on the Hadoop platform.

2. Data Management technologies.

   An active area of research is to develop highly scalable frameworks that can exploit modern

[7] http://ppl.stanford.edu/main/index.html
[8] graphlab.org
[9] mahout.apache.org

parallel, distributed and heterogeneous computing architectures [1] Apache Hadoop is an open-source software framework that supports data-intensive distributed applications, licensed under the Apache v2 license. It supports the running of applications on large clusters of commodity hardware. Hadoop implements Google's MapReduce where the application is divided into many small fragments of work, each of which may be executed or re-executed on any node in the cluster. In addition, it provides a distributed file system that stores data on the compute nodes, providing very high aggregate bandwidth across the cluster.

Hadoop Yarn and Storm. It has been widely recognized that MapReduce by itself, isnt sufficient for a very wide variety of use-cases. YARN, is the next generating Hadoop framework for generic resource-management and distributed applications. Similar to how Hadoop provides a set of general primitives for doing batch processing, Storm provides a set of general primitives for stream/micro-batch processing. Storm is being integrated into Hadoop YARN for resource management. Storm-on-YARN enables Storm applications to utilize the computational resources on tens of thousands of Hadoop computation nodes.

3. Big Data Analytics

Machine Learning and Algorithmic Statistics. There have been striking development of new techniques in response to the challenges associated with datasets of massive size and dimensionality, including settings where the dimensionality of the data is growing faster than the number of data points, the so–called p >> n problem.These developments have occurred at the intersection of traditionally three different fields: algorithms, probability and statistics and optimization [2]. Sophisticated new probabilistic models are now developed in the framework of probabilistic graphical models [5] and the resulting inference and learning problems are now solvable on a large scale due to new methods for convex optimization [3]. Algorithmic techniques include sketching, random projections and hashing, large-scale online learning, and parallel learning.

Visual Analytics Massive and complex multidimensional data necessitates new approaches to visualization and representation of data that allow users to understand the data, the analyses of the data, and the potential new information models. A further challenge is to represent streaming data and temporal changes to streaming data where no records are or can be kept.

4. Data Representations

Synthetic populations are artificially created populations that are tailored for particular purposes of study and spatio–temporal context, which are statistically accurate representations of the real population. Approaches based on synthetic population resources coupled with very large scale agent based simulations on high performance computing systems have been a very successful tool in addressing socially–coupled systems in transport, public health and city planning. An advantage of synthetic populations is that they ensure anonymity and privacy while yielding similar aggregate answers, and that they are a means of aggregating information from disparate sources such as census studies, geo–spatial maps, social network data etc.

Borderless data-driven decision making

Leo Camiciotti and Ciro Cattuto

The world is experiencing an unprecedented and accelerating socio-economical connectedness driven by technological and political changes. As a consequence, the unavoidable challenge of this era is to discover, to manage and to exploit complexity in order to advance knowledge, to enable informed decision and policy making and to foster a sustainable global growth. Taking up this challenge demands a shared research vision and policy-making effort, that defines the core scope of "Global Systems Science".

Complex systems are by definition global. Single components, decisions, actions and behaviours are tightly intertwined worldwide and therefore they cross borders between disciplines, sectors and policies. A global awareness is mandatory in order to prevent risks, to avoid unintended effects and to exploit emergent opportunities. This can be achieved by fostering cross-discipline research and by promoting collaborations among apparently uncorrelated sectors.

A borderless approach will allow leveraging the "Big Data" revolution. Indeed a "mirror world" is being created every day by digital traces produced by humans and machines in every field of activity. As a consequence, fragments of potential knowledge are scattered in the digital data landscape: a core technical and scientific challenge is to process these pieces of information, interlink them, and create meaningful information mosaics by mastering digital input from sensors, infrastructures and traces of human actions.

In order to achieve this vision a new category of data researchers and practitioners is strongly needed: the data scientists. The Data scientist ideally must be able to master both the knowledge on data (statistics, data mining, machine learning, modeling), the techniques to process data (scalable computational infrastructures, programming languages and frameworks, APIs, a host of vertical data analysis tools) and the languages to communicate data (visualization, narratives), so that they can support the development of a full pipeline from data to evidence-based and model-based global decisions.

The Data Scientists, able to mix an empirical, theoretical and action-oriented approach will need a dedicated education, positioned in the value-adding zone that links universities, scientific institutions, public organizations, startups and corporations. By acquiring new skills, through traditional and online courses, and by tackling real datasets and problems the "new" scientists will be the "smart connection" between knowledge and impact, capable to foster socio-economical growth and to support the creation of sustainable development paradigms and the deployment of smart data-driven processes.

"Global Systems Science" can turn this sought paradigm shift into reality.

A borderless and data-driven approach will establish the added value link between knowledge and impact, enabling scientific discoveries to support meaningful policy making and to produce tangible effect at global social level.

Big data challenges and opportunities in the energy sector

Chris B. Davis and Gerard P.J. Dijkema;

The energy sector is rapidly changing as new technologies are being deployed which are starting to have fundamental impacts on the nature of energy supply and demand. Many of these new technologies aim to make the grid more intelligent, responsive and adaptive. Indeed, producer and consumer devices are already capable of reporting varied data on their status and operation. At the same time, there is a great desire to change our the structure and content of our energy systems in response to concerns over sustainability. Doing this well requires data beyond status and operation. We need data on finance, technology characteristics, investment costs, markets, the weather, regulation etc. in order to understand the interplay of technology, policy, market forces, and consumer behaviour. We need data on the operation and the evolution of these systems.

We want to be able to manage these systems, but what we are managing is becoming more complex. In order to understand the directions in which these systems are evolving, we not only need to amass more diverse and complete sets of data, we also need to improve what we already have and can mine, in other words the ways in which we collect, manage, curate and interpret the data about these systems.
With respect to the operation of energy systems, as energy companies deploy more smart meters, significantly more data is being generated about real-time consumer demand, which can be used to improve models of future demand patterns and inform ways to change consumer behaviorthrough dynamic pricing or even shifting operation of energy-intensive appliances to reduce demand during peak times. Similar opportunities for demand management are arising with electric vehicles and their ability to function as both a source and a sink in the power grid.

At the same time, we are seeing new opportunities for data collection arising from non-traditional areas and bottom-up initiatives that would not have been economically feasible a decade ago. Smartphones have become ubiquitous and essentially function as mobile data recording platforms. Currently, phones with barometric pressure sensors are being used to crowdsource data which can increase the accuracy of local weather forecasts. Noise mapping of cities is occurring by combining microphone readings with GPS coordinates. Augmented reality apps are allowing for people to visualize the sources of CO2 from the facilities in their immediate vicinity. For several euros, people can buy an attachment that turns their iPhone into a spectroscope to measure the amount of particulate matter pollution.

This is not just limited to smartphones, and as the costs of sensors and microprocessors such as the Arduino and Raspberry Pi has plummeted, we are seeing the rise of the Internet of Things. For under a hundred euros, people are deploying internet-connected pollution sensors. Despite having cheap uncalibrated sensors, given enough of these devices distributed in an area, data scientists are able to use sophisticated techniques to extract usable signals from the noise.

With respect to the development if not evolution of our energy infrastructure, we need to know what is out there, and how the operation effects decisions on new energy technology and investment in new systems. In this realm, we are seeing increasing availability of Open Data published by governments, which is being coupled to initiatives such as Linked Open Data which aims to connect these data sets together through the use of Semantic Web standards. Through this, new opportunities are being opened up as people can freely re-use this data and connect different datasets in innovative ways to gain new insights, e.g. on the carbon intensity of a country's electricity generators. These developments are laying the foundation for us to get a more complete and comprehensive view of energy systems whose properties are documented in distributed databases, each published by different agencies.

A fundamental challenge behind these developments is that data is not a single thing and comes in many different forms, each of which leads to different challenges. Part of challenge can lie with the sheer volume of it, as in the case of Big Data. Here the data is of such a size that it can no longer fit on a single computer and sophisticated techniques need to be employed to efficiently search for meaningful patterns in it. It can be difficult to create appropriate models that can reproduce and explain the underlying phenomena observed. Another issue is that data is available in a range of formats from relational databases to raw text on websites or in reports. Each of these formats requires different processing techniques which further depend on the type of insights that are desired to be gained. A further challenge relates to enabling interoperability of different data sets. Data sets differ in terms of the scales, resolution, and accuracy of the data collected. In order to join data from different sources, the assumptions and methods employed in the data collection process need to be understood, with appropriate translations and interpolations performed to ensure a consistent interpretation. Finally, this is not just about having more data, but about understanding the context and interdependencies between the different actors, technologies, and policies in the energy system, and how this gets reflected in the different slices of data that are available.

GSS: If it’s social, it needs to be there from the start

Merijn Terheggen

A traditional approach to big data is the ‘collect-first and analyze-later’ approach. The initial Google search functionality is a great example of collecting the dataset first (web crawling) and analyzing it later (building an index and ranking using PageRank). This works well for many projects. However, the growth of globally distributed user driven networks, like the enormous adoption of social networks like Twitter and Facebook, have shown a post-Google era development in which the network propagation and analysis that provides real-time user relevance feedback is critical to the emergence of successful user driven (social) networks.

This means that data has to be analyzed as it comes (at Facebook, tens of millions of interactions per second) in and the results of the analysis be routed back to the user, that in turn will interact with it again. It’s clear that this requires a joint effort from two different disciplines, interaction design and big data software engineering, in creating scalable and real-time data analysis to be part of the core application. This is one of the most challenging big-data problems. It also typically requires co-design where data-model design and user interaction (UX) design go hand in hand. DJ Patil, ex-Chief Data Scientist at LinkedIn and one of the leading big data experts in the world evangelizes the notion that user interaction design is a key component of most big data because it drives what data comes in and can be by far the biggest multiplier in effect when people are effectively mobilized to interact and contribute. Without the right UX, Facebook would be nothing more than the traditional 'about me' personal web pages that people used to put up in the early 2000's.

After the initial growth of the first social networks (Friendster, MySpace, etc) took place, user engagement focused social algorithms have made an enormous difference in adoption of social networks by users, making the winners succeed because of the use of scalable algorithms. At Twitter, this was achieved by continuously showing Twitter users what is 'trending' and what other users and tweets might be relevant (at real-time) to the user based on the information that the user is currently viewing. At Facebook, it was achieved by creating a selection from all available events that shows the user only the most important items based on his/hers specific social network connections and interactions. This means analyzing at real-time what discussions are currently developing and growing in the users' own sub-networks and feeding that back to the user based on the user's interaction patterns with these discussions.

Big data analysis in these types of situations needs to be real-time and continuous, versus the more traditional batch-like post-processing approaches used in collect-first analyze-later. The added complexity comes from the fact that an application that implements this strategy needs to be designed from the ground up to have the analysis and feedback-loop be an integral part of the functionality delivered by the application. The collective knowledge of the world is rapidly becoming more complex (enormous amount of c-existing perspectives on global issues like climate change that can not easily be reduced into a single model like the traditional sciences) and for a large part develops in online and asynchronous discussions. Harvesting the knowledge of the crowd using social interaction and social network mechanisms requires applications and frameworks to include massively scalable data analysis components from the beginning instead of as a post processing step after the fact. If there's anything that Twitter and Facebook have shown us then it's the enormous power of complementary user driven data development combined with scalable analysis algorithms. The 'Social Graph' that many people are enchanted by and recognize as 'revolutionary' is in fact a hybrid structure combining both the interaction driven user data and the real-time analysis capabilities in a feedback loop.

Use of Topology to Identify Global Properties in Data

Mario Rasetti

General, far reaching methods have been recently developed that allow us to extract global topological information from spaces of data of arbitrary complexity, based on three basic steps:

i) The construction of a space of data from the collection of 'points' associated with data themselves. Approximation of such space with a family of simplicial complexes parametrized by some 'proximity parameter' turns the data set into a global topological object (space). The choice of the parameter can be metric independent. ii) The use of topological invariants (homology groups) and their persistence under parameter variation to distinguish noise from signal. iii) Encoding of the data set persistent homology in the form of a set of topological invariants: Betti numbers.

These three steps provide an exhaustive knowledge of the global features of the space of data, even though such a space is neither a metric space nor a vector space. Homology is a powerful mathematical tool that 'measures' the shape of an object (manifold), encoded in the number and the type of holes or other invariants in the manifold: it allows us to devise new methods for data mining and the extraction of significant patterns hidden in large amounts of data.

It is suggestive that the relevant methods adopted in this approach are denoted in mathematics as 'global', in that they indeed refer to properties of the mathematical structure at hand that are shared by global systems: complex, combinatorially extremely rich, but – above all – universal (i.e., independent on the system details, such as metric) and not local (namely depending on the features of the system at large, not only the local ones) and representative of ensembles of very large class of phenomena (be they natural, societal, technological or other, or a mixture of all of these).

The conventional way to convert a collection of points within a space into a global object is to use the point cloud as the vertex set of a combinatorial graph, **G**, whose edges are exclusively determined by the given notion of proximity. This is what is typically done in complex network theory. In case such dependence had to do with distance, such distance may be (in fact, should be) a non-metric notion (for example, chemical distance, ontological distance, affinity). A graph of this sort, while capturing pretty well connectivity data, essentially ignores however a wealth of higher order features beyond clustering. Such features are instead accurately discerned by thinking of the graph as the 1-skeleton (scaffold) of a different, higher-dimensional, richer (more complex) discrete object, obtained by completing **G**: a simplicial complex, **K**. **K** is a piecewise-linear space built from simple linear constituents (simplices) identified combinatorially along their faces.

Algebraic topology provides a mature set of tools dealing with objects such as **K**: for example, counting and collating holes and other topological pattern features, both spaces and maps between spaces. It is therefore able to reveal, based on the simplicial complex approximation of the space of data, patterns and structures not easily identifiable otherwise. As persistent homology is generated recursively, corresponding to an increasing sequence of values of the proximity parameter complexes grow, naturally identifying the chain maps with a sequence of successive inclusions. Persistent homology, image of the homomorphism thus induced, encodes just that precious topological information that provides summaries, enabling us to better understand relationships among the geometric objects constructed from data (and extracting from them information). The emerging geometric/topological relationships involve continuous maps between different objects, and therefore become manifestations of functoriality, i.e, imply the notion that invariants can be extended not just to the objects studied, but also to the maps between such objects. Functoriality is central in algebraic topology because the functoriality of homological invariants is what permits one to compute them from local information.

Patterns are derived knowing the set of transformations of data space into itself that preserve its topology via correlations. They are the 'picklock' to open the casket of the future. Data, indeed, as photographs, the moment they are acquired consign their object to the past, whereas characteristic patterns of the system data dynamics allows us to make predictions about the future, without violating the unavoidable restriction (a sort of mixture of the second law of thermodynamics with the principle of relativity) that prediction can only be based on the process's past, not on any outside source of information. Patterns represented in this way are: robust, because they are derived from persistent homology and hence free, to any desired accuracy, of irrelevant noisy components; global, as they describe deep lying correlations dictated by the non-local features of the data space topology; optimal, based as they are on the inherent variational principles of the theory; flexible, due to the freedom inherited from their underlying language theoretic structure. This is why they provide strategic directions as how to search the data space. Preliminary results in the area of analysis of MRI brain imaging and immune system antibody concentration are extremely promising: the techniques can be easily applied to other fields, such as social networks or financial data.

Queries and Microblogging for financial data

Guido Caldarelli, Stefano Battiston and Antoine Mandel

State of art Every day millions of users search for financial information and make financial transactions on the web via general and specialized search engines and financial portals. These users provide implicit and explicit feedback by clicking onto specific pages and by performing specific actions. Twitter and Query-logs have been extensively analyzed in the area of Web usage mining with the goal to characterize users and to derive valuable information on their preferences, This analysis is of critical importance for performing many of the applications of search engines, including ranking, personalization, popular queries and trends, query suggestion, spam detection, presentation of search results. This feedback is encoded in the form of a query log that consists of a sequence of search actions, one per user query, each describing the following information: (i) terms composing a query, (ii) documents returned by the search engine, (iii) documents that have been clicked, (iv) the rank of those documents in the list of results, (v) date and time of the search action/click, (vi) an anonymous identifier for each session, and more.

Progress We are interested in analyzing queries that are generated by users interacting with financial portals, especially those provided by financial websites. It is possible to use query logs for detecting financial trends by aggregating the behaviorof large populations of financial actors that interact with the portal and correlations between different financial instruments that could be used as a base for the analysis of financial distress. For example Bordino et al in 2012 shown how volume of queries is related to volume of trading

Crowd sourcing and Semantic Web analysis

Guido Caldarelli, Stefano Battiston and Antoine Mandel

State of art Individuals in society face the daily necessity to have opinions and ultimately make decisions and take actions whenever they are able or willing to do so. According to rational decision theory, individuals make decision taking into consideration their utility, which includes estimating the cost and benefit of a decision [Kleindorfer et al., 1993]. However, it is well known that people systematically violate principles of rational decision depending on how problems are framed or perceived [Tversky and Kahneman, 1981] or if low probability events are involved [Camerer and Kunreuther, 1989].

Progress we want to devise A Social Intelligence Network (SIN) that is a new conceptual framework that overcomes the limitations of traditional crowdsourcing. The idea is to create a single virtual place where individuals' actions (e.g. voting, purchasing, investing) co-evolve with their value sets and knowledge. In particular, individuals can confront the values to which they subscribe with the knowledge they have and the actions they take every day and improve themselves in terms of consistency. We refer to this virtual place as the values-knowledge-action concept.

Final remarks

The importance of big data for GSS is perhaps best explained by a double analogy, with flying and with speech recognition. For centuries, people dreamed of being able to fly like birds, and sometimes experimented with devices that somehow had moving wings. These attempts all failed, but eventually a different route proved successful: devices with rigid wings whose geometry would create smaller pressure on top than below when the device was moving fast enough. For a much shorter time span, computer scientists and linguists have tried to develop devices that can recognize spoken language the way humans do. Again, this proved rather elusive, but big data provided an alternative approach: huge databases with snippets of spoken language can be searched with Google-type algorithms to find correspondences with oral input.

The point of these analogies is that big data can become essential tools to perceive global systems, but only if they come with new ways of using them. Mindlessly trying to apply techniques used to target individuals when trying to understand global systems will not work; nor can computers be expected to form concepts the way humans do in conversations and joint actions. By exploiting the relation between models and narratives of globalization, GSS can define practical problems and preliminary concepts that can be used to mine big data sets – often to be obtained by crowd sourcing – in view of the dynamics and structure of global systems. The results can then be used recursively to improve problem definitions and concepts, as well as to monitor the intended and unintended consequences of policies dealing with global systems.

3.1.3 High Performance Computing

Once high performance computing (HPC) moves from well-defined problems in science and engineering towards the world of policy-making, mindless computing is an increasingly serious danger. In global policy areas like financial markets, climate policy and more, the evidence to be provided to policy-makers needs to be "reflexive evidence", i.e. evidence that comes with an assessment of its reliability, validity, and relevance. So far, HPC has rarely, if ever, been used in such a spirit. Nevertheless, it holds considerable promise in this regard, e.g. because of the possibility to explore large, complex sample spaces of parameter values and boundary conditions.

The need for reflexive evidence is not peculiar to global systems science – by now, the cases where decision-makers can safely rely on evidence to be taken, as it were, at face value are the exception, not the rule. However, when dealing with global systems the need is particularly urgent, because our understanding of and familiarity with those systems is so limited that scientific evidence always results from a whole array of non-trivial decisions by researchers. HPC is particularly well-suited to produce reflexive evidence under such conditions.

For this purpose, the computational skills required to develop and use HPC must be combined with great skills in communication and in assessing the relevance of evidence for addressing specific practical issues. Therefore, GSS will systematically embed HPC work in dialogues with scholars from the humanities and with practitioners dealing with global systems.

Michael Resch

Global Systems Simulation usually requires detailed simulation of the key processes of the system that is under consideration or a detailed analysis of data provided to understand such a system. In both cases High Performance Computing plays a role as a key enabling technology to achieve reasonable and reliable results.

With respect to High Performance Computing there are two main issues that are of importance here. The first one is the availability of such resources. The European activity PRACE (Partnership for Advanced Computing in Europe) a basic infrastructure for HPC has become available to all European researchers over the last years. It is vital for GSS to keep such an infrastructure available and open for all European scientists but also to update such an infrastructure continuously to be able to harvest the potential of improved systems and turn it into improved GSS results.

Furthermore there is a research part that comes with HPC. As HPC relies on very large scale systems based on millions of parts like processors, memory chips and disks, GSS has to master the handling of such systems. This includes a number of issues:

- First, and foremost the development of scalable models. Existing models were often developed with serial computers in mind. New models have to be developed that are scalable to the same extent that HPC systems scale.

- Second, the development of scalable programming tools to be able to implement the scalable models on existing hardware. This includes programming languages, debugging tools, performance analysis, and many more.

- Third, the development of new and scalable methods to make things visible.

While all of these issues are in principle covered by each of the focussed subjects discussed here (models, data visualization, formal languages, …) The successful usage of HPC requires that scalability becomes the central feature. Only when scaling all of our efforts to very large systems are we able to get the necessary answers to our GSS questions from the European HPC infrastructure.

3.1.3.1 GSS, High Performance Computing and Functional Programming

Martin Elsman

A central part of Global Systems Science is for society and decision makers to understand the effects of political decisions and societal changes, including, for instance, global climate changes, environmental changes, geological changes, sociological changes, financial systems changes, and political changes.

Well-justified decisions can only be made by understanding aspects of the past and the present. We make models that capture the essential behavioural properties of the systems we are part of and use these models to understand the systems and to predict the consequences of decisions.

An essential part of constructing and verifying models is continuously to analyse and extract patterns from big data sources. Complementary, for understanding a model, and in particular, for understanding consequences of decisions, big computations (e.g., Monte Carlo Simulations) are often used. For many of the systems, big data sources need to be analysed quickly and big computations need to be run with immediate response time in order for decision makers to respond immediately, in real-time.

Tomorrow's computational platform is much different than Yesterday's, as we start seeing parallel architectures getting renewed attention, based on the general purpose usage of parallel architectures, as found, for instance, in graphical processing units (GPUs). The renewed attention on parallel architectures comes from the fact that engineers have reached a barrier as to how efficient a central processing unit (CPU) can compute. On the other hand, Moore’s law still holds: the amount of transistors per silicon area is roughly doubling every 20 months. Thus, the number of parallel processing units found in new hardware, such as the graphics cards of a standard gaming PC is growing exponentially, leaving an open problem to the software architects: how are we going to program these new very parallel architectures. Approaches are of course materializing, for instance, in the form of toolkits, such as NVIDIA's CUDA programming platform or the open source programming platform OpenCL. But higher-level programming models are needed, as expressed, for instance, by Bill Dally, chief scientist at NVIDIA and senior vice president of NVIDIA Research:

“Making it easy to program a machine that requires 10 billion threads to use at full capacity is [also] a challenge. ... We need to move toward higher-level programming models where the programmer describes the algorithm with all available parallelism and locality exposed, and tools automate much of the process of efficiently mapping and tuning the program to a particular target machine.”

> [From http://www.hpcwire.com/hpcwire/2013-04-15/future_challenges_of_large-scale_computing.html]

Research into the area of high-level parallel programming models is essential to develop, maintain, and manage tomorrow's high-performance, parallel systems. The functional programming paradigm captures exactly the declarative properties that make it possible to express parallelism at a high level and also make it possible to generate efficient high-performance code from the high-level functional specifications. In the context of financial IT, the HIPERFIT Research Centre (www.hiperfit.dk) is one example of a centre that investigates these research opportunities.

3.1.3.2 GSS in the presence of faults

Sibylle Schupp

Global systems, if they fail, may fail big; it is for that reason that policy makers have a central role and responsibility. Whenever policies are backed by simulations, they rely on the results of a computation. Yet fact of the matter is that those computations inevitably contain faults.

At present, most faults do not manifest themselves in a way that incurs practical problems. Which faults are benign, however, and which ones may seriously impact the result of a simulation, is largely unclear and can be said with certainty currently only in hindsight. A fundamental task of the science of global systems, thus, is to provide methods for understanding the impact of faults. Specifically, metrics need to be defined to describe the magnitude of a fault, qualitative descriptions are necessary to capture its semantics, root causes need to be identified, and the dependencies between a fault and the healthy part of the system as well as among faults need to be researched.

Big data implies big faults. A large class of faults concerns the logic of the program; those require the investigation of formal languages. Yet, other classes of faults exist that go beyond logic, ranging from the malicious tampering of a system over physical errors in the environment of the simulation to hardware faults in the computational architecture. Those faults can be transient, silent, non-reproducible, non-deterministic, or random, and are thus hard to detect. They are found in data, models, computations as well as networks, storage media, and computational units; and they may emerge at the interfaces of software and hardware components that by themselves may work just fine. They also are expected to dramatically increase in numbers.

For the future computers for global systems, exascale computers capable of a million trillion of calculation per second, the “Mean Time to Failure” is projected to be so short that useful computations are seriously impeded. At the other end of the scale, and indirectly promoted by global systems themselves, one can observe already today that malicious intentions grow rapidly and that the financial, social, or personal incentives for manipulating simulations to one's own advantage only become larger. Both the kind of faults and their mere quantity defeat traditional concepts for resilience, reliability, and robustness. One has to fundamentally think over how computations for global systems possibly can be protected.

Understanding faults requires first and foremost that one knows _of_ them. That knowledge does not exist today since the required infrastructure is completely lacking. At present, faults are hidden in regression tests, traces or log files, and even if one had access to those files, neither standards or notations exist to describe them nor concepts for evaluating or comparing them. Further, traditional recovery mechanisms cease to work.

Classical redundancy in space or time is too expensive---neither can one hold big data twice nor can one easily run a large simulation multiple times. Smarter ways are needed than those brute-force approaches, and redundancy must be made affordable with respect to energy costs and resources.

3.2 Communicating/Framing /Democratising Scientific Evidence

3.2.1 Computer Science, Complexity and Narrative: A Research Priority

David Tuckett,

(This contribution is complemented with a draft paper on: "A computer algorithmic investigation of conviction narratives in unstructured data sources." by David Tuckett, Robert Elliot Smith and Rickard Nyman.)

A conventional valuation which is established as the outcome of the mass psychology of a large number of ignorant individuals is liable to change violently as the result of a sudden fluctuation of opinion due to factors which do not really make much difference to the prospective yield; since there will be no strong roots of conviction to hold it steady…the market will be subject to waves of optimistic and pessimistic sentiment, which are unreasoning and yet in a sense legitimate where no solid basis exists for a reasonable calculation.(Keynes, 1936 p154)

Most important economic and related decisions are made in conditions of ontological uncertainty – that is in situations where the future development of entities and their future relations are profoundly unknowable ahead of time. Imagine, for instance, a set of predictions made before the development of the wheel, steam engine, transistor, PC, or Internet – let alone AIDS.

Taking decisions, in other words acting, in these circumstances requires conviction. But the factors that create conviction when outcomes are inherently uncertain are neurobiological, social and psychological rather than merely calculative. There is growing evidence, in fact, that economic and other important decisions that require pictures of the future to be created are subject to the forces (in urgent need of good understanding) that produce narrative conviction and narrative truth.

Aggregate behavioris subject to the convergence and sudden co-ordination of shared narratives about the future and inherently fragile and unstable. Whereas the state of the world changes rather slowly the state of narratives about what is happening in it can alter very sharply and is strongly subject to social interaction and influence. Recent events in financial markets have demonstrated this proposition forcibly.

The digital revolution has produced large quantities of "big data" and especially text data which we have begun to show can successfully be investigated rigorously using algorithmic methodology to capture historical shifts in narrative sentiment which appear to warn about possible future patterns. Essentially some topics and projects start to be discussed and pursued with significant alterations in the presence within narratives of realistic doubt.

The fact that economics has not adequately taken into account radical uncertainty and the impact of human actors being social and sentient interacting units producing complex and unexpected novel outcomes are the two largest weaknesses in current economic thinking, which severely limit its usefulness in the finance and macroeconomic spheres.

The new methods that exist to investigate conviction narratives circulating in large datasets produced by networked institutions and individuals – public and private data – offer a fruitful avenue to remedy this lack and to understand the role human emotion and subjective narrative capacity have in creating economic and social reality. Linked to conventional social science methodology this new technology has massive scientific and policy-making potential. Attention to ensuring access to relevant data sources and research on narratives from interdisciplinary teams comprising social, brain, humanities and computer scientists should, therefore, be a priority area for scientific development. It will assist understanding and modelling (via simulation) such vital areas as the complex functioning of financial markets and changing social attitudes to climate change and economic policy, among others.

3.2.2 Gamification

Web-gaming, social computing and internet-mediated collaboration

Vitorio Loreto

In the last few years the Web has been progressively acquiring the status of of an infrastructure for social computing that allows researchers to coordinate the cognitive abilities of users in online communities, and to suggest how to steer the collective action towards predefined goals. This general trend is also triggering the adoption of web-games as a very interesting laboratory to run experiments in the social sciences and whenever the peculiar human computation abilities are crucially required for research purposes. There is a wide range of potential areas of interests going from opinion and language dynamics to decision making, game-theory, geography, human mobility, economics, psychology, etc... For instance Spatial Games (related to traffic, mobility, coordination, etc.) are aimed at investigating how people (from literate to non-literate) explore geographical spaces and use geographical information in a way that is meaningful and culturally appropriate for them. Specific tasks can include coordination, exploration, cooperation, annotation. At the same time these games/experiments would allow the collection of sensible information about how people perceive their environment, e.g. by evaluating which scale and level of details in imagery is most meaningful. This information can be organised in layers, e.g. traffic or pollution in urban environments, social interest, landmarks, etc., and made available through suitable interactive visualisation tools in order to help people to understand environmental changes, so to facilitate informed decision-making. Along the same lines, the Citizen games share the common denominator of the management of the commons as well as the monitoring of the environmental changes. Interesting activities here include the development of new tools for the sustainable management of natural resources (in particular for marginalised communities), a more aware use of them, good practices for recycling, food management, mobility, energy consumption, communication, etc.

Behavioural aspects of techno-social systems

In social phenomena the basic constituents are not particles but humans, and behavioural and cognitive aspects, as well as the way humans take decisions are crucial ingredients that have to be taken into account in order to make sensible predictions. It is thus crucial to deepen our understanding of the causal link between the level of the individual and the emergent collective phenomena. In order to do this one has to parallel the monitoring of emergent phenomena in social dynamics with the investigation of the behavioural and cognitive foundations of social interactive dynamics in human computation tasks. Relevant objectives include: i) The dynamics of cooperation and human computation. Here the problem concerns how to sustain over time collaborative behaviorin intelligent tasks, which is fundamental both for the understanding of social dynamics and for the design of effective forms of web-mediated collaboration; ii) the role of motivations, incentives and mechanism design together with other factors such as social ties, culture and the cognitive framing of problems.

3.2.3 Need for narratives

3.2.3.1 Models, stakeholding and narratives

Ilan Chabay & J. David Tàbara *(*and anonymous sources recorded from the first GSS conference audience).

GSS will massively rely on computer models, taking advantage of advanced technology to tackle the complex multi-scale – spatial and temporal – structure of global systems. By their algorithmic structure, however, computer models presuppose a set of concepts that are unambiguously given for the purpose at hand. While such models can and will surprise the user in many ways, they are ill-suited to deal with the ambiguities that are a vital ingredient of human life. From Homer's Odyssey to Joyce's Ulysses and Kubrick's "A space Odyssey", story-telling is one of the most important and fruitful ways for humans to deal with those ambiguities.

Narratives help to crystallize the concepts needed to build suitable computer models, they can help to delimit the scope within which a particular model is useful, and to understand what goes wrong when it is used beyond that scope. Especially important for GSS is the possibility of using narratives to tackle the thorny problem of unintended consequences, both of policies to be analysed, and of using the models developed by GSS. In this sense, ICT could play an important role in gathering these different perspectives and articulating the various narratives and framings from different parts of the world on what GSS ought to be. Narratives can be based on pictures and images, and these can be very powerful means to capture complex issues which can be very difficult to communicate otherwise. But a challenge is also how to provide the *right* picture in ways that then it can be used to readjust our GSS models.

Narratives are not only stories, they can also be can be images, performances, etc, and they should not only be understood a means for communicating but also for engaging publics. We need to realise that these narratives emerge in many cases from models and that they are the product of an interactive process with the larger community of stakeholders. The existence of these narratives depends on the possibility of creating such relationship and a process that goes along the whole he generation of models and production of model outputs as well as during [the process or organising and making sense of] the collection and analysis of data. But: How do we describe the systems in the models? This process should not be normative or predictive –telling us how things should be or will be- but only to provide a series of options about the future which in turn depends on how we act in a particular way. So we need to consider the following questions: Who is asking these questions?, How do we create visions on the future? (so there is a motivation to move it into collective behaviorchange), How we analyse the responses? And whether we begin to see changes or not. In addition, we also need to capture both the quantitative and qualitative aspects in the modelling, analysis and data in ICT, so we don't loss the richness of the qualitative aspects of the narratives.

ICT plays a substantial role in providing the connectedness across spatial domains and needs and equally important as a means of empowering communities and individuals through distributed information and knowledge sources and systems. Hence such integrated strategies must be developed, tested, and communicated to the community in ways that they can implement them. This is not simply a matter of information diffusion, but critically of creating and using narratives that provide engaging visions for a sustainable future. Narrative kernels are the core notion expressed in locally appropriate forms that can be effectively communicated and remembered and thus foster coherent and cohesive communities of practice and collective action. When coupled with global systems science strategies to address specific issues, narrative expressions can empower and mobilise people at different levels to engage in the process of global transition and transformation.

Therefore, narratives should not only be understood a means for communicating but also for engaging publics. We need to realise that these narratives emerge in many cases from models and that they are the product of an interactive process with the larger community of stakeholders. The existence of these narratives depends on the possibility of creating such relationship and a process that goes along the whole generation of models and production of model outputs as well as during the process or organising and making sense of the collection and analysis of data.

We need to involve stakeholders, but if people ARE to make use of GSS then it will be necessary to consider societal actors embedded within the many different kinds of institutions which mediate their actions. Each of these has their own values, and use particular types of narratives and this is a complex issue indeed.

GSS needs to connect information on global systems with models and scenarios in ways which are useful for policy making. One possibility to do so could be to develop a process to select first the relevant information; next running computer experiments and making use of ITC tools; and then, connecting such insights with the lessons learned from the past and for the future so as to adapt and create adequate models to do all this –and its associated narratives.

In particular, the analyses of framings and narratives should help to unveil how we describe global systems in the models. This process should not be normative or predictive – telling us how things should be or will be - but only to provide a series of options about the future which in turn depends on how we act in a particular way. So GSS needs to consider: How do we create visions on the future? How motivations can be activated to move it into collective behaviorchange in this regard? How we analyse the responses? Can we begin to see any positive changes? Who is asking these questions? GSS should capture both the quantitative and qualitative aspects in the modelling, analysis and data in ICT, in ways that we do not lose the richness of the qualitative aspects of the narratives.

There are some cultural aspects (e.g. in language development) that need to be taken into account in developing and communicating GSS, and in particular when discussing the future of communities or how GSS could be useful in other parts of the world (Africa, Latin-America). Thinking about characterising global systems we may also need to think about how people in communities in other parts of the world characterise the 'global' - which is what they actually see in those communities. In addition, we have global universal problems, but which are manifested in many different ways locally. We should consider what is happening in terms of changes at the local level in these places in the mode of transition areas, and how these experiences interact with other scales. Therefore, not only we have to create new narratives and visions on GSS but also it is necessary to connect these narratives and vision with many other existing ones which are very diverse, which could help people learn, to help people understand where they are and we need to listen to them. In this process, ICT is to play a central role to support mutual learning.

3.2.3.2 Narratives for socially sustainable future: participatory process to build narratives for action

Filippo Addarii

Indignez vous! The pamphlet by retired German-French diplomat Stéphane Hessel in 2011 inspired the establishment the Occupy Wall Street and Indignados movements. This is a case study of how narratives emerge and operate. Millions of people across the world found in the pamphlet the expression of their anger against the system, the frame to build a shared understanding/identity across cultural and geographical boundaries, and a call for joint action against governments and financial institutions.

This was not in the intention of the author but it happened. This is just an example amongst many but exemplifies the dynamic of narratives. The question is to understand in which conditions narratives emerge and if they can be engineered.

Understanding this is important for Global Systems Science because it's not sufficient for science understanding how the globalizing world works - the opportunities it generates and the crisis it provokes - but needs getting policy makers and the general public to understand as well and change their behavioraccordingly.

The process is not just a matter of communication and manipulative techniques as a policy adviser Karl Rove would recommend because the level of complexity faced and adaption required is beyond any command and control approach. Moreover the public trust in public institutions and science – often even cause of more uncertainty - has plummeted to such a low that the cost of control is likely to be unaffordable.

A strategy for engagement and empowering process with policy makers and the large public to build a new common value framework is required to get each one to take responsibility and respond to the specific challenges of the places they inhabit. Narratives can do the job.

Technological advances coming out of internet makes the task even more possible. New technologies such as crowdsourcing and social networks allow making this process as genuine collective production engaging all sorts of stakeholders across borders and boundaries.

The process does not need to start from scratch. There are also socio-economic trends already happening in society such as fair-trade and microcredit that already engage millions of people responding to the same needs to understand and build a new vision for a globalizing society. These trends could become the tassels for the new narrative underpinned by scientific knowledge. Actually science and emerging trends could just reinforce each other.

This strategy should include 3 elements critical for success: shared purpose, sense of belonging, plan for action.

This could be the beginning for a narrative suitable to the challenges of the 21st century. It would start on Aristotle theory of narrative ie poetics but also build on the new opportunities opened by the new century to mobilize people across borders and boundaries towards a socially sustainable future.

3.2.4 Education and Learning

Global Sustainability Learning and GSS

J. David Tàbara

Integrated ICT can play a decisive role in supporting and consolidating global communities of learning regarding the improvement in the understanding and governance of global systems. This can be of particular relevance with regard to the articulation of open networks of action organised around meeting specific needs and problems that relate to global sustainability –that is, societal problems which inevitably have a multi-scale, multi-domain, multi-agent complex nature.

The ambivalent nature of ICT means that, on the one hand, the new tools and data available can become instrumental in organising knowledge partnerships around specific boundary objects constructed within the interface of: 1) science/knowledge integration, 2) policy design and transformation, and 3) the engagement with general public. But at the same time, ITC tools also increase the complexity and the degrees of freedom in which human action can take place. For this reason, ITC will need to move from its present role as enhancers of 'first-order social learning' –that is, doing more or less the same, but simply by more and faster- to become triggers for a truly second-order global social learning –changing not only the means to do the same but also the goals, the values and the cognitive frameworks we use to decide upon such goals. This massive process of global reframing in human perceptions, values and practical tools for understanding and transforming reality (e.g. towards non-dualistic worldviews) will necessarily have more aligned with the present predicament of global sustainability; and in this respect, it can referred to as *sustainability learning*. In order to move towards this more reflective and empowering role of information and knowledge systems, large policy and social efforts –e.g., to harness innovation and to learn also 'what we shouldn't do'- will have to be devoted.

In particular, an integrated understanding and learning about global systems ought to able to unveiling and provide substantive insights on the options for innovation: in global institutions and social structures (S), in the change in the quality and quantity of stocks and flows in information and knowledge (I; e.g. including the role knowledge erosion derived from globalisation), of energy and natural resources (E), and the cumulative and irreversible (often negative) effects on human agents interactions in the process of global environmental change (C; the SEIC conceptual model, Tàbara & Pahl-Wostl, 2007).

Global sustainability learning will necessarily entail a shift in our collective capacities to represent and to deal with the 'global crisis of crises' in precautionary but also transformative mode. This means boosting our abilities to systematically unveil the multiple interactions and interdependencies between the various ongoing crises and propose viable *system options* to deal with them – including those options that entail disruptive changes in existing power arrangements and global inequalities. Only by securing that large amounts of people can contribute to such process of knowledge-building, and in ways that improve their own conditions and those of future generations, will it be possible that GSS plays a significant role in the process of global sustainability learning and transformation.

Last but not least, while it is true that global human dynamics have become increasingly coupled and intertwined with those of the natural systems, this is not necessarily true with regard to Human Information and Knowledge Systems (HIKS) used by individuals and organisations in their daily lives. The basic means of information used to value, judge and communicate the world about us (e.g. price systems, media, etc) do not reflect the kinds of changes occurring in the natural and social world in ways that can support fast learning and transformation for sustainability. What is needed is to develop multiple learning feedbacks connecting agents at their closest level possible with feasible systems options in ways that they can meaningfully contribute to minimise the negative cumulative aggregate effects on global systems derived from the unintended consequences of their own actions. Mapping out such systems-agents options, and making understandable and supportive by the citizens at large is a challenge in which GSS can definitively contribute in the decades to come (Tàbara & Chabay, 2013).

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3.2.5 Participatory Approaches to Knowledge Acquisition

3.2.5.1 ICT for participatory sensing

Vittorio Loreto

One possible way to respond to the above mentioned societal challenges is that of pushing the evolution of ICT so that it can support informed action at the hyperlocal scale, providing capabilities for environmental monitoring, data aggregation and mining, and information presentation and sharing. Nowadays low-cost sensing technologies are being developed to allow citizens to directly assess the state of the environment; social networking tools allow effective data and opinion collection and real-time information sharing processes. Through the use of ICT tools deployed to gather user-generated and user-mediated information from web-based and mobile sensing devices knowledge, the social awareness and understanding of environmental issues and living conditions in urban habitats will be enhanced. The possibility to access to digital fingerprints of individuals is opening tremendous avenues for an unprecedented monitoring at a ``microscopic level'' of collective phenomena involving human beings. We are thus moving very fast towards a sort of a tomography of our societies, with a key contribution of people acting as data gathering ``sensors''. Interestingly, this participatory sensing also presents challenges regarding quality and cost of sensors, reliability and representativeness of collected data, widespread and enduring participation, as well as privacy. Participatory sensing data will have to be integrated with pre-existing information. The possibility to collect relevant and capillary data about human urban activities can stimulate the development of data-driven modelling schemes integrated in ICT-based infrastructures for an empirical, computational and theoretical approach to social dynamics processes. In addition new models of interaction between citizens, authorities and scientists will have to be developed. Finally, the innovative integration of mobile technology, sensors, and socially-aware ICT can contribute to a shift towards a green and sustainable economy, which has been seen by many policy makers as one of the exit strategies from the current financial and economic crisis.

3.2.5.2 Decisions about the future: Achieving stakeholders' agreement and trust by participatory narratives

Ilona Heldal

Today's global society have to deal with many complex projects involving different interest groups, uncertainties, delays and dilemmas during the communication and collaboration regarding decisions. The more democratic the intended project is, the greater is the risk for unintended obstacles. The communication between the stakeholders can easily be too slow or delayed. Many projects are looking for visualization based support for communication and collaboration regarding decisions about the future. Virtual and Augmented Reality models can make it possible for all interested parties to have access to a common representational medium. This makes it easier to achieve an understanding of topics on the basis of their own common sense, i.e. the models can visualize non existing, future objects and processes. Stakeholders use to appreciate the 'near-to-real', believable models as a complement to their other materials. However, believable models are not necessarily trustable too. Stakeholders often have difficulties for using the models, fully experiencing them, using them as a communication medium or trusting them and therefore they cannot use them as evidences in the decision making processes.

The issue of trust is often based on the ability to follow processes, to have a strategy with the major steps through the process. Narratives facilitate following a process from a start to possible outcomes and enhancing the relevant structures. For this one has to understand actual patterns and structures of complex problems; be able to analyze parts while keep the attention on the whole problem; perform systematic data reduction while also focus on essential components. Developing visual models based on a storyline can enable stakeholders to test the effect of certain decision(s) regarding some interested aspects during the process and contribute to a deeper understanding of the process and the ways in which decisions are made and supporting evidences (e.g. documents, calculations, developing scenarios) are handled.

This document argues for the benefit of defining new visual models based on narratives, models that can support decision making processes towards obtaining stakeholders' agreements. In these models the narrative stands for understanding a structure for a whole process within a coherent content. The visualization stands for providing visual content for the structure and the main issues in the structure. By this more trustable models can be built.

Telling a story with the aim to solve a complex problem and being able to explore issues and their consequences visually by the time playing with adjustable timeline, resources, environmental or economical impact, and visually showing actual stakeholders involvement, would contribute to increased engagement, experiences and trust in the whole process. Playing with simulated decisions and making the effects of them more clear and tangible would also contribute to understanding the problem. By visualizing potential tensions between requirements or needs can prepare stakeholders to earlier deal with the eventually upcoming problems. There are several challenges that need to be further investigated in relation to the idea of visual models based on narratives. For example:

- Incorporating different modalities beyond visual models (e.g., by seeing-augmenting, by touching, by listening or by smelling).
- Combining narratives with other methods supporting decision making regarding future issues, e.g. with scenario planning.
- Describing what can be trusted in a narrative and how, e.g. by missing evidences.
- Combining existing narratives with alternative (possible or impossible) scenarios.
- Assessing simulations.
- Considering data, tendencies from the large public.
- Involving the public, for example by using social media.
- Making available and calculating possible deviations behind simulations. Visualizing possible deviations behind simulations. For example the external stakeholders need to know if a new building can be placed closer or far away during the next steps in the building process, and within which threshold interval. The threshold interval needs to be available since even small changes may influence experiencing of e.g. shadows or air corridors.
- Considering time related consequences (e.g. visualizing the different effects of a delay).
- Forming the risk analysis for the entire project.

Defining illustrative examples to better understand how ICTs support communication and collaboration with the purpose to reach stakeholder agreement

3.2.6 Collective awareness and decision making

Vitorio Loreto

Awareness is very much related to learning. The societal challenges of our rapidly changing world call for a need to increase the number of people that are educated and capable of using the technologies that will sustain large human societies safely and prosperously. Learning is at the basis of our ability to construct models of our reality and take decisions. This is especially difficult when we face the complex problems of our interconnected societies. This calls for a commitment of the scientific community to generate new concepts and innovative learning schemes through which a much needed breakthrough can be obtained.

The access to both personal and community data, collected by users, processed with suitable analysis tools, and re-presented in an appropriate format by usable communication interfaces, has the potential of triggering a bottom-up improvement of collective social strategies. By providing personally and locally relevant information to citizens, i.e., related to their immediate locality rather than to the city or region in which they live as a whole, one can hope to stimulate fundamental shifts in public opinion with subsequent changes in individual behaviorand pressure on policy makers. The integration of participatory sensing with the monitoring of subjective opinions is novel and crucial, as it can expose the mechanisms by which the local perception of an environmental issue, corroborated by quantitative data, evolves into socially-shared opinions, eventually leading to local and global changes. Enabling this level of transparency critically allows an effective communication of desirable environmental strategies to the general public and to institutional agencies. For instance fostering awareness and improving environmental monitoring could contribute to the reduction of pollution and waste of energy or the improvement of biodiversity in urban areas. Fostering the birth of environmentally positive communities, stimulating bottom-up participation, collecting public opinions and perceptions in a trusted way, are all factors that will empower the general public and policy makers with tools to gauge and orient the democratic processes of decision making.

3.3 Coordination Problems

3.3.1 Computational Logic

Logic for GSS methodology

David Pearce

Logic forms a crucial part of traditional scientific methodology and there is no reason to suppose that GSS is in this respect different. The fact that systems studied may be non-deterministic, that behaviormay be emergent, or that phenomena may be chaotic does not change this. Logical methodology seeks to formalise the reasoning mechanisms involved in the processes of discovering knowledge, applying scientific theories and models and judging their success. For much of the last century logic was dominated by the classical, deductive paradigm of formal reasoning in the tradition of Frege and Hilbert. It was applied in particular to mathematics and to traditional concepts of descriptive methodology, to study concepts like explanation, prediction, and confirmation. However, the classical paradigm of mathematical logic has been challenged in recent years from many different directions. Modern computational logic has abandoned many assumptions and greatly surpassed the boundaries of the classical view. Induction, learning and discovery are now bona fide research topics for logic, while the foundations of logic are being enriched by dynamical concepts from information, interaction, games and argumentation. GSS is attempting to develop a new scientific paradigm that is as yet only partially formed and one of the areas most in need of development and explication is that of theory evidence, testing, prediction and forecasting. Whatever the nature of the formal models developed within GSS, in logical methodology we are dealing with what inferences can correctly be drawn from them and whether and how such inferences can be used for testing and improving those models. In other words we are irrevocably working within a logical domain.

Logic for reasoning about GSS and global challenges.

Logic typically forms the metatheory of the mathematical sciences. While the different disciplines in GSS may involve very different styles of laws, models and mathematical structures at the level of theory, at a metatheoretical level there may be much more uniformity that logical frameworks can reconstruct, analyse and compare. Another issue raised by GSS is concerned with the communication of science to stakeholders, decision makers and the wider public. This process is intended to be not merely a unidirectional one of communicating scientific results and evidence to a non-scientific public, but to be interactive and include active citizen participation through discussion, dialogue and debate, possibly supported by social networks and platforms. It has been emphasised that techniques such as narratives, games or even art may be important vehicles for expressing evidence and forming opinion. However, this “human-centred” aspect of GSS, including citizen participation, is clearly concerned with reasoning. Ultimately, in order to ground decisions as rational, equitable or otherwise reasonable, we need to examine the reasoning steps that led to those decisions and provide their justification. Here again logic may be expected to play a crucial role, along with argumentation theory, game theory and other formal methods.

3.3.2 Social and governance processes

Diana Mangalagiu

Global Systems Science and Global Governance

Since the term governance started to be used in the early 1980s in a policy document by the World Bank, its use in both public policy and corporate world more and more focus was put on good governance and principles of good governance[10]. However, such principles, adopted by the World Bank to evaluate governments of developing countries on the basis of governance has been widely criticized by developing nations and development economics specialists as being a one-sided criterion established by industrialized nations.

[10] Specifically, good governance refers to enforcement of the rule of law, due diligence, willingness to encourage foreign investment, determination to prevent corruption and the ability to formulate and implement sound fiscal, economic, monetary, foreign currency and trade policies.

The more recent discussions about 'global governance' such as Rosenau (1995) and McGrew and Held (2002) are mostly elaborated and focused on Western contexts, which are getting poorer and less powerful and attempt to keep their historical advantage. While new players are joining the conversation (creation of the G20, OECD opening to BRICS), the dominant pattern remains the same.

What we start to better understand today is that global governance challenges and more largely most global challenges are ill-defined problems, so-called 'wicked problems', where both the problem and the solution are unknown at the outset of the problem-solving exercise (Churchman, 1967). This is as opposed to 'well-defined' problems where the problem is clear, and the solution is available through some technical knowledge.

Global Systems Science should build on insights from the environmental experience such as Ostrom et al (1999) and Young (1997) in tackling challenges concerning the management of large-scale resources and the so-called 'global commons' that depend on international cooperation. Such studies imply a departure from 'design, control and command' approaches to governance towards 'adapt and navigate' ones. These also suggest moving from expectations to find local solutions to local problems and global solutions to global problems towards a more patchy mix of multi-level solutions siting in global contexts.

Global Systems Science has much to contribute to the scoping and framing of global governance, which is nowadays taking place. A few examples of questions a GSS research program should tackle:

- How ICT and GSS can help building future-oriented global governance in an inclusive way based on multiple worldviews and actors including the usually missing voices?
- How ICT and GSS can help bringing about comprehensive solutions of global governance and overcome the sharing power/sharing burdens frame of mind towards win-win coordination mechanisms?
- How GSS can help to further understand how the ingredients of global governance interact and co-evolve: energy and resources, development, human and cyber security, global commons, financial and reserve currencies etc.? How to tackle systemic and emergent risks?

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Need for Foresight in Global Systems Science

Angela Wilkinson and Diana Mangalagiu

Global Systems Science needs a deliberate and reflexive element of actionable 'global' foresight that recognizes the contingent nature of an unpredictable future as a motivator for change in the present. Today's big policy challenges benefit not just from looking back to see established patterns, but in looking forward and imagining different possibilities. They are also increasingly associated with new approaches to change, not just developments in systems thinking and complexity science. For example, the momentum in collaborative futures, transition management, resilience management, sustainable inclusive and green growth initiatives, etc. each, in their own way, recognizes the limits of established economic theory (neoclassical economics) and indicate a search for new approaches to appreciating, addressing and 'managing' change in the context of irreducible uncertainty and complex systems dynamics.

Connectivity has become the key driver of vulnerability and value creation, and created a 'perfect storm' of complex systems, higher decision stakes and inherent social/values conflicts. The future as probable, possible and preferable is as pertinent today as it was 20 years ago, but the methods to engage the role of the future in the present continue to evolve.

Big Data and (better and/or new types of) model-based analysis and simulation might seduce some towards renewed predictive confidence. While forging shared and more systemic understanding of international and global systems is needed, enabling and sustaining the collective, cross-scale action involved in changing established systems dynamics is even more so.

Navigating between narratives, forging new common ground, and attending to the evolution of strategic vocabulary open questions of systems boundaries and framing contests. There is also a question of ethics: the contingent future as a design challenge and who is designing what and for whom? It requires attention to the quality of judgment not just the availability of data – a sensitivity to narratives, to framing contests, to making space for conflict and to managing disagreement as an asset within science and within policy making processes.

It requires rethinking the science-policy interface – Global Systems Science to support a better quality of strategic conversation and experimentation not just a better quality of analysis and predict and decide approaches.

Developing 'global' foresight relevant to new global polycentric policy context is core to the effectiveness of Global Systems Science and requires a multi-method modern futures toolkit in which rigorous analysis and intuition, numbers and narratives, hard and soft systems thinking have a role to play but not at the exclusion of the other.

How can Global Systems Science contribute to enabling 'whole system' governance and help with institutional innovation that is currently locked out by rigidities of established policy domains, structures and lack of interdisciplinary and trans-disciplinary science? What sort of science do new practice communities need/are they able to use? How can policymaking reorganize to attend to cross-scale dynamics (not top down vs. bottom up) and connected challenges (rather than issue-by-issue basis)? How does policymaking enable new value creation not just risk control?

Digital anticipation and global understanding

Big Data but what about the future?

Antoine Mandel, Diana Mangalagiu and David Tuckett

A quick search on Google about what “made the world faster” returns as first results: the cloud, internet, globalization, technology, wireless communication, the end of the Cold War, machines, information technologies. We have begun to design technologies that can take advantage of this increase in the speed of information transmission to develop better short-term insights. Some claim we can now forecast the spreading of flu pandemics or the volatility of stocks using search query data, the results of elections using prediction markets, the demand of new products by tracking their adoption by influential characters in social networks, and better manage prevention of and recovery from extreme events.

One question to ask is whether we can really do all of that and what might be its limitations. Is the availability and rapid analysis of large quantities of big data making societies better or what might be the problems? Another question is whether the developments that have increased the speed and reach of communication mean that our societies feel better empowered and more confident when facing the future? In fact it can seem rather the contrary. A sense of powerlessness is spreading from the unemployed, underemployed or less and less relatively well paid workers in Western Europe to the nation based policy-makers who have to confront global challenges such as financial and economic crises, climate change, or the rebalancing of power and influence at the global scale. In part, the picture is reminiscent of “the end of the economic man“ in the 1930s.

The sense of empowerment or powerlessness may have to do with how we create narratives and visions of the future at an individual or collective level. Recent studies such as Tuckett et al (2013) showed that “aggregate behavior is subject to the convergence and sudden co-ordination of shared narratives about the future and inherently fragile and unstable. Whereas the state of the world changes rather slowly the state of narratives about what is happening in it can alter very sharply and is strongly subject to social interaction and influence.” Such studies suggest that big data analysis can help to capture historical shifts in narrative sentiment and possibly warn about future patterns.

Most decisions at all levels are made in conditions of ontological uncertainty, which is in situations where the future development of entities and their future relations are profoundly unknowable ahead of time. While scientific and technical developments seemed to develop better tools for prediction and control, if we look longer-term it now seems that could be an illusion. The crises of all kinds can be viewed as wake-up calls to remind us of the limits to our anticipatory capabilities and the need to consider and improve our capacity to question models and to expect unintended long-term consequences.

There is a need to reflect on and experiment with how knowledge and foresight are developed and to understand how confidence and empowerment appear in multi-level, multi-stakeholder decision and policy-making processes. How emerging narratives and visions connect and co-evolve with existing ones and what is the role of human emotion and subjective narrative capacity in creating economic and social reality?

Preliminary questions to be addressed:

- In what ways is faster also better and in which ways perhaps not?
- What happens to digital communications and what do we know about their effects?
- Is there a sense of powerless among national decision-makers and, if so, what is the connection between that and the new communications systems?
- How can we make sure the short-term and specific issues on which scientists and experts are able to say something (e.g. insights on financial markets which suggest new regulations) also address longer-term consequences?
- In what ways, if any, can ICT help us to know where we want to go as societies and the obstacles facing us? What role for the emerging digital society(ies)?
- What is “big data”, what do we know about how is it being used, what seem to be the potential advantages and drawbacks and how can we try to make sure we have more of the former than the latter?
- How can large quantities of big data and new digital structures such as social networks and source of information help individuals, organizations, communities shape their vision of the long-term?
- How do we understand the impact of real uncertainty on us and in which ways do we manage it?
- What is a narrative?
- How do narratives of the future get constructed, spread, modify or dissipate and with what consequences?
- Can ICT help us to make use of human feelings (such as to be anxious or optimistic and excited) and to understand and analyze the effect on us of narratives and visions when we are placed in situations of uncertainty?
- How to use multi-tool and multi-method approaches? E.g. combine insights provided by traditional social science methods and tools with big data analysis, modeling, simulations, foresight methods and tools.
- Where and how to search for futures in the digital spheres (crowd-sourcing, data-mining, trend-hunting, weak signals…)?
- Given that human decisions are interactively reflexive, what are the implications for drawing conclusions from digital communication or creating policies on shifting data?

3.3.3 Computational Decision Support

Michel Morvan and Eric Boix

Being able to model, simulate and show deep results for the understanding of the systems involved in the problem is fundamental for the Global Systems Science but is not enough. Indeed, one of the main target of this science is to provide concrete tools to decision maker. Therefore, being able to couple the modelling and simulation approaches with simple to use demonstration and experimentation platforms is of key importance. These platform have to allow decision makers to understand and “feel” the involved processes, to make decisions and to be able to create a story to "sell" them. These platforms need to provide the access to different possible views on a same system/model to allow various experts to find the information they need.

3.3.4 Coordination problems in markets and Global System Science

Antoine Mandel

Though invisible, the classical hand that coordinates individuals' self-interests can perfectly be located: it is tied to the efficient operation of the market. Hence, even within the neoclassical realm, there can be coordination problems, markets' failures and inefficiencies. The electronization of Trade offers the opportunity to use advances in computer science to overcome part of these failures. More generally, improving institutional design in settings where the rational approximation is valid, offers a wide range of challenges at the interface between computer science and game theory.

The state of the art and the challenges facing Algorithmic game theory are very clearly summed-up in Nisan (2009)[11]:

- *At the beginning of the decade there were scattered attempts to model and study issues related to the Internet using a combination of computer science with game theory or economic theory. By the end of a decade a full blown academic discipline has emerged*.
- *Much work during this decade has gone into determining the computational complexity of various types of equilibria in games and in markets.[…] Most of the picture is understood at this point, with the most significant remaining open problem being the computation of approximate Nash equilibria.*
- *Starting with Koutsoupias and Papadimitriou (1999), much attention has gone into the analysis of the costs that the game-theoretic point of view levies on computational problems. The catchy name "Price of Anarchy", together with the convincing results of Roughgarden and Tardos (2002) who analyzed these costs in models of network congestion, have been extremely influential on the field.*

Beyond network congestion, most real-world applications have yet focused on online auction design, auction theory being a well-established branch of mechanism design. Theoretically, another low-hanging fruit is the design of efficient online schemes to finance local or global public goods (e.g trying to maximize contributions to climate change mitigation through an update of platforms such as http://thecompensators.org). Yet, the most important application of algorithmic game theory might be the reduction of transaction costs: first by the design of exchange mechanisms and market institutions that leave less room for strategic behavior and that make it easier to detect anti-competitive practices, second by decreasing the cost of contract enforcement by making the judicial process more transparent, its outcome less uncertain and immune to strategic manipulation.

In the negative mode, another potential contribution of algorithmic failures in game theory is to indicate what are the likely limits of validity of the rationality paradigm. As the scale of the system and the magnitude of feedback increase, in a nutshell when one moves from a market to a system of markets, the price of anarchy and the computational complexity are likely to grow beyond what is

[11] Reproduced here with the author's autorization.

reasonable. Drawing this limit might involve answering questions like: what are the limits of mechanism design with boundedly rational agents ? What is the optimal level of incompleteness in financial markets with error-prone agents (see Blume and Easley 2006) ?

When one reaches the limits of standard game theory, the problems that emerge call for adaptive governance technologies rather than a priori institutional design. Numerically, one might have to shift from algorithms to interaction (see Wegner 1997).
Building on insights from the management of the global commons (see Ostrom et al 1999), Global System Science can make a core contribution to a better governance of complex socio-economic systems by developing intellectual and technological frameworks that foster the coordination and the aggregation of individuals' objectives in a socially meaningful way, and facilitate the decentralized implementation of social objectives.

Thanks to the explosion of information technologies, all citizens of the world are potentially only one click away from each other. How can this structure be used to let people recognize common objectives and get organized towards their realization ? On the theoretical side, one needs to understand how the evolution of preferences and social conventions through networked interactions can help overcoming the impossibility theorems about social choice, how do social networks lead to preference distributions that are socially consistent? On the technological side, one must search for platforms that allow citizens to coordinate in view of addressing societal challenges. Embedding insights from Network Science, ICT and semantic technologies, one must target the development of self-provided, data driven and independent tools that allow the emergence of collective opinion and action. A major challenge in this respect is to promote self-awareness of groups and individuals while protecting privacy.

Beyond the construction of social objectives, Global System Science can contribute to their implementation by increasing knowledge about the socio-economic impact of policy, awareness about the impact of individual behavior. At least two fields are wide-open in this area: the development of our perceptive capacities of the socio-economic system thanks to appropriate data-mining tools, the reconciliation of economics and simulation in order to develop models of economic systems at a scale which is consistent with social reality.

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4 Concepts and theory building. An example.

4.1 Uncertainty quantification

Henry Wynn

Uncertainty quantification (UQ) can be seen as one of the newest of the series of encompassing themes of the last three decades which have an underlying stochastic nature. The quality improvement revolution came to the fore in the early 1980 as response to the competitive edge that Japan had gained by selling high quality goods into the US and European markets. The next big theme was risk, given an extra boost by threats from disasters of one kind and another various events that may affect populations on a large scale: climate change, financial crises, infectious diseases, geopolitical risk, and so on. UQ is close to risk, and perhaps one can be seen as containing the other, and maybe risk is just the negative of quality.

The special feature of UQ seems to be the realization of the dependence of decision making on large scale modeling. Climate change is a canonical example, but also engineering: think of the sheer complexity of the modeling that goes into the design of a new aero engine.
In fact, if there is discipline that started UQ it is engineering or applied mathematics. A list taken from the web in the start-up discussion for the new Journal on Uncertainty Quantification includes

- Code verification
- Model validation and estimation of structural model error
- Computational error estimation for numerical solutions, e.g., a
- posteriori error analysis
- Data assimilation and model calibration
- Detection and forecasting of high-impact, rare events
- Emulation of computer models and dimension reduction
- Inference with complex multiscale, multiphysics models
- Representation of uncertainty and error, and integration of
- different types of uncertainty, e.g., parameter uncertainty,
- numerical error, and structural model error
- Inverse problems, decision making and optimization under uncertainty
- Treatment of high-dimensional spaces

The absence of the words “statistics” or “probability” is striking, but is rectified in later versions. It is also notable that that SAMSI, the Statistical and Applied Mathematics Sciences Institute, which was set up, idealistically, to provide an interface between the two disciplines, had a whole year’s workshop on UQ recently in 2011-12 [1]. Although the area is wide we can attempt a classification.

Sources of uncertainty.

Much is made about different sources of uncertainty: model uncertainty, parameter uncertainty, observation error and so on. And a distinction is made, between objective and subjective uncertainty with the somewhat pompous terms aleatoric (statistical, empirical) and epistemic (knowledge) uncertainty. We will not dwell too much on all these distinction here see [3].

Sensitivity analysis.

This is probably the most universal method of UQ. For computer modeling, particularly finite element modeling in engineering, it has a formal meaning as the (partial) derivatives of the output with respect to an input or internal parameter. For example this might measure the first order effect of a system's response to change in a material property. Such partial derivatives can be computed with special methods such as the *adjoint method* to enable the derivatives to be output at the same time as solving for the absolutely output level. The most used method to use pure *Monte Carlo (MC)*: randomly changing the inputs or parameters and analyzing the output. Various less costly quasi-MC methods of generating input configurations are used such as Latin Hypercube Sampling and low-discrepancy sequences (Sobol, Halton, nets etc). These methods can be capture under the terms *error propagation*.

One of the most useful methods is that of *Sobol indices*. These are derived from a form of functional analysis of variance, very similar to traditional analysis of variance in elementary statistics, except that summation is replaced by integration. The marginal effect of all except k variables is integrated out, for various k and various choices of variables [2].

Polynomial chaos expansions and stochastic simulation

One concern or critique which has led to the growth of UQ is the fact that much scientific modeling has historically be deterministic: there was no probability in the input-output equation $y = f(x)$. A major attempt to rectify this has been *stochastic finite element* methods where a stochastic element where a serious attempt is made to model randomness. These are either extrinsic in which only the input and/or the output are affected or intrinsic in which the mechanism to express randomness is built into the actual solver. The best know method is that of polynomial chaos expansions (PCE) which are, briefly, polynomials in Gaussian random variables. To obtain the coefficients of the expansions, whether they are used extrinsically or intrinsically great attention is paid to integration and traditional Gaussian quadrature over special "sparse grids" are used.

Both the computer experiments (see below) and the methods of the last paragraph are not very well adapted to situation when the quantities being simulated are discrete (counting) variable when, say, multinomial or Poisson processes may be more appropriate. There are branches of simulation such as discrete event simulation which deserve more attention from a stochastic view-point.

Inverse problems

This is a huge area and, again, has an applied mathematics heritage. The basic aim for a system $y = f(x)$ the task is to invert to the input x-space from some behaviorof the output space. A canonical example is to find the x-values for which y lies is some region R. Thus R could be a "safe domain" in a reliability problem, an extreme value of y in some risk-related area, some design specification target or tolerance region and so on. In a nuclear accident one may not have measured the true release of radioactive material but can estimate it from the later air or ground readings. In radar one may be able to see around obstacles by recreating the image even when it is not in a direct line. This is very much related to idea of finding a "blind source" in signal processing. It might be argued that any estimation (identification) is a type of inverse problem. Uncertainty arises because of the intrinsic difficult of inversion, model inadequacy and because there will often not be an oracle to verify the answer.

Computer experiments

There is a host of issues relating to the accuracy of models. A very serious issue with large scale modeling is that large models are slow to run. If in addition to the basic modeling one needs to add a layer of secondary analysis, sensititivity analysis, inversion etc then, it then size may be prohibitive. In climate change change, for example a single experiments may take weeks. The cost pressures in time and resources leads to a search for simpler but effective surrogate models. This motivated the area of computer experiments in which interpolators are fitted to computer models using statistical principals of experimental design and analysis [4]. These "emulators" can be used to carry out any of the UQ methods that may have been computational difficult on a more complex and slower computer model. This raises the whole issue of which level of *resolution* of a model provides a good trade-off between cost and accuracy. At its simplest one may model in a very elementary way just to find out which inputs affect which outputs, a technique often referred to as *screening.* More advanced, *subspace methods* in various fields from classical principal components to modern machine learning methods have the same motivation.

Risk and Robustness

As mentioned, UQ and risk are close in spirit. Risk issues arise, perhaps more, in the case where models are used for decision support or, to use another well known terminology, as part of a *decision support system.* Satisfactory is that one can formulate utilities so that negative utilities are losses and expected utilities losses are risks. Ideal is that the uncertainty, whether subjective or objective or both, can also be captured in this way. Several areas combine the absolute level with the uncertainty about the level. Thus a good stock is one with high yield and low volatility, such as in portfolio theory. Optimal and robust control and robust design seek to keep on target while minimizing variability. These are hard problems precisely because the modeling must take into account the variation in the natural environment where the mechanism of interest (share, product etc) must operate. The notion of robustness is key.

Risk is a cornerstone of modern statistical theory under the banner of Bayesian methods. There the framework of utility is used in the first instance to gauge how well a statistical procedure, such as estimation or testing a hypothesis is performing. A great advantage of the methods is their ability to update a judgment of uncertainty with objective data, via the celebrated Bayes theorem. Importantly, the methods also apply outside formal statistical methods to cover any action which may be taken on the basis of the data, not just the statistical modeling actions. Interestingly, Bayesian methods have made great use of advanced Monte Carlo method to perform the necessary conditioning and integration which are part of the machinery.

Non-standard methods or representation

Whether Bayesian or more classical in the use of statistical methods in UQ the underlying expressions of risk are based on probability theory which has a very firm foundation. However this sometimes considered to be too strict a framework. This applies particularly to subjective assessment. Why should the rather vaguer feelings that express ones half-knowledge of unknown parameter or future events necessarily be best expressed by probability? A number of alternatives have been suggested. The two best known are *fuzzy* logic in which membership of a class becomes to key indicator and leads to a special way of manipulating sets and *upper and lower probabilities* which, as the title indicates, give upper and lower set coverage probability rather than probability attach to a set. That is to say the sets are random rather the parameter. This method has lead to so-called Dempster-Schafer belief functions which sit somewhat between Bayesian methods and fuzzy methods. In the hands of experts in "methodology", with strong foothold in philosophy and economics departments, there are many extensions of these ideas, see [5].

Stochastics

This is the study of stochastics processes and has been mentioned several time but deserves it own section. There have been huge developments in the field and UQ cannot ignore them. The largest advances has been made within financial mathematics which has lead to a microcosm of UQ and where we have seen many of the pitfalls played out. Thus, there is a hazardous and difficult to describe economic environment into which advanced mathematical models have been led and which have sometimes and catastrophically been found wanting. The risks have been huge. None of these failures say that there is anything wrong with the mathematics and, indeed, there have been great successes: martingales and asset pricing theories, large deviations, extreme value theory, copulas and various theories of risk. The UQ issues are, rather, about model validity, scope, timeliness etc all connected with the gap between model and reality.

Big models, big data, big risk

It is difficult to keep up with the sheer volume of activity arising fom access to very powerful computers, very extensive data collection, and very large computer models. To make matters even harder a long term debate is taking place between, to put it naively, the "modelers" those who think that science proceeds by careful data collection via designed experiments and model validation and by what we may call the "big data empiricists" who are happy to grow models, as one might a field of wild flowers, from the data. For the former the latter are simply unscientific, for the latter the modelers are close-minded luddites. Of course, this is just a re-hashing of an old debate which goes back to Francis Bacon versus Aristotle: induction versus deduction etc. But these matters will have a profound effect on UQ. We see it in climate change: huge deterministic models based on physical principals in battle with real weather data.

One positive benefit of the debate is that the large volumes of data, such as from social networks, is leading to new *types* of model based on mathematical foundation rather different from the big models from engineering which are often based on partial differential equations. These structures are more discrete: graphs, networks, combinatorics, geometries, ideas of complexity and hierarchical models of various kinds. It is exciting that geometry, algebra and topology, usually considered as part of pure mathematics are now being brought to bear on the emergent features in large data sets. These also have a stochastic side such as random graph theory.

Conclusions

We briefly summarize some key points

1. UQ is close to risk as an area whenever there is a decision aspect
2. Sensitivity analysis of some kind is critical
3. The range of model types that UQ will need to cover is increasing and should include a stochastic elements
4. Much can be learned from simpler surrogate models
5. Bayesian methods are valuable but other non-standard methods are useful.

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4.2 Prediction: Function and Limits

Introduction

J. Doyne Farmer

The question of how much can be predicted using GSS is a matter of considerable debate. On one side are those who think that by their very nature complex systems are unpredictable, that forecasts are necessarily inaccurate, and focusing on prediction is a waste of time. On the other side are those who feel that, without the discipline of making quantitative predictions, it is difficult to distinguish good science from nonsense.

To put some perspective on this debate it is worth noting that the word "prediction" means many things to many people. Some might interpret it to mean "accurate prediction", in the sense of celestial mechanics, while a seasoned forecaster might interpret it to mean far weaker forms of prediction. It is perhaps important to stress that prediction is often (perhaps even typically) not about temporal prediction in the sense of Newton's Laws, but rather about understanding relationships between different quantities, which may not have any specified temporal relationships. A good example being the ideal gas law, which simply states that at a given temperature pressure and volume are inversely related. The ideal gas law says nothing about how pressure or volume will vary in time, but rather it allows us to compress information because if we know the pressure, we can then predict the volume.

Indeed, according to standard results in machine learning and statistics, the problems of prediction, data compression and noise reduction are equivalent. This is not surprising -- if it is possible to compress data, then it means that it is possible from a subset of the data to predict the remainder. From a quantitative view a model is useful only insofar as it compresses data, and thus any useful model has at least some predictive power.

Of course, it can be difficult to quantify the predictive power of a qualitative model. For example, most people have models of their close friends, which allow them to predict how they will respond in a given situation -- indeed we all use such models for people in general to avoid socially unacceptable behaviour. Such models are essential, but their value is hard to quantify.

One of the reasons why GSS has so much potential is that it offers us the possibility to make better predictions, at least in the more general sense discussed above.

End of Doyne's Farmer contribution here

Market Prediction

By Armin Haas

Hayek is famous for his hypothesis that a market is a very efficient device for collecting and aggregating dispersed information. In recent decades, the idea of using the wisdom of crowds for predicting the outcome of various events or processes spread. The best-known examples are markets for predicting election results.

The idea of setting up artificial markets for predicting the outcome of social processes has a long history. Nearly 150 years ago, betting markets were organised for predicting the outcome of U.S. presidential elections. On these markets, contracts were defined for each candidate, which paid off a fixed dollar amount in the case of the winning of this candidate. All other contracts of the non-winning candidates would pay zero. These contracts were traded on betting markets. The amounts invested in these markets were enormous. The maximum was reached in 1916 with $165 million (in 2002 $), which was twice the total spending on the election campaign (Rhode & Strumpf 2004).

Rhode & Strumpf (2004) analysed US presidential elections between 1868 and 1940 and found very successful betting markets with a remarkable forecasting performance although the information via media was relatively sparse compared to today. In one case, only, the favoured candidate – one month before election – was not the winner.

With the rise of polling, these markets became out of fashion. Only in 1988, a modern prediction market was conducted for the 1988 U.S. presidential elections (Forsythe et al. 1992). As this market performed remarkably well, it gave rise to many more markets under the label of "political stock markets" that showed good results compared to traditional political forecasts (Berlemann & Schmidt 2001). The good performance of political stock markets induced the spread of the concept of prediction markets to topics as diverse as macroeconomic risks, product marketing, political instability, and military success (Fucik, 2010).

Typically, prediction markets concern outcomes that can be observed in rather short time, which is necessary in order to determine the pay off of the contracts traded on these markets. Fucik (2010) suggested setting up prediction markets for events in the far future, like the outcome of climate change in 2100. The Potsdam Climate Exchange (PCX) is a platform for experimenting with such innovative prediction markets (http://www.potsdamclimateexchange.org).

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4.3 An Example of Theory Building: Cities

Michael Batty & Denise Pumain

In examining new theories of urban systems, we consider that we should divide our potential research directions into a concern for inter-urban location and interactions in systems of cities, and then focus on what happens in terms of locations and interactions within the city system, in the intra-urban context. To an extent this reflects the way research has developed over the last half century, and we intend to relax this distinction in this research by examining the extent to which common theories can apply to this range of spatial scales. Moreover the dynamics in cities and in systems of cities is somewhat different in that systems of cities increasingly display a global dynamics while single city systems have their own competitive forces. The challenge of course in global systems science is to figure out the extent to which a global dynamics involving all cities influences what goes in in individual cities. This would lead to an integration of inter-urban and inter-urban theories.

4.3.1 Systems of Cities

Since their emergence a few thousand years ago cities were always a specific way of inhabiting the earth by connecting places of diverse capacities and resources enabling a reduction of local uncertainties through exchanges of goods, persons and information. The territories and the networks they irrigated became on the whole larger and larger in scale during history with increasing intensity and frequency of exchanges that at the same time rendered individual cities more and more interdependent of each other. When observed in consistent territories as nations for instance, these "systems of cities" share common properties in different parts of the world, mainly a strong hierarchical differentiation from a large number of small towns to a few huge metropolises; a functional specialization following the uneven location of resources and historical path development of places; and a pattern of growth rates that are distributed almost evenly in territories having homogeneous conditions of demography and economy. As since a few decades the upper part of the urban hierarchies of different countries as well as a few specialized cities become more and more engaged in a variety of exchanges through globalization networks, new challenges appear for policies aiming at monitoring the development of this expanding global system of cities. The first one is the growing divergence between urban hierarchies where cities are ranked by their population and the one where they are ranked according to their GDP: as the highest accumulations in production value and income are still concentrated in the major urban nodes of developed countries that have finished their urban transition, the major cities of tomorrow in terms of population concentration are already observed in emerging countries, especially in China, India and Africa with many cities of unprecedented sizes (many of them above twenty or thirty million inhabitants) and huge conurbations (megalopolises) concentrating from fifty to hundred million inhabitants in a continuum of urban settlements; a second challenge is about how these cities may accommodate in decent living conditions and working places the millions of rural workers and new urban citizens who will arrive in mass in the cities without increasing too much the already considerable intra-urban social inequalities; a third challenge is linked to the pressure exerted on planetary environment by this unprecedented urban growth through resource and energy consumption at world scale.

If the urban dynamics and processes are comparable today all over the world, the qualitative form and structure as well as the cultural aspects are still very different according to the region, because of the strong historical path dependence effect in the dynamics of systems of cities: for instance, Asian cities are ten times more compact than European ones and twenty times more than North American. As there exists nothing like any optimal city size or form, different solutions have to be invented (and many already are) for meeting locally these global challenges. There is indeed a need for a variety of urban realizations that can share the same objectives but perform better adaptation by contributing to maintain the urban geodiversity. This intrinsic value of the variety of urban settlements is not only linked to maintaining the urban heritage for touristic, geomarketing or patrimonial reasons but as well for preserving the global capability of further urban evolution.

Challenges for research at the scale of systems of cities are at first in developing consistent data bases for worldwide comparisons. This is indeed a huge task considering the diversity of urban definitions and plurality of local systems of administration and governance that make all quantification of urban facts a tedious although necessary exercise (still even inside Europe!). The new stocks of "big data" may be helpful but have to be tested and interpreted through confrontation with other more "classical" sources of information. Especially, the step identifying relevant local urban entities (i.e., the spatial envelope of daily urban activities for a majority of urban citizens) is absolutely necessary for modeling in a correct way the dynamics of systems of cities. Second, dynamic modeling of systems of cities is necessary for envisaging plausible predictions of the future of these open and heterogeneous systems. Knowing the numerous short term fluctuations and the several decades duration of trends in the trajectories of individual cities, a reasonably long span of time is required for observing and modeling their dynamics. New models that would link the urban and economic growth with scenarios of energy and resource consumption and pollution emissions at continental and global scales are necessary for improving these predictions. Obviously, their construction requires the collaboration of different sciences that are too rarely connected, including all social sciences, engineering, ecology and climatology as well as complexity sciences. Finally, the development of global networks has to be analyzed through a close comparison of their local anchoring and transnational expansion, together with international regulations.

4.3.2 The City System

Cities are highly structured spatially usually with a predominant core around which land use and economic activities are differentiated according to the extent in which different types can output one another for access to the central core, which is often the most accessible point in the city. This differentiation can be reflected in concentric zones of various land use types where their density and the prices or rents that they can command vary inversely with distance from the centre which is usually called the central business district in the modern city. This idealised pattern is explicable in terms of a basic model of the urban economy where land use agents maximize their spatial utility subject to various budget constraints. In fact the patterns that we see in real cities can be considerably distorted from this ideal type and in the last fifty years, the core of the city has dispersed with new centres, sometimes called edge cities, appearing within the urban fabric thus producing a polycentric spatial organization, which in turn is further complicated by single cities joining together in terms of ever larger agglomerations.

The various theories that explain these phenomena have been developed over the last fifty years and are cast within a systems approach in which the various components of the city are tied together my flows of goods and people which in turn have been modelled using various gravitational relationships in which scaling laws are implicit. Many of these approaches however assume that cities are in equilibrium and thus more recently there has been a major effort to cast the development of urban structure in a dynamic framework, drawing from complexity theory which enable the evolution of city forms from the bottom up. Ideas from automata and fractals form the essence of various new simulation models of cities that have been developed.

The key problem for explaining how individual cities are influenced spatial in terms of their functions and interactions in a global world, is how activities taking place globally influence local spatial locations. In large cities, sometimes called world cities, with a large proportion of global financial services, decisions made globally impact the local structure and the challenge is to explain and produce local differentiation in urban structure as a function of their position in the global hierarchy. In short, we urgently require our models to be generalized to take account of the multifarious network of global flows involving information, trade, and migration as well as differences in local culture and political practice.

The key challenge then of global systems science is to generate new models of how individual cities which exist in a series of hierarchical systems of cities all the way from the regional to the global level, are able to function interdependently with the differentiation that originally took place within individual cities now talking place at multiple levels of hierarchy across the globe. To explain and more importantly to predict the global urban future, we need to employ the many new insights in network theory, migration theory, input-output modeling of various kinds, in scaling which focuses on the shape and size of cities in this hierarchy, and the way in which city systems evolve towards new forms with new problems that traditional styles of planning and management have dealt with. In fact we need new forms of planning to address the many problems that a global distribution of cities implies, involving questions of aging, migration, relative differences in income and GDP and a whole host of global problems that are evident at the scale of cities. One challenge is to find new agencies who command the political support to address cities that straddle national boundaries and new institutions of planning are needed to address the challenge of the global city.

Only by employing the tools of global systems science can we get to grips with the problems of the global city. In particular, this program will develop new models which will address the interdependencies between cities at the world scale, examining how changes in flows which in turn are manifested in networks can give rise to structural change which in turn can generate crises of migration, trade imbalances, and population growth and decline. We need to build models that enable the new properties of the global city system to be reflected in their predictions and we need these models to enable us to predict distinct bifurcations and catastrophes in the evolution of the global system in terms of cities. This is particularly relevant for Europe because the European system of cities is still fast developing with cities finding new roles within the Community and of course relating more general to other regions of the world in terms of their specialization and urban growth. New urban models enabling such predictions should take account of new ideas pertaining to the smart city and of course new data sources (big data) but should be built around the notion that other themes and perspectives in the GSS programme involving economic and climate science should be reflected in the global urban landscape whose cities represents the key points where such challenges an crises work themselves out.

4.3.3 Employing GSS to Establish a Science of Cities

Colin Harrison

It is a central belief of western civilization that we are capable ultimately of understanding the world. Our understanding is not, at any given moment complete, but exists to a certain degree. Moreover we believe that this degree will improve over time.

I am mindful of watching a BBC documentary at home with my father in the early 1960s. At that time, the UK weather forecasting was based on observations and measurements from a number of weather ships stationed well off the coasts in the Channel, the North Sea, the Atlantic, the Irish Sea, and so forth. The BBC programme was about some British scientists who had the heretical idea that they could use computers to forecast the weather. My father, who was not a particularly religious man, was outraged, since as he believed, the weather was whatever God chose to send.

Indeed in the beginning computer-based weather forecasting was worse than the forecasts based on the weather ships. But this was a great age of science and engineering and in the coming years the weather ships were complemented and finally replaced by satellite observations, by balloon sondes, by Doppler radar, and by hundreds of mainland weather stations networked with dial-up modems. The power of scientific computers grew dramatically enabling them to deal with ever greater amounts of meteorological data and even more complex physical models of the air, the land, and the sea. So more data and more computing power begat better models and better models begat better meteorological science and altogether they begat far better and higher resolution forecasts. Thus today the 5 day forecast is highly accurate and even the two week forecast is valuable to many purposes.

And so weather forecasting was added to the long list of areas of the world that were once viewed as beyond human understanding and yet have proven to be understanding at levels that are not complete or perfect, but that are nonetheless useful. Others include the solar system, the ultimate constituents of matter, the many systems of the human body, and so forth.

We find ourselves today in somewhat the same position as those computing pioneers of weather forecasting. Our weather ships, if one may equate Jane Jacobs provisionally to a weather ship, are being complemented by floods of information from a vast array of sensors in the natural and built environment, by government and industrial statistics, and by the chatter of the social networks. Moreover we can now draw on some fifty years of increasingly realistic and accurate methods of representing, visualizing, analyzing, and simulating complex natural and human phenomena. This body of expertise is gathered under the heading of Global System Science.

We therefore feel emboldened to hypothesise that it may be possible to develop a Science of Cities by harnessing Global Systems Science to help us to gain insights from the floods of urban information. Karl Popper defined the status of a theory as "falsifiability, refutability, or testability"[12]. Until now this benchmark has been beyond our reach, since we had neither the means to observe, nor the means to structure (taxonomy) and analyse (test) our hypotheses. But the advent of the Internet of Things and more specifically Smart Cities brings us within grasping distance of the benchmark of a Science of Cities.

Why should we want a Science of Cities? Because by the end of the 21st century the vast majority of human beings will live in urban rather than rural areas. In this century we will construct as much urban capacity as has ever previously existed on the planet. Finally the cities that we build in this century together with those already existing will probably serve global society for many centuries. It is time that we had a Science of cities to enable us to get the design, construction, operation, and management of our Cities right so that all citizens, wherever they may live, may have the best opportunity for a safe, healthy, prosperous, and sustainable life.

Hypotheses

The problems that GSS proposes to attack across all domains are (relatively) old, of very large scale and complexity, are due in large part to human behaviour, and cross many academic disciplines. That they have not been solved already is not for want of intellectual effort. A central question that GSS must address therefore is why it expects to succeed where so many other methods have failed. We give here a number of hypotheses that a GSS research programme must test.

1) GSS provides methods and perspectives that will allow discovery and definition of formal descriptions (typology, taxonomy…) of cities. These descriptions will provide the frameworks for the integration of the large volume of existing knowledge about cities. This line of research

12 Popper, Karl, "Science as Falsification", Conjectures and Refutations (1963). Found as http://www.stephenjaygould.org/ctrl/popper_falsification.html

will reveal archetypal patterns of structure and processes in cities that have hitherto been obscured. We acknowledge that there are many existing typologies and taxonomies of cities[13]. A similar situation prevailed in the early years of genomics and proteomics. One of the breakthroughs that accelerated the sequencing of the human genome was the invention in Information Science of methods and tools to cross map such information structures thereby enabling all researchers to share a much larger body of data.

2) A crucial aspect of the challenge in Urban Systems comes from the increasing scale of cities with Mega-Cities such as Mexico City, Tokyo Metro Region, and Nairobi reaching 20-30 million people. GSS will provide a channel for integrating successful methods developed in other disciplines for dealing with systems of extreme complexity. For example, GSS might work in Computer Science on the design of information flow in large semiconductor chips, where the feature count today is measured in billions. The semiconductor design community has developed powerful tools for exploring and planning the flows of information in such complex semiconductor systems. We anticipate that such cross-disciplinary methods will bring much innovation to the application of GSS to these complex problems[14]. Lest it be objected that transistors are deterministic machines, whereas in cities we are dealing with the behaviours of millions of people endowed with free will, we note that that at nanoscales the properties of individual transistors are probabilistic and yet it is still possible to produce meaningful simulations of entire chips.
3) GSS will foster a positive spiral of interaction between new theoretical structures and new experimental methods. The formal structures will provide the frameworks for integrating new information emanating from new experimental methods based on Smart City sensors, the Internet of Things, social media, and other novel sources of information. This is the modern analogue of the weather forecasting anecdote.
4) As archetypes or references patterns emerge they can be validated across large numbers of instrumented cities and from this will emerge the deviations from the norm that endow different cities with different characteristics. GSS will begin to identify the pathology of cities, diagnostics to determine the pathology of a given city, and eventually methods to remediate under-performing cities.

Point of View

1) We consider a city to be a complex organism that is developed and exploited by its inhabitants in order to fulfill their lives. Specifically, we consider a city to be a metaphor for a biological system, such as the human body, with sub-systems that scale down to the levels of biological cells and atoms. The biological system contains complex infrastructures that interact by passing information to perform processes that produce (generally) desirable outcomes that serve the various needs of the system and of its external networks. The cell consumes resources from its environment and both produces needed synthesized materials as well as waste and by-products. The emerging system of systems understanding of the structure of biological systems motivates the development of new instrumentation and

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13 We acknowledge the body of knowledge produced by urbanists, particularly the New Urbanists, on classifying patterns of urban land use and layout and this work will certainly need to be integrated into these studies. However, we think here more broadly in terms of a wide variety of structural and functional taxonomies and typologies.

14 Rent's Rule, see http://en.wikipedia.org/wiki/Rent%27s_rule. Rent's Rule falls within Network Theory and describes hierarchical relationships between entities that seek to communicate and the types of networks that connect them. While it origins go back to the 1960s, it is still releant to the design of modern chips that include several billions of features.

experimental method and contributes to the direct understanding of how the biological system works. For many centuries most people did not believe that we would ever understand how the human body works and indeed there is still much to learn. Many had attempted to understand just the circulatory system, but disagreement reigned until the experiments of William Harvey proved that the blood flow through the heart and the lungs into the arterial and venous systems and returns to the heart. By the early 20th century much was understood about mammalian cells, about the <types of molecules> found in them and the many thousands of varieties of cells. But the instrumentation did not exist until the 1950s and 1960s to begin to discover the architectures of cells and even more recently to begin to enumerate the many biochemical processes that regular individual cells and in turn influence the regulation of the whole body. We find ourselves today suddenly blessed with new instrumentation and new methods for discovering the archetypal structures of cities and the processes by which they regulate themselves.

2) In this analogy, we consider cities to be complexes of natural and built infrastructures. These infrastructures support processes that are combined by the inhabitants to perform their desired or delegated tasks. We may call these processes Urban Systems or components of Urban Systems. The discovery and formal description of the archetypal patterns of infrastructures and the resulting Urban Systems are a central goal of Global Systems Science in this domain.
3) The exploitation of these processes consumes raw or processed resources that are extracted from the city’s natural environment, synthesized from such raw resources, or imported from the city’s trading network. The exploitation of these processes also (generally) produces waste or by-products that are passed to another process, discharged into the city’s natural environment, or exported to the city’s trading network. The exploitation of these processes contributes value to the Triple Bottom Line.
4) We may visualize these processes as activities on a set of geospatial layers beginning in the natural environment and extending upwards to the layers of Social Systems consisting of cultural, economic, and social activities. There may be some hundreds of these layers, representing the city’s complex structures that support the Urban Systems. See Figure 1 for a simplified visual representation of this construct.
5) In addition to resource consuming processes, cities are and always have been Information Processing systems that exploit this inherent human capability to create many kinds of value. Some Urban Systems may be (almost) purely Information Processing systems. Information itself contributes both directly and indirectly to the Triple Bottom Line. ICT adds to the inherent human capability for Information Processing many new capabilities for the capture, communication, and analysis of information flows within and among cities.
6) The inhabitants use the Urban Systems by composing choices among those systems that are known and accessible to them to complete sets of tasks that they generate themselves or that are delegated to them by others, perhaps as part of a job.
7) The processes whereby the inhabitants individually or collectively make these decisions are guided by social norms, municipal policy and laws, and personal preferences. The establishment of these norms, policies, laws, and preferences fall outside our competence.
8) Each inhabitant’s choices of how to exploit the accessible Urban Systems are mediated by flows of information and in turn generate further flows of information. In addition to intra-city flows of information, we consider also the inter-city flows of information that mediate trade,

the flow of human and financial capital as well as modulating the exploitation of the internal Urban Systems. These information flows, together with the formal representation of the infrastructures, provide a complete description of how the city works. They form a complete analogue of the biological cell.

9) These factors of resources, processes, information flows, types of actors, and others can be studied at progressively increasingly levels of detail. As more information becomes available, more detail can be extracted about the structures and processes.
10) There is a very large amount of work to be done to discover the archetypal pattern and principles of city's and then to understand how a specific city deviates from the archetype and how these deviations add to or subtract from the Triple Bottom Line. As with biological research, the existences of a complete theoretical framework will provide motivation to structure and filter the large body of existing knowledge about cities and to develop and apply new experimental techniques that will refine and extend this knowledge.

This Point of View leads us to a high-level process model for the application of GSS to the development and application of a Science of Cities as shown in Figure 2. At the heart of the model are the flows of information that are increasingly rendered visible through the digital media that represent and transport them. Across many cities of varyig typology, this information is captured, structured, integrated, stored, and studied for possible structural and behavioural patterns. From these patterns the various interested disciplines may conjecture common principles of cities and test these hypotheses using the experimental information to test or refute these.

Goals

1) To establish a foundation of understanding of the common and distinct features of cities around the world from the perspective of GSS.
2) To establish understanding of how observable differences in the structure and operation of Urban Systems within a city contribute to the city's outcomes in terms of the triple bottom line.
3) To establish understanding of how observable differences in the structure and operation of Urban Systems between a city and its environmental, cultural, and economic partners contribute to the city's outcomes in terms of the triple bottom line.
4) To develop general diagnostic and predictive tools that can be customized and applied to improve the city's outcomes in terms of the triple bottom line.
5)

Programme of Applied GSS Research on Urban Systems

1) To identify a typology of cities in terms of their size, GDP, or other global characteristics, leveraging prior research studies in Urbanism.
2) To identify a "physiology" of cities in terms of observable Urban Systems phenomena and that shows the common features with a given typology, including types of network structures found.
3) To develop taxonomy of Urban Systems that enables a formal description of a city's infrastructure in terms of a stack of GIS layers representing different aspects of its natural and built environment and so forth as shown in Figure 1.
4) To develop increasingly detailed descriptions of the hierarchies of processes that exploit the resources and sub-processes of these layers to produce Urban Systems and to define a

programme for the progressive aggregation, integration and development of various kinds of simulations at various scales.

5) To determine how the city's own Urban Systems inter-connect with those of its network of trading partners and to develop archetypal patterns of information flows among cities.
6) To refine from these observations archetypal patterns of infrastructures, resources, and processes that represent an idealized city or sets of such patterns that can cover the observed typology of cities.
7) To apply the patterns and principles emerging from the above work to create common but customizable tools for mapping a given city's infrastructures, resources, and processes to the archetypal patterns and to analyse how and why the city deviates from these patterns.
8) To describe the pathology of these deviations and determine how they improve or impair the short- and long-term performance of the city in terms of the Triple Bottom Line.
9) To explore new theories of city governance based on insights from integrated systems studies with special focus on governance of Mega-Cities.
10) To inter-connect these GSS models of Urban Systems with other applications of GSS, for example in climate, energy, and finance.
11) To extend GSS itself by learning from these application to Urban Systems.

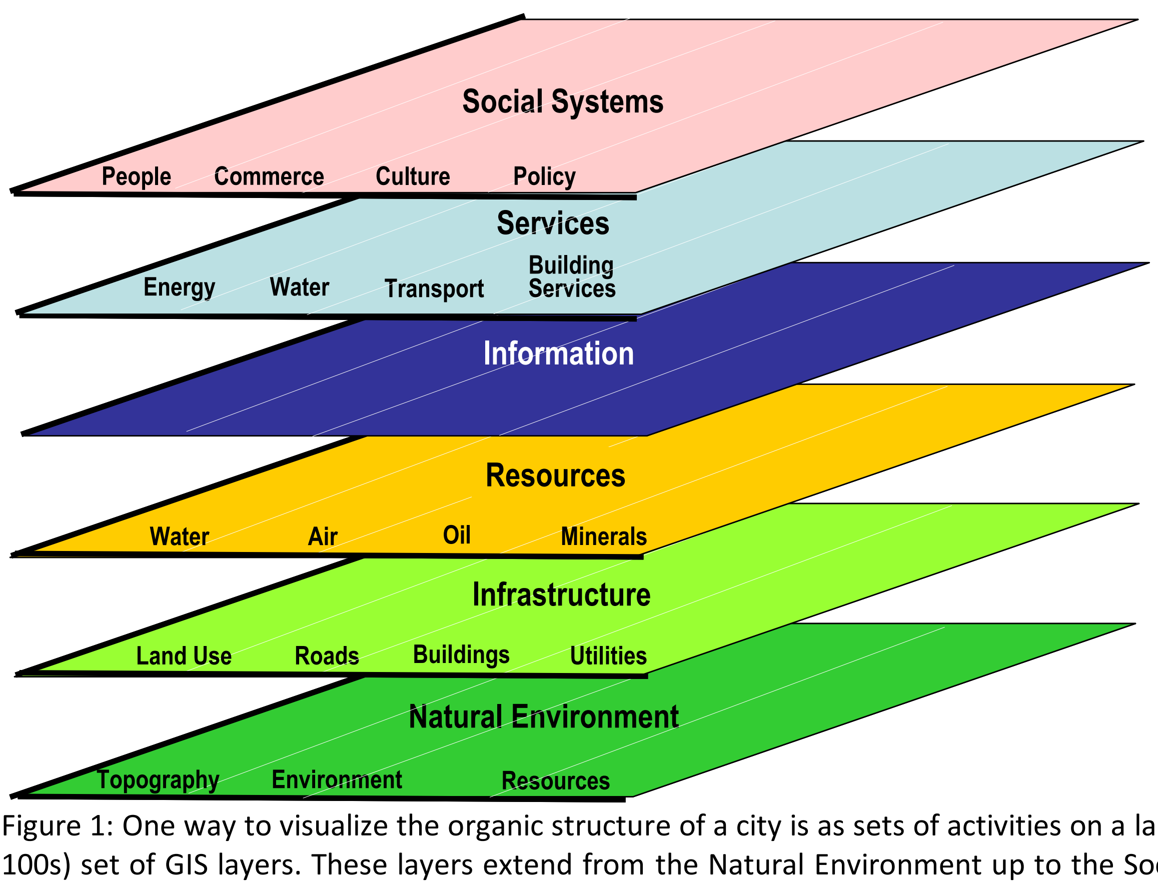

Figure 1: One way to visualize the organic structure of a city is as sets of activities on a large (order of 100s) set of GIS layers. These layers extend from the Natural Environment up to the Social Systems. Activities on all layers generally draw upon resources emanating in lower layers, pass added-value resources upwards and waste or by-products downwards.

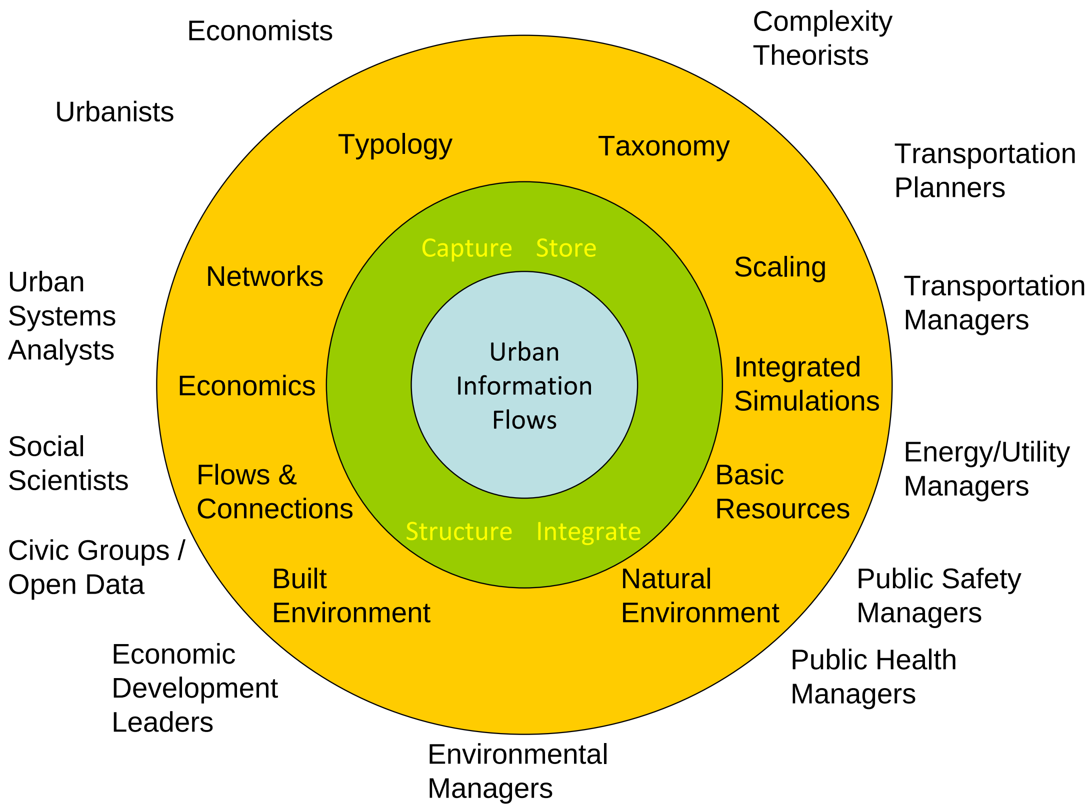

Figure 2: An illustration of the paths to understanding that can result from a GSS perspective on Urban Information Flows as core indicators of the life of a city or urban region. It shows the several perspectives (Taxonomy…..Typology) that can be applied to the raw information and the disciplines and professions that can then exploit the insights produced from this approach and to create collectively a Science of Cities.

5 Towards a Research Programme for GSS

We begin to have sound elements for a theory of global systems. These systems are multilayer networks whose structures change stochastically through time. A promising route of theory building identifies some of the nodes in those networks with human – individual and/or collective – agents, others with artefacts like buildings or computers, and still other ones with elements of the environment like the Himalayas or the West-Antarctic ice-shield. Human agents may belong to families, nations, occupational groups and other networks. Agents can die and be born, including the possibility that lower level agents form coalitions that operate as higher level agents. At a given moment in time, an agent has some goals, a limited perception of the overall system, limited memory of its past behaviour, an action space dependent on resources of the agent, and possibly an internal model of the system as a whole.

The interaction between agents can then be described by means of game theory, with each agent playing iterated games with samples of other agents. The outcome of each iteration modifies perception, memory, resources and possibly goals and internal models. Agents learn both from their own experience and from observing others, with imitation being more frequent than individual learning. The topology of the overall network represents the existence of nations as well as of global interactions via markets and via other channels, including the global ICT structure.

Since Dijkstra's path-breaking analysis of computational systems with distributed control, much progress has been made in analysing the kind of networks sketched above. In particular, work on the evolution of conventions has shown how multiple basins of attraction can be identified and investigated, including transitions from one basin to another or chaotic trajectories between them. By means of algorithmic game theory, speeds of convergence can be estimated and compared to the effects of random shocks. Accepting that on actual markets goods trade at prices set by individual agents allows to applying this framework to market interactions.

This approach can be used to study computer networks, including the internet as a whole. It can also be used to study other global systems, with computer networks themselves becoming possible models of global systems in general – while keeping in mind the challenge of identifying the scope of application of models by means of suitable narratives.

In developing these kinds of ideas, there is the challenge of increasing the epistemological awareness of the GSS community. Is this community aware of all the different contingencies and partiality of all different types and sources of knowledge (social sciences, mathematics, engineering) which need to be considered in GSS? And are we aware how this should help GSS practitioners and society at large to make sense of the tools that we develop and help us to get the right signals from society and from the other scientific community to develop such tools? This is a challenge about how we frame the making of GSS, and what we can expect from it.

In Europe many tend to think in terms of civil society versus the state, but this may not be an accurate way of thinking the world today. We now live in a more knowledge-based and information society, so we need to focus on networks of professionals – to avoid superstitious ways of public engagement. We can do that in GSS, e.g. in medicine and health insurance. That is it is not enough to consider people in their role of citizens, but also as professionals. GSS then can become part of the toolkit used by professionals and citizens of the future to gather, organize and use the know-how they will need to deal with the global systems that will be pervasive elements of their lives.

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7 GSS Workshop reports and additional contributions

7.1 Brief report on the Data and Models workshop on GSS

On 7-8 February 2013, 20 experts were convened in Brussels to kick start a collective inquiry on long term perspectives of Global System Sciences with particular focus on the role of models and data. The workshop was the first of a short series of consultations that will contribute to shape visions and research challenges to inform future Horizon 2020 reflections. Digital Futures animated the conversation on the first day and will host the content co-created by the experts on its collaborative foresight platform Futurium.

Introduction

The European Commission's Directorate General for Communications Networks, Content and Technologies (DG CONNECT) has launched the Digital Futures foresight to prepare for reflections on ICT-related policies beyond 2020.

The project's most distinctive feature is the grassroots involvement of stakeholders to define long-term visions (around 2040-50), anticipate possible challenges and opportunities, and generate ideas to inform the policy reflections that will take place in 2014 around the renewal of the European Parliament and the Commission. Stakeholders use the online platform Futurium to co-create the visions and policy ideas and attach scientific evidence to them through a library of relevant references

An event fitting two purposes

The workshop "Global System Sciences: the role of models and data", took place on 7-8 February 2013. It was hosted by Unit C3, "Digital Science" in DG CONNECT. Thierry van der Pyl, Director CONNECT-C "Emerging Technologies and Infrastructures" welcomed the experts on 7 February morning and set the context for the Digital Futures workshop in the afternoon and for the day after.

The Digital Futures conversation focused on visions and ideas for possible action, to help feeding the foresight content on Futurium.

The meeting on 8 February went deeply on the topics and issues identified during the first day with a view to produce on Orientation Paper for Horizon 2020 reflections.

Goals of the Digital Futures conversation:

1) Reflect on scientific and technological futures related to global system sciences and their possible policy implications.
2) Reflect on ideas that could be offered as hints to the European Commission to underpin the chosen futures.

After a brief "ice-breaker" session to let experts getting into a brainstorming mindset, the visions presented during the morning were summarised in a mind map.

Key aspects of a vision for a Global System

Science were initially split into four groups:

1) Science and Technology
2) Environment and sustainability
3) Society and economy
4) Anything that does not fit under the other groups

Most of the ideas emerged around the aspects of models and data, the underlying scientific and technological foundations, the enabling infrastructures and the potential policy making applications:

- Computer Science and mathematics for interacting Informational, Techno-logical and Social Networks
- The role of uncertainty: how to communicate uncertainty in interaction with decision makers?
- The role of data: How to obtain them? How to validate them? How to sue them in policy context?

This short session produced first elements of a GSS vision characterised by:

- Active data collection and measurement
- Policy making driven by data and evidence
- Democratic decision making underuncertainty
- Continuous feedback loop between perception and action at a global scale
- Removed language and socio-technological barriers
- Open mindedness everywhere across disciplines, communities, roles
- Stakeholder involvement
- New approaches to move from models to
- Domain Specific Languages
- Unintended behavioural models
- Unprecedented levels of computational power through parallel computing
- Resilience, robustness and affordable redundancy in infrastructures

- Understanding plausibility of trajectories
- Established science of policies
- Effective domain-specific policies, e.g. sustainable energy, finance…

What do we imagine life in Europe to be like in 2050? What are the digital futures we imagine will allow us to co-create relevant and adaptable policies for Europe with citizens, member states, sectors, regions, Europe wide?

The process was designed so that the essence of what was happening in the room was continually reflected back to the group as the work progressed.

Challenges and opportunities stemming from the visions In the workshop, we then looked at the challenges and opportunities. Each expert was invited to write on a post-it one "challenge" and one "opportunity" and then to exchange their contributions with other experts to allow commenting and improvement. This was repeated for three rounds.

The challenges and opportunities emerging from the three round interactions were placed on a wall and clustered around groups which were consolidated and structured offline:

--- Breaking inter-disciplinary boundaries
--- Building the scientific foundations
--- Managing and making sense of Big Data
--- Models and simulation, languages
--- Infrastructures and resources
--- Ownership and regulations
--- GSS and policy making
--- Communicating GSS and engaging society

The complete list of challenges and opportunities can be seen here: http://goo.gl/qWbhG .

What needs to be done to achieve the visions?

With the challenges and opportunities in the background, experts were invited to sit around tables. Two rounds of "world café" sessions took place in four small groups to elaborate policy ideas, including needs for Research and innovation investments, to underpin the given visions.

The focus of conversation was articulated around four main topics:

- policy-making&societal challenges
- languages&interaction

- expertise, models and data
- foundation & science building & complexity

Emerging policy ideas:

- capacity building actions (funding of CSAs, thematic networks and exchanges)
- embedding policy modelling and GSS into policy making
- fostering of multidisciplinarity by Horizon 2020 funding
- stimulating work on societal challenges through specific objectives in Horizon 2020
- continuous work on privacy provisions in big data environments and data anonymisation
- IPR and copyright solutions that do not harm collective needs as well as address the problem of collaborative production of such data
- focus on policies (legislation and funding) that stimulate open access to data, models
- and other scientific results of GSS
- investment in infrastructures supporting real-time computing for policy making
- increase participatory approaches to policy making (work on framework
- conditions,

Framing Day 2

Experts were sitting together in a circle to elaborate headlines and big questions to be addressed on the second day. Focus of the second day was to continue the brainstorming but focusing more deeply on the topics to be addressed in a possible Horizon 2020 context.

The outcome of the discussion of day two will be an orientation paper. The first draft for commenting and further contribution is available at: http://ec.europa.eu/digitalagenda/ futurium/en/content/visionsglobal- systems-science-models-and-data

Closing the brainstorming

The day was wrapped up with a large circle in which everyone shared with each other what the workshop had meant to them and what had struck them the most. This exercise showed that experts were willing to share good ideas with each other in an unusual and serendipitous consultation setting.

There was a considerable sense of participation and willing to proceed with incremental development towards a fully-fledged vision for GSS and the associated ideas for action.

Experts co-creators

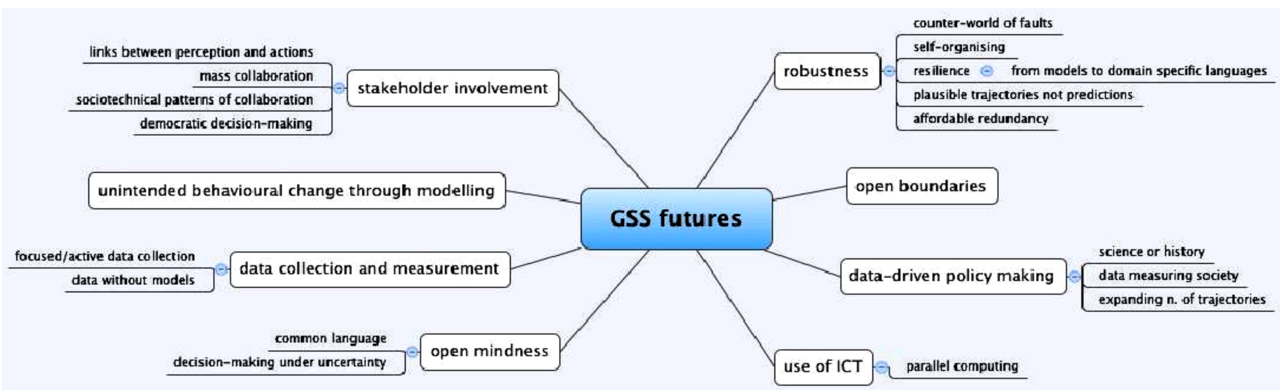
The event gathered 20 participants from various disciplines related to global system sciences, including Commission officials. Participants were invited by Unit C3 "Digital Sciences". The attendees were mostly European with two participants from the United States of America.

Getting involved online

Digital Futures has launched an online participatory lab, the Futurium, to engage all who wish to participate in shaping the visions, challenges and opportunities, and in identifying the policy ideas to be offered as hints for the Commission's next policy framework. You are welcome to join the Futurium at http://ec.europa.eu/digitalagenda/ futurium/en

The session was also accompanied by the Twitter backchannel using hashtag #gss13, see the Storify summary at:

http://storify.com/katarzynasz/gss-2013-models-and-data-workshop



Mindmap of key issues discussed (downloadable at http://ec.europa.eu/digitalagenda/ futurium/en/content/visions-global-systems-science-models-and-data)

Workshop Concept note:

Public policy making, when addressing challenges such as climate change, financial crises, or containment of pandemics, suffers from an intrinsic difficulty: these global challenges generate strong interdependencies between different social, technological, and natural systems. In dealing with them, societies tend to address individual systems, rather than multiple interrelated systems, and thereby fail to achieve systemic change.

The vision is to integrate scientific evidence into the social processes leading to policy decisions addressing global challenges. The ICT engines driving GSS are large-scale computing platforms to simulate highly interconnected systems to make full use of the abundance of data on social, economic, technological and ecological systems available today. The unprecedented in scale and scope of these data represents a step change in how science is able to address societal questions. Equally important are online social media and collaborative ICT platforms that support active participation of all stakeholders in the process of gathering and analysing (scientific) evidence and thereby in the policy process.

Research Objectives as Two Complementary Strands:

- *Policy informatics* – scientific evidence-base for policy: ICT tools to provide models and data highly integrated across different policy sectors;

- *Societal informatics* – a society-centered science: ICT tools - presenting model results via games or visualising data- integrate the scientific evidence-base in the policy processes. Social media and participatory ICT platforms to link better stakeholders in the scientific and policy process.

The Visions in Global Systems Science: Models and Data workshop mainly addressed 'policy informatics' aspects of GSS, that is the role of data and models.
Decision makers facing global challenges increasingly use computer models, simulation as well as large scale heterogeneous data and try to integrate and make sense of information in order to turn it into knowledge available for a future course of action. There is mounting concern that even with the use of such simulations and models we do not know enough to make effective decisions in response to global challenges. What is more, we also don't know enough about our methods of modeling complex systems of this size by computer simulation to be able to effectively operate. A quite more rigorous foundation is necessary to comprehend the deep interplay of systems simulations, data from various sources and the actual problems we are facing as a society.

Scope of the workshop was to explore role and interest of various computer science and mathematical approaches pertinent in this context: from interaction based computing to data topology and modeling languages, from high performance computation to novel data mining methodologies. In particular, the most efficient methods for specification and analysis of dynamics of highly interconnected systems, specification, verification and validation of the computational dynamics simulations; formal approach to the analysis of dynamical network abstractions for complex system representation. Explicit applications to different contexts were discussed. The aim was to propose new viable ways to validate, verify and specify computer-based simulation of highly interconnected systems which might help decision makers in a truly interconnected, socio-technical, data-driven global society.

Questions

ICT tools and research challenges in GSS: What are the research challenges and obstacles that need to be addressed in the two research strands of policy and societal informatics?
What are the challenges for research in ICT (and beyond) resulting from the GSS vision? What are GSS specific challenges and what are challenges shared with other modelling and data research activities?

How can IT infrastructures (HPC, e-infrastructures and cloud, Big Data, and social media) be put to use in GSS? What are the fundamental challenges that GSS poses to ICT research?
What is prediction in this context (given that data and models are presumed to have inherent knowledge to be extracted)? Which connections or interfaces with other fields of science do we need to translate ICT hard data into soft information for society and politics?

Themes

1. Computer Science for interacting Informational, Technological and Social Networks
2. The Mathematics and Computer Science of very large systems: not only high performance computing, but data-driven science as well
3. Advanced computing for Network Science Network Science as an integrating framework for real world complexity
4. Network approach for governance and policy tools for societal action in response to global challenges.

7.2 Report on the EUNOIA urban systems and GSS workshop

1. Purpose, scope and objectives

Globalisation and the resulting increase in interconnectedness and interdependence of people and nations create new opportunities, but also new challenges that require policies and measures at a holistic level. Global System Science (GSS) intends to address in an integrated manner the increasingly global and interconnected nature of challenges facing humanity, with the aim to provide scientific evidence in support of policy options. Pertinent elements of GSS in this context are:

- the capacity to gather, integrate and correlate large amounts of 'Big Data';
- the modelling and simulation of large socio-technical systems;
- the interaction with policy makers and society at large;
- the use of modern ICT to engage collective action.

GSS will focus on a few selected areas, urban dynamics being one of them. The term ‘global urban systems’ means considering urban problems at an integrated scale taking into account many aspects of urban life and urban knowledge, with particular focus on the impact of ICT on cities and their dynamics.

To address these questions, the European Commission DG CONNECT and the FP7 project EUNOIA launched a number of consultations, including a workshop held on 13-14 February 2013 in Brussels that brought together a group of about 25 researchers, practitioners and policy makers. This report is the outcome of that reflection process.

The objectives of this report are:

- to analyse the major scientific challenges associated to urban development from a GSS perspective;
- to identify the role that ICT could play in such context in order to develop policy modelling tools and bridge the gap between modellers, policy makers and societal actors;
- to contribute to the creation of an interdisciplinary research community at the intersection of urban planning, ICT and complex systems science, able to formulate innovative approaches to the challenges facing urban development in the 21st century;
- to provide inputs for the European Commission to develop a research agenda in the field of 'Urban Development and Global Systems Science', with a view to include this thread in the future Horizon 2020 work programme. The results of the workshop will be reflected into an Orientation Paper for GSS research in Horizon 2020.

2. Urban development challenges

2.1 Globalisation and urbanisation

It is now estimated that over 50% of world population is living in urban areas, with a yearly growth rate of about 2%. By 2100, the world's population will be almost entirely urban and will have probably peaked at around 9-10 billion persons. There will be more people, unevenly distributed across the world, and migration will become the predominant mode of population change.

Cities and global challenges

The global challenges of economic recovery, poverty eradication, environmental sustainability, climate change, or sustainable and secure energy, are all intimately and intricately linked to cities. The implementation of solutions to these challenges will, to a very large extent, be implemented in cities around the world. The issue of sustainability, which is now on top of the political and societal agenda, has a strong urban dimension, increasingly important as the world becomes more urban. Urbanisation is unfolding, and wealth is being concomitantly created, but urbanisation might not be occurring in a sustainable and resilient way. There is a need for an integrative analytical framework that can facilitate the design of policies promoting resilient and sustainable urban development.

The pervasiveness of ICT: impact on spatial dynamics

The pervasiveness of ICT and the coupling of the real world with the virtual (digital) world are having an impact on spatial dynamics, e.g. changing microspatial dynamics, which is having a profound impact on location and activity patterns in cities.

ICT and globalisation: world cities

In the coming years, most cities will be somehow locked into the global economy if only through the fact that their populations will engage in accessing information which is non-place related and somewhere in the cloud. In this sense, all cities will be world cities, which will have strong implications in terms of their economies, trade, specialisation, or polarisation of communities. There will be a new kind of urban dynamics through access to ICT and through new migration streams. Cities' global connections raise an entirely new set of issues. What this will do to cities and urban planning is largely unknown, but the need to think globally in space and time will be essential.

Smart cities

Most smart cities work is what we call intra-urban rather than inter-urban, except of course that the larger and the more global the city, the more likely it is to be involved in new ICT. Cities can be studied from many different vantage points with respect to ICT, such as embedding ICT into cities, big data and real time sensing, urban services optimisation, longer term transportation and land use modeling and forecasting, or digital participation. The list is endless. Particularly interesting are new kinds of short term dynamics which come out of real-time big data, sensing, and integrated databases and that are likely to provide new kinds of longer term data about cities in due course.

The economy of cities

New kinds of economic data and the new ways in which economies operate in a global world have a major impact on cities, particularly through markets. A new push for an economy of cities is needed in terms of understanding how markets are being structured using real time and online data. Capital markets are a key issue here, as well as the flow of global capital into different places.

2.2 Challenges for urban development in the 21st century

In the short and medium term, cities are facing the major challenge of overcoming the current financial and economic crisis and emerging stronger from it. As a result of the financial crisis of 2008 and the subsequent economic recession, cities are suffering from high levels of unemployment and lower business survival rates, among other effects. Cities act as the main engines of the economy, and are therefore crucial for driving economic recovery. In the long term, cities are also facing other structural challenges, such as globalisation, climate change, pressure on resources, migrations, and demographic change. Some challenges are shared by cities from developed and developing countries across the world, but there are also specific factors depending on geographical, structural, political, institutional, socio-economic, or cultural differences at different scales (city, country, region, etc.) that must be taken into account. The main challenges for urban development in the 21st century derive from contradictory trends and forces that are difficult to reconcile.

Managing demographic changes

Cities will have to manage an increasing longevity and declining fertility in developed countries, and fast demographic growth in developing countries. Cities will have to adapt to changing family structures and migration, and be able to exploit the potential of socio-economic, cultural and generational diversity (e.g. the economic and social value of the activities of the elderly) as a source of innovation and progress.

Converting quantitative growth to qualitative improvements

Developing countries will have to manage rapid economic urban growth. Developed countries must face shrinking demography and lowering rate of economic development: the links between economic growth, employment and social progress are weakening, the cuts in public budget are having a strong impact on the welfare state, and an increasing number of neighbourhoods are suffering from poor housing, low-quality education, unemployment, and difficulties to access certain services, such as health, transport, or ICT. Both in developed and developing countries, there is a need to find more effective solutions to ensure the provision of essential services and to face rising urban rents and land prices while avoiding social polarisation and segregation.

Combining competitiveness in the global economy with geographical diversity

Cities will have to reconcile competitiveness in a globalised world with sustainable local economies by developing key competences and resources. The challenge is to improve the quality of urban life and urban environment by sharing emerging solutions at worldwide level, while preserving the geographical diversity of urban systems (in terms of size, economic specialisation, architecture, culture, etc.), which is essential to maintain and develop urban dynamics.

Ensuring the sustainability of urban ecosystems

There is overwhelming evidence that the current organisation of our economies and societies is seriously damaging biological ecosystems and human living conditions in the very short term, with potentially catastrophic effects in the long term. In addition to the challenges posed by energy scarcity and climate change, cities shall be able to organise urban sprawl while mitigating growing pressures on local ecosystems. Soil sealing reduces biodiversity and increases the risk of flooding and water scarcity. Land is not only an economic resource, but also one of the most valuable natural assets. Urban sprawl and suburbanisation threaten sustainable territorial development, making infrastructures and public services more costly and difficult to provide, leading to the overexploitation of natural resources, and increasing the energy and environmental cost of transport. In developed countries, and increasingly since the advent of the economic crisis, many urban planners are advocating a shift in the focus of attention from urban growth to urban regeneration, including rehabilitation of industrial sites and contaminated land areas, urban regeneration projects, clean urban transport, or energy efficient buildings.

Transition from industrial age centralisation to the distributed systems of the information age

The core principles of the industrial age were the concentration of the means of production; defined products and services based on historical demand; the distribution of these products and services to an anonymous group of consumers; and the combination of these capabilities by consumers to best meet their needs. Though there were good reasons in the past for employing this model, a key shortcoming is the disconnection between the design and production of the capability and the actual needs of the consumers. In the age of information we have new ways of providing complex capabilities, new levels of education, and new methods of capital allocations. Across many domains, e.g. media, electrical utilities, and manufacturing, the industrial model is breaking down: broadcast media give way to self-selection; electrical utilities realise the need to understand and influence consumer behaviour, while consumers implement distributed generation for sustainability and resilience; and 3D printing enables individuals and small companies to design and produce complex mechanical devices. Perhaps the greatest failure of the industrial model has been in transportation, where the private car has largely displaced public transportation. In the coming decades there will be significant changes that we may not be fully prepared to face, e.g. the change in the nature of car ownership, with the advent of autonomous driving vehicles procured, rather than owned, via organisations like ZipCar, weakening our emotional attachment to driving and raising new questions such as the role for public transport. Cities will need to be more agile as they are confronted by global challenges, which will make it necessary for both public and private institutions to develop new forms of governance and management thinking.

Managing new ICT-driven forms of spatial organisation

The emergence of new social media and electronic communications are providing more and more access to distant information and replacing sense of place and proximity by sense of connectivity, leading to profound social and behavioural changes and modifying location and activity patterns in cities (more distributed work, new sense of communities, etc.).

Exploiting the opportunities offered by ICT while avoiding a new alienating coupling between machines and society

Exploiting new sources of big data will change the way we plan and monitor cities. ICT systems will improve information processing at citizen level and enable new forms of planning and governance, but they can also orient towards more control. The challenge is to make best use of this opportunity while avoiding risks such as threats on confidentiality and privacy, addiction, or dehumanisation through machine use, especially in public urban space.

Adapting governance structures and empowering citizens to achieve a better matching between global/societal needs and individual needs

There is a tension between existing and future needs and demand from the city users and inhabitants and emerging constraints (physical, environmental, social, economic, etc.). For instance, city dwellers request more space in and around their housing (hence sprawling), while transport or energy constraints push towards more compact cities. A lot can and must be done from the technological and policy making perspective, but it is only when people become fully aware of their actual environmental conditions and their future consequences that the much needed change of behaviorwill truly happen, which requires adapting governance structures for the empowerment of urban areas and facilitating widespread citizen participation.

3. Concepts and methods

GSS combines two different, yet complementary paradigms:

- the provision of scientific evidence for public action: ‘policy informatics’; and
- the use of ICT to communicate these scientific evidences and facilitate stakeholders’ engagement: ‘societal informatics’.

3.1 Policy informatics: models and data

When studying entities as complex as cities, we face three fundamental, intermingled problems:

- the many components of the natural, social, economic, cultural and political urban ecosystems are strongly interwoven, giving rise to complex dynamics which are often difficult to grasp. Cities can be seen as very large sets of interactions over many layers, including the topography of the city; the fixed resources within the region (arable land, minerals, aquifers); the renewable resources (air, water, soil, vegetable and animal life); the built environment (major infrastructure, housing, workplaces); the public and private capabilities (government, public safety, healthcare, utilities, education, transportation, industry, commerce, entertainment); and the living systems by which each inhabitant or visitor conducts his or her own life, thereby creating the social and economic systems. The spatial scales for these layers range from one meter to several kilometers, and the timescales range from a few seconds to several decades;

- the limited understanding of urban dynamics makes it difficult to anticipate the impact and unintended consequences of policy action. The interdependencies within each layer and between layers, in many cases not yet fully understood, may have crucial bearing on the sustainability and resilience of the city;
- urban development policies are subject to highly distributed, multi-level decision processes and have a profound impact on a wide variety of stakeholders, often with conflicting and/or contradictory objectives.

The role of modelling

Urban models are mathematical representations of the 'real world' that describe, explain, and forecast the behaviorof and interactions between different elements of the urban system. Models serve various functions, which can help address the three abovementioned fundamental problems:

- in a scientific explanatory role, models allow a better understanding of urban dynamics;
- in a predictive and policy design role, they enable virtual experimentation, providing evidence of the impact of new policies;
- in a narrative and deliberative role, models are powerful tools to enable collaborative policy assessment process, allowing the empowerment and participation of societal stakeholders and facilitating the construction of shared visions and objectives.
-

Each of these three purposes probably requires different types of models, but at the same time different types of modelling approaches can mutually inform and enrich each other. We believe that GSS should adopt an integrative and pluralistic approach, encompassing the three purposes of models described above. Recent advances in areas such as network theory, and more generally the intrinsically holistic and eclectic approach advocated by complexity science, appear as a suitable theoretical framework for the integration of different modelling approaches — coming from fields such as urban economics or social physics — into a comprehensive toolkit to address the many different questions related to urban development.

Scientific explanatory models

There is a general recognition that cities, regardless of their size, geography, time or culture, share many underlying organisational, social and economic characteristics, and play similar functional roles. A citizen of New York City will quickly understand how Tokyo works. Arriving in Tenochtitlan (today's Mexico City) in 1519 as part of Cortes' invading army, Bernal Diaz del Castillo famously described the city as spectacular for its scale (about 200,000 people, one of the largest cities of the time) and wealth. But perhaps the true surprise should have been — given its independent development from old world cites — how familiar it all was, in terms of its roads and canals, its public buildings and neighbourhood organisation, and its markets and social life. The same could be said of many travellers, emissaries and historians encountering (to them) new cities in (to them) strange locations. There is a sense in which human settlements of ancient Mesopotamia and of modern nations share enough features that the term 'cities' can be used to meaningfully refer to entities separated by thousands of years of cultural, social and technological development. All of this suggests (but only suggests) that the functional role of cities in human societies, as well as some of the general aspects of their internal organization may be 'universal': they may be expected to develop and evolve independently, and display similar dynamics regardless of socio-temporal and locational specificities. The endeavour to discover broadly general empirical regularities of urban life is relatively new but increasingly possible given the growing availability of more and better data, and a growing interest in developing a truly multidisciplinary and scientific understanding of urbanisation.

One approach to building a theory of cities and urbanisation takes the self-similarity of cities as its starting point: the hypothesis of urban scaling. In its strongest form it states that essential properties of cities in terms of their infrastructure and socio-economics are functions of their population size in a way that is scale invariant and that these scale transformations are common to all urban systems and over time. Any urban system is ultimately rooted in material resources derived from food, energy and other basic materials but it is the connection of these many (smaller) settlements with larger cities that drives the system as a whole to greater resource and economic efficiency and productivity, and permits increasing returns to the population scale of large cities in terms of innovation and wealth creation. These are ultimately the reasons why cities exist and can continue to grow. Yet we still don't have simple, out-of-equilibrium models that describe satisfactorily the evolution of a city and extract generic features and stylised facts.

Another line of progress in academic modelling has been the move from simpler aggregate equilibrium models to highly disaggregated models. The dominant trend has evolved towards disaggregation of population and employment groups by various socio-economic attributes, and there has been a shift towards bottom-up approaches (activity-based and agent-based models) relying on data of single households and their members, together with their daily activities and the resulting transportation needs. Transport models, for example, have moved from aggregate trip based models to disaggregate discrete choice models and more recently to activity-based microsimulation models, utilising the exceptional flexibility of microsimulation frameworks and the increasing availability and affordability of computing power.

Predictive models

Decision makers need reliable facts to take decisions. In many situations in which decisions cannot be taken upon experiences with similar applications in other places, modelling can be a useful instrument to forecast the impact of different policy alternatives. However, despite the significant progress made on the scientific track, our forecasting ability has not improved much. Many researchers in systems science contest whether people can be modelled in a meaningful way. If we aspire to relevance in the real world, we must assume that our models will be imperfect in many ways, which will require caution and specific expertise in how we interpret our results. Forecasting is in many aspects different from explanatory modelling. Where is the limit of modelling for practical forecasting purposes? Was Alonso right that simpler models can be as good as or even better than very detailed and disaggregated models for the purpose of forecasting? It is surprising how little evidence has been gathered to answer this question.

One of the key elements is the accuracy of the input data, which often implies estimates about the future. If the future is going to be very different from the past, then this future "data" is likely to be much less accurate than current expectations. On the other hand, the emergence of big data is opening new avenues. In the frame of the open data movement, public administrations are beginning to open up data available in many different formats. In parallel, the increasing penetration of modern ICT, such as smart phones, e-transactions, Internet social networks or smart card technologies, allows the automatic collection of a vast amount of spatial and temporal data, which combined with more traditional, cross sectional demographic and economic activity databases (e.g. census data), can be used to extract relevant information. In contrast with hard science, historically we have been heavily restricted in the experiments we could undertake on cities, and have had to rely on models based on very small samples complemented with partial theories of behaviorand assumptions about the permanence of behavioural traits over time. Tomorrow, we will be able to micro-track the effect of spontaneous experiments — fare adjustments, strikes, infrastructure closures, flooding, etc. — and achieve deeper learning from interactions with volunteers. With very large samples at nearly no collection cost (processing and analysis is another matter) we will have, for the first time, detailed longitudinal data. The first uses of this rich database are likely to adapt it to the needs of current models, including agent-based models. However, the type of models that make the best use of this fertile data source could be different from the current trends, at least for short and medium term and for pragmatic forecasting purposes.

With the emergence of big data, some authors have raised concerns about the risk of focusing on descriptive work and predictive, non-explanatory models, abandoning theory. The (sometimes contentious) relationship between theorising and empiricism, between model building and data collection, between explanatory and predictive modelling, has long animated discussions among epistemologists, philosophers of science and scientists themselves. We see an abundance of data as a necessary but by no means sufficient condition for developing a thorough understanding of a phenomenon, and advocate an integrative approach based on a fruitful interaction between data analysis and theoretical modelling. But it remains to be seen whether the explosion of available data and new forms of data analysis will inform the development of better urban theories or the scientific and forecasting modelling streams will not only not converge, but diverge further.

Models for participatory planning and governance

Cities will only be truly smart if the advances in terms of data and models are properly integrated into governance processes. While simulation models have been widely applied in areas like transportation planning and traffic engineering, in many other areas, like land use planning, the potential of urban models is still largely unexploited. Particularly relevant is the issue of participatory planning and governance: while contemporary trends in urban planning — such as transactive planning, advocacy planning, bargaining or communicative planning — aim at integrating a plurality of interests and an active public engagement, it is a fact that there is not much use of models in participative mode (except in some enlightened examples), and in many cases, the potential users do not have the skills to use such models or are not convinced of the benefits.

The use of models in collaborative planning needs a fresh way of thinking. The development of the models needs to be based on a continuous dialogue between modellers and policy makers. New forms of information visualisation and visual analytics, which can make model results more accessible, can help lower these barriers. Finally, ICT enables new ways of citizens' engagement, by capturing the inputs from the community (e.g. algorithms for reconstructing citizens' opinion from data resources distributed throughout the Internet) and support an increased participation of citizens (e.g. through applications that allow citizens to monitor and report the system status in real time). User-specific interfaces and tools for the visualisation of policy impacts in an intuitive and graphical manner can facilitate multi-stakeholder policy assessment and collaborative decision making processes in which societal actors collaborate with experts in the generation and analysis of urban policies, bringing together and exploiting the synergies between policy informatics and societal informatics.

3.2 Societal informatics

ICT opens the door to the development of new ways of citizens' engagement in the design and planning of their cities. New scenarios are now possible in which active citizens can help gathering sensible data through participatory sensing and social computation activities, with the twofold purpose of: (i) stimulating individual and collective awareness and learning; and (ii) providing relevant inputs for data analysis, modelling and decision making.

ICT for participatory sensing

ICT can support informed action at the hyperlocal scale, providing capabilities for environmental monitoring, data aggregation, and information presentation. The goal is to enhance knowledge, understanding and social awareness about urban habitats through the use of ICT tools deployed to gather user-generated and user-mediated information from web-based and mobile sensing devices. The possibility to collect digital fingerprints of individuals is opening tremendous avenues for an unprecedented monitoring at a microscopic level of collective phenomena involving human beings. We are thus moving very fast towards a sort of a tomography of our societies, with a key contribution of people acting as data gathering 'sensors'.

Web-gaming, social computing and internet-mediated collaboration

In the last few years the web has progressively acquired the status of an infrastructure for social computing that allows researchers to coordinate the cognitive abilities of users in online communities and steer the collective action towards pre-defined goals. This trend is also triggering the adoption of web-games as a laboratory to run experiments in the social sciences and whenever the peculiar human computation abilities are crucially required. Potential areas of interest include:

- Spatial games (related to traffic, mobility, coordination, etc.). These games/experiments are aimed at investigating how people explore geographical spaces and use geographical information in a way that is meaningful and culturally appropriate for them. Specific tasks can include coordination, exploration, cooperation, and annotation. At the same time these games/experiments allow the collection of information about how people perceive their environment, which can be organised in layers (e.g. traffic or pollution in urban environments, social interest, landmarks, etc.) and made available through interactive visualisation tools in order to facilitate informed decision-making.
- Citizen games. Interesting activities here include the development of new tools for the sustainable management of natural resources (in particular for marginalised communities) and good practices for recycling, food management, mobility, energy consumption, etc.

Collective awareness and decision-making

The access to both personal and community data collected by users, processed with suitable analysis tools and represented in an appropriate format, has the potential of triggering an improvement of collective social strategies. By providing personally and locally relevant information to citizens, i.e., related to their immediate locality rather than to the city or region in which they live, one can induce changes in individual behaviorand pressure on policy makers. The key idea here is that fostering awareness will stimulate fundamental shifts in public opinion, contributing to more sustainable behaviour, and will stimulate bottom-up participation, by collecting public opinions and perceptions in a trusted way and orienting the democratic processes of decision making.

Learning

Learning is at the basis of our ability to construct models of our reality and take decisions. The societal challenges of our highly interconnected and rapidly changing world call for an increase of the number of people that are educated and capable of using the technologies that will sustain large human societies safely and prosperously. ICT tools can be used to generate new concepts and innovative learning schemes through which this much needed breakthrough can be obtained.

3.3 Complementarity between societal and policy informatics

In social phenomena, behavioural and cognitive aspects, as well as the way humans take decisions, are key ingredients that have to be taken into account in order to make sensible predictions. It is thus crucial to deepen our understanding of the causal link between the level of the individual and the emergent collective phenomena. In order to do this, one has to parallel the monitoring of emergent phenomena in social dynamics with the investigation of the behavioural and cognitive foundations of such dynamics. The possibility to collect relevant and capillary data about human urban activities can stimulate the development of data-driven modelling schemes integrated in ICT-based infrastructures for an empirical, computational and theoretical approach to social dynamics processes.

4. Research challenges and opportunities

Globalisation raises a set of issues, both at intracity and intercity level, which are in many respects different from those faced in the past decades. These issues require new models and tools, as well as more integrated approaches to urban development. At the same time, this need for adaptation is an opportunity for new emerging technologies to deliver their full potential and contribute to the more liveable, resilient and sustainable cities. We discuss hereafter the main challenges and opportunities associated to the different research threads relevant to GSS, organised in four research areas:

- data integration and analysis,
- modelling and simulation,
- social computing and collective awareness, and
- policy making and participatory governance.

4.1 Data integration and analysis

Data availability and quality

The calibration and validation of urban models require abundant and high quality data. However, data requirements are not always met, and modellers usually have to operate in a data-poor environment, despite the wealth of information now available. The proprietary nature of certain information about urban services (e.g. on water or energy consumption) limits access to data. There are also potentially useful data belonging to other types of companies, e.g. phone companies, banks, or online social networks, which need to be engaged in the study of cities and in the benefits derived from granting access to their data. Large scale systems are being developed for new data sources, such as open data initiatives or self-tracing apps employing GPS-enabled smart phones, opening promising venues that need to be further explored. An open data policy, and in general a simpler access to data, can boost urban research and enable innovative ideas.

Relevant issues related to data collection are:

- The way data collection means and system interfaces bias the data we collect.
- Privacy issues. The resolution of many data sources can go down to the single individual. Most of the time, this resolution is not needed for the question under investigation, so data can be anonymised and aggregated retaining only those aspects that are important.
- Coherence and harmonisation. The format of data also varies across jurisdictions and operational domains, and many indicators relevant to urban systems have yet to be agreed upon and established at a system-wide level.

Data filtering and integration

For many problems we don't need big data, but the right data. This means that, before big data, we need the ‘big picture’. In many cases, data acquisition is being done indiscriminately without paying attention to the real needs. The data can also be noisy and may depend on local particularities; a consistent representation of cities is needed, allowing the extrapolation from one city to another and the identification of general trends. Local coordination, redundant information and data filtering are key issues here.

Once filtered, different heterogeneous data sources, including conventional as well as new ICT-based data sets available in various forms, will have to be coupled into new forms of coherently integrated databases. Crossing data from different databases can help to develop synthetic data, the so called contextual information or procedural data, which can complete missing information in the databases or extrapolate known data to unexplored geographical regions.

Spatio-temporal data analysis

In the present situation, the concept of smart cities is well established and the proliferation of sensors provides a humongous amount of information. We are moving from “data hungry” research to data abundance, but we still don’t know much about how to make sense of this abundance of data from a behavioural perspective. We need to develop data analysis tools, including filters to reduce noise levels and tools to extract system information out of a sea of data. Relevant issues are the representativeness of the new data sources (e.g. the representativeness of credit card or social media users as a source of survey sample), or the development of spatio-temporal data mining methodologies able to uncover mechanisms that operate at different scales.

Until recently, most research efforts for the analysis of spatial data had taken a static view. However, as all spatial phenomena evolve over time, temporality is central to our understanding of spatial processes. In recent years, the increasing availability of large sets of data referenced in space and time has stimulated a great interest in spatio-temporal data mining, which still remains, however, a largely unexplored territory.

4.2 Modelling and simulation

While some models of urban systems and processes are intended as tools to improve scientific understanding, other models are specifically developed to assist decision making. As already discussed, both trends can mutually enrich each other, so we believe that the GSS research programme should have room for both types of research efforts. But it must also be acknowledged that they have different purposes, which suggests different practices in the commissioning of models, the process of their development, and their application. We discuss hereafter a number of research challenges related to modelling and simulation. Some of these challenges are more relevant either to scientific explanatory models or to models for decision/planning support, while other challenges are relevant for both.

A science of cities

A first, fundamental questions is whether there can be a science of cities, i.e., whether a quantitative, predictive and falsifiable theory of cities is conceivable.
In relation to this fundamental question, several other questions arise:

- How well do we currently understand urban phenomena? What do we robustly know and what are major lacunae in our understanding?
- To what extent such theory would be based on generic underlying principles that transcend history, geography and culture? How temporal and context-dependent are cities?
- Interconnection is not a new element, but why things are connected and why some things are more connected than other? Is Tobler's first law of geography true?
- What should a science of cities be able to accomplish? Examples of relevant targets are to explain general empirical relations concerning infrastructural and socio-economic characteristics, the reasons why cities arose in the first place, or the mechanisms behind socio-economic development and decay.
- What are we missing in terms of data and theoretical developments?
- How to do it? We believe such an effort would necessarily involve an interdisciplinary effort, bringing together researchers from areas like anthropology, urban planning, sociology, economics, environmental sciences, ICT, complexity, or political science, among others.
- Would such theory offer practical solutions for the management and planning of cities?

Theoretical challenges

As indicated in section 3, further progress is needed to develop out-of-equilibrium models able to describe urban dynamics. Examples of relevant research areas of which we still have a limited understanding and that required more theoretical work are:

- Behavioural drivers and social determinants of the observed trends.
- Systematic approach for human modelling, including modelling of partial rationality and emotional behavior.
- Coupling between slow and fast dynamics.
- Coupling between intercity and intracity interactions: impact of global trends or urban dynamics, and cities contribution to global challenges.
- Path dependence and evolutionary urban theory (integration of the past into the present).
- Identification of critical parameters (key variables), and analysis of tipping points and critical transitions.
- Analysis of urban resilience, disturbances and vulnerability
- Impact of the overabundance (and exchange of) of information on urban dynamics.
- Model calibration and validation, including the analysis of how errors and accuracy are affected by the level of disaggregation of our models and data.

Adaptation of models to the current socio-economic landscape and new global challenges

The current generation of urban models was developed in an era when urban growth and sprawl was in the ascendency. We are now facing a wider variety of urban development models, from shrinking cities as Detroit, to fast developments of new metropolis like Songdo or the transformation and regeneration of existing metropolis like Rio de Janeiro. In the case of Europe, it is now clear that the prosperity generated by the 1st and 2nd industrial revolutions has massively slowed and that the recession is having a deep impact on European cities, especially with regard to employment and social cohesion. Other trends include aging, migration flows, and the overlay between climate change, cities and economy. Particularly relevant is the restructuring of the local economies to embrace new varieties of ICT-based services: in the past, people used to accommodate in cities according to economic drivers, but this is to some extent changing with ICT penetration, leading to a disconnection between information and physical layers that could challenge the urban theories developed along the past decades. Urban simulation models need to be refashioned to deal with these and other emerging trends, which are in turn being reflected in changes in transport and spatial interactions.

New tools for planning and decision support

The availability of new data and the theoretical advances in urban modelling should be exploited to develop new tools for urban planning and decision support, both in terms of real-time city management and strategic planning tools. Relevant issues are:

- Development of new and more meaningful performance indicators.
- Development of ‘city dashboards’ monitoring the critical parameters that drive the dynamics of the city
- Improvement of travel demand models
- Improvement of land use transport interaction models.

- Coupling between different models
- Development of early warning and risk management systems.

Coordination of the efforts of different urban modellers and model integration

In many situations decision makers need models that are really 'global' and integrate engineering solutions and scenarios from social, economic and geographical situations. Despite major improvements in urban data collection and modelling accomplished in the recent years, there remains a huge gap between technical models (for instance transportation models) and physical models (for instance about environmental risks), and current models present a series of limitations derived from the lack of integration. Many models are aggregation of pre-existing methods and packages loosely integrated and adapted for particular situations, rather than being holistic tools applied generically as a standard set of integrated methods. More generic models (usually developed privately) often present limitations in their capacities of integrating complex set of data.
Further work is needed to couple different models that differ in their methodology and scale, including the development of built-in validation mechanisms to ensure the robustness and coherence of the coupling algorithms. Relevant examples are the coupling of GIS-based models of property and demographics with models of energy consumption, or the integration of sectoral models, such as models of housing choice, retail or public services location, into land use transport integrated frameworks.

Multi-level modelling

Urban dynamics exhibits multiple spatial and temporal scales. The increasing sophistication of urban models comes at the expense of computational resources and has serious implications for the calibration and validation of the models, e.g. the need to reduce the number of sensitivity tests to check the plausibility of model behaviour. The identification of the time horizons and spatial resolutions relevant for the analysis of different phenomena and the question of the right level of granularity remain open. In a recent paper, Wegener calls for a 'theory of multi-level models', according to which there is an appropriate level of conceptual, spatial, and temporal resolution for each question under investigation.

4.3 Social computing and collective awareness

The dynamics of cooperation and human computation

Here the problem concerns how to sustain over time collaborative behaviorin intelligent tasks, which is fundamental both for the understanding of social dynamics and for the design of effective forms of web-mediated collaboration. Research is needed to enhance our understanding of the role of motivations, incentives and mechanism design together with other factors such as social ties, culture and the cognitive framing of problems, in order to effectively use ICT as means for mediating behavioural change and introducing self-awareness of the citizens within the urban environment.
Special care must be taken about certain feedback loops. One example is that of satellite navigators for cars with information about traffic. If a zone of the city is congested, the navigator may try to redirect the user through a less transited route. But if all the navigators act in the same way, the new

route will become collapsed. Game theoretical considerations can be useful to address this sort of problems.

Societal informatics gives us the opportunity to pioneer a new type of experimental science, by using the web as a laboratory for the social sciences. The challenge here is to develop the means for integrating different perspectives to test the limits and potentials of collective knowledge production.

4.4 Policy making and participatory governance

Integration of urban models into multi-stakeholder policy making processes

Policy assessment and participatory planning are still largely based on qualitative considerations, and there is a sense among practitioners that urban models are immature with respect to institutional integration and operational use. Interaction between model users and model makers during model development remains rare, which often creates a gap between model providers and user needs.

Potential users include a broad diversity of stakeholders (usually non-experts), which constitute a major issue influencing the effectiveness of models in application and their capacity to influence understanding and decision making. Typically, model users now include:

- technocrats (employed within government or consulting companies) who interface with the models and the community at large;
- policy and operations decision makers (elected government officials or advisors to government, such as private sector planners and designers);
- the general public (communities with interest in specific issues or places);
- the technical and scientific community (other modellers and urban specialists).

Model users often identify an issue about which they want to be better informed, but may not know what they are looking for or what models actually do. They possess a very valuable implicit knowledge about the issue under investigation, but do not always understand the limits of models, or how data availability influences them. Conversely, modellers make assumptions about how models should be applied and may lack the skills to interact effectively in the socio-cultural and political domains in which models are used. In addition, they may not have the training (or time) to produce models of complex interactions that are comprehensible to non-experts.

The challenge here is to integrate state-of-the-art with multi-stakeholder decision making process, bridging the gap between implicit and explicit knowledge. The development of models and decision support tools needs to be accompanied by new forms of user-model interaction and procedures facilitating stakeholders' participation in the construction and validation of the models. We need to exploit the potential of models to act as a catalyser for integration, interdepartmental collaboration, collaboration between authorities and stakeholder involvement.

Transparency and ease of use

As already discussed, urban development policies imply highly distributed decision processes and influence a variety of stakeholders. The policies under study often being controversial, models will not gain the necessary credibility unless it can be explained in simple terms what they are doing, and why. The term ‘black box’ has often been used to criticise the lack of transparency. Models shall be built according to the question to be addressed, and people need to understand what the models are intended for.

Models must also achieve a threshold of usability that makes it possible for model users to use the model without excessive support. In particular, models must be consistent with the level of competence of the relevant (local) authority. Progress is still needed to conciliate transparency and ease of use with the necessary sophistication required for a realistic modelling of a system as complex as the city.

User-model interaction - Information visualisation and visual analytics

To bridge the gap between modellers and model users and facilitate user-model interaction, new forms of information visualisation and visual analytics have a particularly important role to play. Several research challenges can be identified here:

- Development of more intuitive, user-specific interfaces addressing the needs and requirements of different communities and enabling a better integration of quantitative and qualitative information.
- Real-time interaction and analysis. Big data production rate is growing faster and faster. Real-time interaction and analysis have to be addressed carefully in order to reduce latency, so that the analysis capabilities keep the pace in terms of effectiveness and efficiency. Scalability and computational efficiency are key issues here.
- Integration between visualization and analytical functionalities. Visualization is a fast growing area, but there is still little integration with data analysis functionalities. Progress is needed in terms of combining data mining tools with iterative visualization on top of specific geographical representations.

Societal informatics for participatory urbanism

Participatory urbanism, which promotes new styles and methods for individual citizens to become proactive in their involvement with their city, neighbourhood, and urban self-reflexivity, also implies a different approach to urban models and new research areas at the crossroads between policy informatics and societal informatics. Relevant issues are the collection of user-generated and user-mediated content which can feed in and update models, which will in turn require more flexible modelling tools; and the development of tools for more active involvement of citizens in the evolution of urban systems.

5. Expected impact and implementation strategy

5.1 Expected impact

A research programme on GSS and urban development would have positive impacts of different nature:

Scientific and technological impact

The programme will contribute to making progress in the integration and analysis of spatio-temporal databases; the understanding of urban location and activity patterns, and the interaction between globalisation and urban development; the development of improved urban simulation models; or the increased take up of new data sources for urban research.

Impact on policy and governance

GSS can contribute to a more integrated approach to urban development; lower the barriers for the use of state-of-the-art simulation models in policy making; develop better links between modellers and stakeholders, and new methodologies for collaborative policy assessment and multilateral governance processes; and help design better policies and more efficient provision of public services.

Impact on innovation and competitiveness

There is a growing consensus among the industry that smart city technologies will offer exciting market opportunities in the decade ahead. The smart city market being a worldwide market, a global approach to cities and an enhanced understanding of global and local urban issues will help Europe to be a leader in this market.

Impact on society

The different impacts on science and technology, policy and governance, and innovation and competitiveness described above will ultimately revert to society through new products and services, better public policies and new and more efficient public services, contributing to the goal of a achieving a holistic and integrated model of urban development that is economically efficient, socially inclusive and environmentally sustainable.

5.2 Implementation strategy

Different instruments can be applied to ensure the efficiency and effectiveness of a research programme on GSS and urban development. We highlight hereafter a number of aspects to which particular attention should be paid.

Stakeholder engagement

Urban research and innovation can significantly contribute to solve the challenges of the future, but only if research results are adopted by policy makers, industry, and society. Linkages established between researchers and stakeholders during the research process can contribute to end use, because useful channels for information exchange are established.

EU funded research in the field of urban and regional development is first of all taking place in large interdisciplinary networks representing several countries and cultures. Besides, different research institutions and stakeholders are often involved in the urban-oriented research projects in one way or another, however sometimes at a late stage of the research process, implying limited value added.

For applied research, stakeholders possess important knowledge, so extensive stakeholder involvement is particularly relevant to achieve meaningful and useful results. Representatives from society, public administration, business and NGOs should be involved in the research application from the very beginning.

Further dialogue throughout the research process is in many cases indispensable. However, some research may be opposed by stakeholders if it does not serve their interests. Furthermore, research should always have the potential for surprise, so the assessment criteria must reward novelty and accept that the potential impacts will not be known a priori.

Flexibility and adaptation

In projects of significant policy content, increased flexibility on deliverables is highly desirable. As the time that elapses between project contract negotiations and the end of the project is usually significant, sometimes a procedure to update what needs to be done is necessary.

Dissemination

Needless to say, further to connections between researchers and end users, publication of research results or other forms of dissemination is a precondition for use. More attention should be given to local dissemination networks as a multiplier of the messages. Also social media provide for innovative engagement of end users in urban research. Observatories set up under the universities and publicly financed laboratories with joint participation of regions, metropolitan areas, local councils, entrepreneurial associations and trade unions could help bridge the gap between research and end users.

7.3 Report on the Urbanisation, Sustainability and Property Workshop.

Compiled by Jose Lobo, Kevin Stolarick and Sander van der Leeuw

For further information about the workshop agenda can be found at:

http://www.gsdp.eu/nc/workshops/?event=154&workshop=Workshop+on+Urbanization%2C+Sustainability+and+Prosperity

Executive Summary of the discussions

1. The effects on "planetary boundaries" of the ongoing (and seemingly inexorable) process of urbanization unfolding in Asia and, Africa and Latin America needs to be urgently studied. The challenge of sustainability, as many other challenges facing humanity, is inherently an urban challenge. [Whether such understanding would have an effect on policy is an entirely different issue.]
2. Of particular urgency is to understand the energetics of urbanization and urban life ("urban metabolism").
3. Humanity's urbanization process may soon (end of the century) come to an end --- Why? What will the implications of this be for the processes of invention, innovation and economic growth?
4. There was general agreement that a "theory of cities" (or "theory of agglomeration") --- understood as a formal treatment of what are processes common to cities and urban life over the past 10,000 years or so --- would be useful, and there are enough tantalizing hints and incipient efforts to suggest that it is possible. But the proof will be in the flan.
5. What is sustainable urban prosperity? This question was largely ignored, a casualty of the difficulty of specifying what "sustainability" and "prosperity" are (but see below in the report on pre-workshop contributions).
6. Multi-disciplinarity was celebrated but the difficulties in carrying out multidisciplinary work were illustrated by the transaction costs of trying to understand each other and unpack our various methodological and epistemological stances.
7. Engagement with policy-making: Do we have something to say to policy-makers? How central to our research concerns should policy-matters be? Is building a "science of cities" use-centered research? A variety of strongly held and divergent opinions were voiced on this topic.
8. Going Global & Data challenges: We all want to go global (meaning take our metrics and models outside the geographic confinement of North American and Western Europe) and we all want to capture the interactions among cities. But how? There are severe data limitations at play here, as well as spatial definition issues: what are the equivalent of MSAs for India (for example). --- And while there are intense efforts going on at building adequate proxy measures for urban extension and urban life (such as the use of night time lights data) or the use of cell phone data to reveal networks of information flow linking urban dwellers across the globe ---data constraints on model and theory building are severe.
9. What next? Participants expressed an interest in staying in touch and continuing the conversation -- which needs to get more precise. Did a research agenda emerge? Will new research collaborations emerge for the workshop? Time will tell. Participants are engaged in ongoing

efforts -- for these to merge or be combined into new ones will require effort and resources.

Background

This workshop was organized against a backdrop of rapidly growing renewed interest in the theme of urbanization, which was characterized by Simon in the 1980's as "the major challenge for [organization] sciences in the 20th century". To be clear, that does not in any way reduce the importance of the huge amount of work that has already been done on this theme, both in Europe and in North America, in part by participants in this workshop (Batty, Pumain, etc.).

But this work is now reaching a different stage, in part due to the application of complex systems theory to this domain as a result of the work first initiated in the ISCOM project (funded by the ICT directorate of the EU, and led by Lane, van der Leeuw, Pumain and West as PI's), which seems to be pointing to the possibility that the community may actually be reaching a mature stage in which a theory of urbanization is achievable.
Clearly, this renewed activity is also driven by the fact that the percentage of the world's population that is living in cities continues to rapidly increase, and that many cities are now so large that a whole new set of challenges arises.

What researchers are currently aiming for, with some hope that this may ultimately be realized, is nothing more or less than a 'science of cities', a conceptual framework about all cities no matter when or where, that is predictable of the properties of urban agglomerations and falsifiable. It would bring predictability about the future of cities, enabling us to provide practical guidance to what makes a “good” city, both in terms of defining “good” but also in terms of understanding the linkages between design and outcomes. That would prepare cities for future developments by determining norms that can be adopted to carry out systemic urbanization (e.g. deciding upon appropriate population densities and urban layout).

Clearly, such an ambitious aim involves (a) that the approach be based on urban data from across the world, and (b) that this huge mass of data (true Big Data) be dealt with by newly developed, sophisticated methods of analysis, representation and modeling that use current computation on a much grander scale, and in many different ways than is currently possible.

This workshop has begun discussions on what the questions might be that need to be answered, how one might begin to design such a theory, and which kinds of data are going to be required to implement this approach.
We have invited for the workshop a number of specialists from a range of different disciplines, including archaeology, geography, complex systems science, ICT, economics and other disciplines, in this case both from Europe and the US.

As is usual at the beginning of such kinds of discussions, these have some time to go before they will reach the stage where a formal plan of action can be launched. But there was remarkable synergy between the participants, who desire to keep this effort going with a number of smaller workshops in different locations, and eventually a second workshop of the same kind as the present one, again to be held at ASU in a year's time or so.

Finally, the organizers would like to express their profound gratitude to the Walton Sustainable Solutions Initiative for its financial and logistical support.

Main themes of the workshop

In discussing these themes, we make a distinction between the ones proffered by the participants before the start of the workshop and the ones suggested towards its end (respectively detailed in the 'responses to pre-workshop questions', and in 'challenges to be tackled').
One important goal of the pre-workshop questions was for then organizers to assess the degree of convergence on the definition of certain crucial concepts, and to inventory any related questions and challenges. The concepts were:

- Urbanization
- Resilience (in the context of cities)
- Prosperity
- Sustainability
- Innovations in Energy Technologies
- Science of Cities
- Smart Cities

To also allow space for issues that we did not initially put on this list, we included an 'open' category, which we labelled:

- Any other terms you feel are important to this conversation

The reader can convince herself of the original degree of convergence in the detailed text of the 'responses', which at the request of the participants themselves have been included without their names.
But we have tried to enhance that convergence a bit in order to focus the discussion. Admittedly, that has involved making numerous choices, and the responsibility for these is ours and ours alone. We hope the participants will accept this as part of our role as organizers of the workshop.

Urbanization
Under '*urbanization*', we find an emphasis on population migration to high-density centers, where they find 'a better' more dependable' living by securing and increasing resources through innovation. This process leads to the construction of dense, multi-scalar and overlapping interaction networks made possible by proximity and extended beyond the urban perimeter by transportation and communication networks. It results in the expansion of the urban perimeter and the densification of the urban core, and change across multiple dimensions (political, demographic, infrastructure, land use, economy, etc), which favors inequality. In these places, land use and human activity are not directly related to natural resources or processes, but to the creation, accumulation, trade-off and direct/indirect use of distinct types of capital (physical, human, financial, ecological) from near-by or distant locations.
Urbanization can be characterized in terms of non-equilibrium thermodynamics as expanding dissipative structures that depend on flows of energy and matter into, and information out of them.

Because it is self-organized, it progressively generates a common anthropogenic dynamic in systems of cities whose development become more and more interdependent despite the diversity of historical and ecological contexts of their development. Urbanization therefore works against global sustainability.

Resilience

Resilience (in the context of cities) is the ability of a city to adapt and evolve in response to internal or external disruptive perturbations (whether physical, economic or social) in such a fashion so as to preserve its integrity and maintain and potentially enhance the quality of life and interactivity of its citizens. It can be expressed in terms of the time taken for the city to recover from a shock.

The resilience of cities and urban systems is rooted in their diversity and openness as systems, which enables all three layers of the city (physical, social and economic) to absorb information about the environment outside the city, so as to enable adaptive structural changes in the functional purpose of each layer. In this manner, the urban systems stays 'in tune' with its ecological niche so that the two interactively reinforce each other.

The virtuous circle between social, economic and physical is broken if outside dynamics strain any one of them without leading to adjustments in the others. The inability to acquire and process information may be one of the principal reasons why one or more of the layers loses its functional utility in sustaining urban life.

Once resilience is established the system becomes sustainable if, either voluntarily (thanks to proper political action) or involuntarily (the main vectors defining the three layers happen to be aligned), a protocol is established where the constant information from the outside is disseminated properly across the components in each layer, and reaction to the new information is reassembled leading to change at macroscopic level.

Sustainability may be then understood as the repeated exercise of uncovering the system requirements leading to resilience.

Prosperity

Prosperity is the ability and encouragement to pursue one's vocations and interests within an urban society. Cities are points of maximum concentration for the power and culture of a community. They control, accumulate and direct the excess (economic, but also cultural and social) capital of their (global) hinterlands. In the urban context, prosperity implies success in terms of balanced social, economic and environmental wellbeing of its inhabitants, including the satisfaction of physiological needs, attaining a level of assured safety and security, and "higher" levels of belonging/love, self-esteem, and self-actualization/creativity. Hence, prosperous cities have been centers of art, culture, and spirituality, technological innovation and ramifying productivity, as well as exemplars of social organization in varying forms.

Prosperity is a relative concept. Temporally, it implies hope or belief in progress along valued dimensions such as happiness, wellbeing, utility, etc. But it is also socially relative. Individuals' sense of prosperity only truly increases when it does so relative to others. This sets up a perpetual conflict between individual and social prosperity, which nowhere is more visible than in the confines of a densely urbanized matrix. Markers of community or neighborhood prosperity

include collective action, freedom from negative social forces such as poverty and crime, and resilience to shocks.
At the systemic level, urban prosperity implies that the social processes are in harmony with the physical and built environments because information effectively circulates among all three layers of the urban fabric.

Sustainability

Sustainability (in the context of economic and social development, urbanization and city life) is a most challenging term to understand adequately. In very different ways, both the second law of thermodynamics and history teach us that there is no such thing as absolute sustainability. Sustainability is therefore a relative term that invokes the human capacity to [temporarily] 'beat' the second law of thermodynamics by increasing organization and information flow and reducing entropy. Hence the conception of urban systems as dissipative flow structures.

One definition of sustainability we like is "Living our [collective] lives as if we expect to be there for the long term". Urban sustainability is then defined as the longevity of settlements and groups. Generically, this implies maintaining, and potentially enhancing, the prosperity and resilience of cities according to ways of life we value. In practice, this involves the capacity to absorb and transform arrivals into more prosperous versions of themselves isn't degraded over time by either environmental or socio-economic factors. This can only be attained [however temporarily] in an integrated, continuously adapting systemic framework where the city is recognized as a landscape of which the infrastructural and network constructs facilitate interaction leading to innovation.

Sustainability thus implies designing for change that is able to accommodate a complex pathway between the three almost always contradictory or even conflictual objectives of economic growth, social justice and environmental quality. The normative element requires answering the four questions of sustainability:

- Sustain what?
- For whom?
- For how long?
- At what cost?

The question about costs acknowledges that not all values can be maintained. Tradeoffs are required, and some values must be prioritized over others. Achieving sustainability seems in part, to depend on a process of convergence of human understanding that will create solutions to problems that threaten the life support systems of the planet and promote human prosperity.

(Renewable) Energy

Energy [flow] is foundational to the survival of human individuals and societies, and has been a constraint on urbanization for as long as cities exist. The rapid explosion of urbanization that we observe since the industrial revolution is due to the fact that introduction of fossil energy lifted that constraint. As we become aware that fossil energy is not limitless, and produces greenhouse gases and other kinds of waste, the search for (a) reduction in energy consumption and (b) potential new sources of energy is becoming of major concern.

Jevons' Paradox suggests that efforts to reduce energy consumption through efficiency are bound to fail, or at least backfire because the rebound effects are greater than the savings. (At least that was the case with coal, and it may be the case with shale natural gas.) Moreover, they are likely to increase complexity and associated costs. It is essential to develop clean, infinitely renewable sources of energy. This implies rethinking the way we do things, including (but not limited to) implementing solar, wind, and algae (or other single-cellular "factories") as sources of energy.

A science of cities?

A core issue for the workshop was the question: "*Can we develop a science of cities*?" A conceptual framework about all cities no matter when or where, that is predictable of the properties of urban agglomerations and falsifiable. It would bring predictability about the future of cities, enabling us to provide practical guidance to what makes a "good" city, both in terms of defining "good" but also in terms of understanding the linkages between design and outcomes. That would prepare cities for future developments by determining norms that can be adopted to carry out systemic urbanization (e.g. deciding upon appropriate population densities and urban layout).

Cities are the ultimate complex adaptive social system, in which evolution takes place at every scale imaginable at a pace that accelerates non-linearly with a city's size. There is no domain of reductionist science that cannot look to cities for interesting questions. However, the challenge is twofold: cities need to be studied from a holistic perspective as singular living, evolving, and adapting entities. A science of cities requires a shift to the principles and methods of complexity science.

A critical feature would the integration of this paradigm, inspired by the mathematical, physical and biological sciences, with the wealth of traditional, sometimes more qualitative and phenomenological, ideas and concepts that have been successfully developed in the social sciences including geography, urban planning, economics, sociology, etc., to investigate the major dimensions of cities and urbanization. These dimensions include size, urban form, social life, and urban functions.

That would provide us with a body of language that allows different people with different methods to communicate unambiguously about the phenomena that occur in cities, and to test and put into question the explanations about the "hows" and "whys" of such phenomena. It should enable us to document the variability in cities across space and time, including rich studies of interactions, values, and their embodiment in the urban fabric, and to explain that variation using causal mechanisms anchored in both the features of cities and contextual or structural variables. If there is to be such a science of cities it may be through the use of network theory and the collection of real-time location and activity data through smart phones and other hand-held devices to construct real-time maps of social networks moving through urban space.

Such a “Grand Unified Theory of Sustainability” (with cities and urbanization at its core) would integrate the multiple challenges we face across the entire spectrum from global warming and the environment to questions about populations growth, energy and resource considerations.

Smart cities

This concept has recently undergone a fundamental bifurcation, which prompts us to distinguish two of its senses.

First of all, smart cities are a term that is used to denote cities that excel not only in the organization of their physical infrastructure but also in terms of attracting the creative resources to build a competitive advantage. To sustain the infrastructure, one needs the pool of creative resources, which can build upon the infrastructure to bring about positive social and environmental impact as well as economic prosperity. This may mean cities where the 'science of cities’, as mentioned above, is optimized in terms of movements and quality of materials and energy. But a smart city also has diversity in technology and scale, to maintain a certain amount of robustness and resilience over time. In this sense, smart cities have always existed, even though their relative 'smartness' in the urban system has fluctuated through time. At 'smart' times, they outcompete other cities in a Darwinian struggle for survival, at other times they are the most resilient cities in their system.

But the term is also used to characterize greater cities that use automation of technology and information processing to make better decisions than people can presumably make alone, and thus improve the running urban services. Some, particularly [but not only] in the business community see this development [positively] for developing and testing an incipient Science of Cities (and sustainability) as well as for its obvious enabling impact on monitoring and mitigating urban problems and making decisions regarding development, policy and growth.

But there are reservations among the majority (but not all) in the group about this concept of 'smart cities'. Technology and innovation are developed and implemented to support socially constructed values and priorities. In order to have smart cities we need smart citizens. More data and information” does not equate to 'smart'. 'Big Data' without 'Big Theory' (a “unifying” integrated conceptual “scientific” framework which recognizes cities as complex adaptive systems) may well create even greater problems and unintended consequences. Moreover, there are serious privacy/control/etc. issues with the way many people speak of this (massive anonymous data collection, monitoring, etc.).

Hence, the following statement may serve for the moment as a concluding one on this topic. "The complex urban systems including people, businesses and services, environment, as well as governance, provide efficient conditions for innovative digital information and communication technologies to monitor their interaction, not only adequately responding to the requirements of the system components, but preferably outstripping them in becoming a source of development and innovation for each of the parts. Sustainability and resilience as well as creating the synergetic effect of the interaction between parts of the system are the necessary conditions for the smart city system. On the other hand the smart city system concept also implies the requirement for the active system components [...people ...] to be aware of the whole system's objectives, sharing them and maintaining the activity with respect to those objectives."

Any other terms you feel are important to this conversation

As the responses under this category are both much more complex, and reflect the opinions of individual participants, we have not here tried to summarize those. They have been included 'as is' for the reader to consult.

Challenges raised during the workshop

It seems that, apart from the presentations (see the relevant chapter), one useful way to measure the impact of the workshop is to summarize some of the questions raised by the participants at the end of the second day (these are noted in full below). For the sake of easy reading, we have again grouped these into a few categories, well aware that there are major overlaps:

Evolutionary change mechanisms

- How similar or different are pre-modern and contemporary cities?
    - Are the empirical patterns the same, and/or do the same theories/concepts apply?
    - Are there common dynamics but specific path-dependent trajectories leading to different designs?
    - Why do cities emerge in the way we observe them to (in terms of different parameters like size, population, etc.)?
- How do cities gain advantages?
    - What would drive emergence or attraction of specific/certain sectors/industries within a city?
    - What is the role of 'name' or 'branding'?
    - What is the role of migration as a factor in city growth?
    - Can we design integrated urban mobility solutions for dense cities?
- How do networks of cities evolve?
    - Why do they look the way they do?
    - What feedbacks exist between a city and its position/connectedness in a larger network?
    - What fundamental commonalities exist between networks of systems of cities and networks/systems of other “organic” entities?

Macroeconomics of cities and their performance evaluation

- How do economic, social, and political processes factor into a “science of cities”?
- Can the “macro performance” of an urban region be usefully predicted as the emergent outcome of the actions of individual agents?
- What is the impact of the configuration of the built environment (density, segregation of uses, topographical factors, etc.) on urban productivity?
    - Are informal housing markets inevitable in rapidly growing cities?

    - How does this relate to socio-economic variables (including "creative class" factors)?
- Which policies would build an ecosystem for growth and prosperity within cities?
- How to convince politicians that regulating financial activity is a condition for improving the quality of urban dynamics?

Science of cities and networks

- How to develop a "Grand Unified Theory of Sustainability" with cities and urbanization at its core that integrate the entire spectrum of dialogue we face from global climate change and the environment to population growth, energy, resources, etc.
    - How to develop a conceptual framework for understanding the integration of information network dynamics and organization (the "genomics" of cities) with energetic resource infrastructural or network dynamics (the "metabolics" of cities) in a unified, quantitative, materialistic theoretical framework?
    - Can we determine the coarse-grained parameters and dynamics that determine and can be determined in a way to address the plethora of issues?
    - What are the "distinct laws" of social, ecological, and infrastructural systems in urban settings.
    - How do we conceptually integrate each of the systems?
    - Such a theory should consistently link urban to global, intra urban to interurban, a city system to the system of cities.
    - How do you operationalize the new science of cities for sustainability policy?
    - How can plans for new cities be informed by novel conceptualizations that emerge from this community?
- How do you best model the connections of urban areas to distal places (and in particular land use/cover changes)?
- Do these connections pose a challenge to a view of new science of cities that centers on the identification of 'scaling' or 'power' laws?
- How to construct the global multi-layer network of cities with respect to different kinds of interaction between them? (data availability?)
    - How do we connect the various networks that model a city?

Sustainability and resilience

- Are there studies that try to integrate models of cognition together with dynamics of the city?
    - How about models of social change vs. city change?
- To what kinds/sizes of hazards are cities and networks of cities naturally resilient, and to what kinds/sizes are they vulnerable?
- How to balance the degree of urbanization of cities with population growth to attain optimal resilience?
    - How to balance urbanization in India with making lives better for urban population

Understanding the context

- How do we define our objects of interest?
    - We need clear rules for how to define cities for different purposes, and we need agreement about these.
    - How to define the city borders based on human activity?

- Would our analyses or conclusions change if cities were seen as a dependent variable situated within contexts, rather than as independent variables?

Urban metabolism

- What drives the growth of urban areas?
- How/where do urban areas and cities get their resources?
    - What is their global or regional reach?
- How and to what extent can one influence on the urban metabolism in order to be more sustainable?

Urbanization metrics and distributions

- What are the statistical distributions of urban metrics across cities of the same population size or conditional in other metric?
    - And how about for each city across time?
- How does global energy use relate to urbanization pre-1965?
- What is the relationship between Zipf's laws and a general theory of socioeconomic growth (at a national level)?
    - Why are primate cities typically exceptions to Zipf's law?
- What are the statistics of urban qualities inside cities and how do explain them?
- Which parameters of the cities affect human activity of different kind within them and how?
- What influence does the number (or diversity) of services provided by a city have on the population/development of a city over time?
    - And does this correlate with prosperity or resilience of the urbanized environment?
- Are there cities that differ from the norm in interesting ways?
    - Cities that recurrently find themselves in the tails of distributions, positive or negative?
    - What cities?
    - Why?
    - Can we address a set of hedonic characteristics or a set of network characteristics elucidating such outliers?

7.4 Report on GSS and energy futures worskhop

FOREWORD

This report is the result of a workshop on "Vision in global system science: energy futures" organized by EC DG Connect in collaboration with the Joint Research Centre, Institute for Energy and Transport on 18th and 19th March 2013 in Brussels. Experts from different fields of expertise convened to present their ideas and discuss the future challenges of emerging energy system in the context of GSS.

The objective of this document is to summarize the discussions held in the workshop, with special attention on the methods and models that can be used in science based support to policy making.

GLOBAL SYSTEMS SCIENCE AS AN EMERGING SCIENCE

Global Systems Science (GSS) comes at the intersection of two major 21st century developments, one societal and one technological: the increasingly global and highly interconnected nature of challenges facing humanity and the pervasiveness of Information and Communication Technologies – ICT - in all human and societal endeavours.

Global systems science studies the possible structural, physical and socio-cultural transformation of the earth, environment and society. The goal is to capture the whole of the interactions of those systems and, given a set of objectives, such as sustainability, security, competitiveness,..., to study the possible scenarios in order to provide support to the policy decision makers. The challenges that GSS aims at addressing are both borderless and multi-dimensional, therefore they cannot be handled by one single country or by one single discipline, if aimed at providing sound policy support. This can be done in both qualitative and quantitative terms, with a focus on interactions, systemic effects and emergent phenomena.

In particular Global System Science:

- is an integrated trans-disciplinary approach which uses but moves beyond inter-disciplinarity by trying first to identify the kinds of key societal and policy needs which policy makers needs to address throughout scientific-based approaches;
- should provide an improved understanding of the interactions –interdependences of multiple social-phisical/technical-ecological systems of systems;
- uses an integrated perspective to address multiple problems at the same time that operate at different scales and domains
- should support social learning and transformations at institutional and individual levels by focusing on developing new concepts, tools and methods to prevent large-scale systems failures and improve resilience of global systems.

EMERGING ENERGY SYSTEMS

Emerging global energy systems can be conceived as a ‘complex systems of systems’; they can be conveniently described and represented in terms of dynamic complex multi-layer structure that integrates various different, interacting layers. The different layers of energy systems span from physical/technical (the hardware of the network), cyber (measurement, communication and control), market and business (wholesale and retail, services and operations), social (customers, users, stakeholders…), normative (administrative issues, standards, etc.), and political (local, national and regional decision making, and geopolitical implications).

This multilayers structure of emerging electricity systems (as well as general energy systems) increasingly show a "flow networks" structure, spanning over different geographical areas, often on a continental or cross-continental base. This provides to energy systems their "global flavour".

The interconnections between the different layers exhibit an emerging complexity in which it is impossible to abstract the overall behavior by the analysis of the single component. The coupling of the various layers with an incumbent widespread of IT and other systems (urbanisation, financial, etc.) may be a relevant source of the weaknesses of such systems and need to be studied to identify the potential risks, vulnerabilities and benefits of various systems configurations and interconnections.

‘Butterfly effects’, in which small event at local scale may cascade and accelerate to large-scale largely unpredictable effects and 'cascading failure' in which the failure of one or a few nodes in a network can influence the entire network, often resulting in large-scale collapse in the whole network (for example, the largest blackout in US history that took place on 14 August 2003 or the Western North American blackouts in July and August 1996).

Energy systems are constrained by considerations and goals from the environmental layers (environmental impact, climate change and limitation of usable natural resources) and the set of externalities (from local to global; from immediate to long lasting).

All this results in the co-evolution of the technical, cyber, market and business, social normative and political layers, in a given environmental context. From the policy and industrial perspectives. The analysis of these systems must consider a global perspective.

The Global dimension is typical of energy systems. There are many examples situations in which global systemic effects have been observed within the energy domain, being the oil crisis in the 1970’s one of the most outstanding one. Others, of lower scale but with equally multiple causes and effects include, for instance, the emergence of Standard Oil monopoly through a minor loophole in the US law that previously prohibited corporations from owning other corporations and which triggered the emergence of monopolies in many areas within only nine years, and which had to be countered by legal action. The California energy crisis also can be seen as an illustration of adverse consequence of partial unbundling, leading to power shortages and the transfer of billions of dollars from California taxpayers to Enron. Another example of the "globality" in emerging energy system is the July 2012 India blackout, the largest power outage in history, where more than 620 million people were affected (about 9% of the world population). The blackout spread across 22 states in Northern, Eastern and Northeast India. The overdrawn power in the northern region led to the tripping, cascading failure and ultimate collapse of the Northern Grid. One of the possible reasons for overdrawing power was the deficient rainfall which meant increased use of electric pumps to withdraw water for farming in these agricultural states.

Inside the emerging energy systems, the Electric Power Systems (EPS) are an exemplifying case. EPS are multi scale and multi layers systems characterized by two different interconnected and interacting levels, with different scales both in terms of extension and energy (power) involved. The High and Extra High voltage transmission systems (Super Grids) are emerging as global energy infrastructures, spanning over continents (from EU to Russia and China to northern Africa), while, at a smaller scale, the distribution systems (Smart Grids) serve a set of prosumers with local distributed production and storage of electricity with new real-time bidirectional communications. The social networks among prosumers may play a crucial role in the feasibility and sustainability of these systems.

GOALS AND POLICIES IN ENERGY SYSTEMS

Policy decision making, at local, national and international level, and regulation provide the rules that constrain the behavior of the different players in the energy sector (consumers, producers, wholesale and retail traders. It is generally considered that the goal is that of maximizing the system performance (technical, economic, energetic, environmental), striving towards the highest *sustainability*, *efficiency* and *security* of the energy system. The decisions of the players are (conceptually) based on the maximization of individual utilities although social values can determine, for instance, the choice of more expensive options.

Policy decisions in energy will have systemic consequences and need to be properly addressed. Very often policy makes use of many narratives that are not always backed by scientific evidence. The goal of GSS is providing approaches, models and tools to understand the possible future energy scenarios instead of contributing to "build smart futures" that seems a too vague concepts. In the current narratives about smart future there is a tacit acceptance that smart future will be a better future.

The logical chain from modeling and simulation over concepts/performance, into the policy decision processes is of the essence. Feedback between modellers and stakeholders can be facilitated by, among others, the use of narratives and gamification.

The key stakeholders (supranational, national and local policy decision makers, civil society) should be involved not only in the final stage of the application of the tools but also interactively during the design stage.

Key concepts, describing desirable performance, such as sustainability, interoperability, security..., need to be clearly defined and quantified. The approaches and theories to be used must be identified (complex systems and sustainability sciences …). The concepts express goals in the policy decision making that need to be quantitatively defined and linked to the possibilities of the former scientific approaches to provide adequate assessment.

KEY POINTS AND OPEN ISSUES IN EMERGING ENERGY SYSTEMS

Some key points and open issues in emerging energy systems that can benefit from a Global System Science approach are discussed below.

Energy infrastructure: energy infrastructure involves a chain of interacting processes and systems, including resource extraction, generation and production, storage, transmission and transportation, marketing, distribution, consumption and waste disposal. For instance, the interdependency between different carriers needs to be considered. In this context, the contribution of a GSS is needed because is essential to have a holistic framework and models of the entire energy infrastructure that address the interactions between its components. Such models must incorporate the economic, social, technological and environmental aspects, and provide insights into the effect of policy decisions concerning energy on the well-being of private citizens and society as a whole.

Technological performance and choices: the choice of technology influences all aspects of energy infrastructure and its impacts. Economic models for the mitigation of global warming, for example, are inevitably forced to make assumptions about the likely rate of improvement of different technologies, both in terms of costs and environmental impacts. Outcomes depend considerately on these assumptions. The possibility of implementing a continent wide electricity market needs a proper transmission infrastructure able to minimize the bottlenecks among different countries. The choices that are made dramatically influence all aspects of energy infrastructure; for example, the characteristics of the grid that we will need in the future are very different if we massively adopt nuclear power than if we adopt more renewable energy. To plan our research, development and investment in energy technologies it is not sufficient to "leave technology to technologists". This would lead to bad planning: expert forecasts regarding technological improvement have typically been wrong due to a combination of siloed thinking and bias due to industry advocacy. Here we are not claiming that we should advise technologists in the lab, but rather that we should take global systems science into account when making public investments and in extrapolating the future course of technological improvement for planning purposes.

Understanding the process of technological improvement, in particular as it applies to energy, is essential for planning future energy systems. We must improve our ability to estimate the future cost and performance of energy technologies. GSS is important because the family of all technologies forms a global system in and of itself, which can be thought of as a *technological ecosystem*, which is best thought of as a network. Individual technologies are built recursively out of their component technologies; this is true both for material inputs as well as the processes of production and manufacture. In the modern world technological manufacture is a geographically distributed and in many cases global process. Progress in one technology is automatically transmitted to all the technologies for which it is a component; improvements in semi-conductor manufacture, for example, made a substantial contribution in driving down the cost of photovoltaic modules. Global systems science can contribute by giving us a better understanding of technological improvement in energy, by treating the process of improvement as a networked phenomenon that is driven by the physical interaction of technologies as well as the social drivers underlying supply and demand. Doing this properly requires addressing the economic, environmental and social consequences of our choices concerning technological development.

Externalities: incorporating externalities is a central problem for energy system. Climate change is an effect of the way we produce power and should be factored in. Markets do not price in safety or pollution by themselves -- these need to be enforced via regulations. There are many different approaches to the same problem. For example, we can reduce carbon emissions via a cap and trade scheme, through carbon taxes (internalization of externalities), or by outright bans on technologies that emit too much carbon. We can stimulate low carbon technologies through feed-in tariffs or via public R&D. The effectiveness of these methods depends on interactions between technology and society, and must be evaluated in terms of economic, environmental and social impacts.

Centralized vs. decentralized: Is there really a trade-off between centralisation and decentralisation? Or are these two possible configurations complementary and serve different functions at different levels? To what degree we want to push the global energy system to a decentralised form is a political issue is a question of meeting a series of global objectives. But what are these global objectives? Is this simply a matter of maximising market performances? How to achieve nearly full-automation of energy systems, so that multiple components can run autonomously at multiple layers? In order to answer all this we should need to discuss first what kinds of different social, environmental and social objectives the global energy system is supposed to attain. And also, we need consistent and operational definitions of de/centralised systems and of the different agents that constitute such systems (e.g. individual households).

From a GSS perspective, we want to understand the future potential of various options and of potential trajectories of the global energy system. The question thus raised is: to what extent various forms are technically feasible? A decade ago, it was not possible to ask such questions because of the availability of the micro-generation systems and because the economic, technological and political landscape was very different. At present, we could say that we have insufficient transmission lines for a global centralised power system. How much do we need to invest in various forms of energy transmission and distribution? Is it really possible to centrally control distribution systems? In an ICT-based system we may not need a centrally controlled system and the data needs for a distributed energy control system may be different than for a centralized control one. A challenge therefore is to provide dynamic real-time information of prices, stocks and flows of energy to various costumers. To that aim, we need to understand what kinds of different tools are needed to solve the different kinds of problems of the two possible system configurations. And to avoid speaking completely different languages, we need to have some quantitative approach to separate the good solutions from the not-so-good ones, while acknowledging that different groups and people will have different perceptions of the problems at stake, as well as different interests. In this context focusing on the process is crucial - in particular when generating new models and tools, and the communities of practice that can be constituted a particular energy assessment and decision-making problem.

In addition, we need evidence that one system may be better than the other: measures of satisfaction and performance need to be developed, and to identify some already existing benchmarks to guide policy action in either direction. A much in-depth relational understanding is also required onto what extent the behaviorof prosumers –their constraints but also their capabilities- are determined by different configurations of the market. Some energy system actors may need information and price signals on a very short time span –seconds, minutes- to take their decisions, but such information may not be available in a not-fully interconnected system. IT and data from social networks may help to disclose some information that some actors may be resistant to release. Decisions on various technical aspects regarding production, storage, distribution, consumption and waste control and reduction from a full life-cycle energy perspective need to be taken. Then the question is whether and how can we use the information provided by the market price signals and other social networks to integrate and coordinate these decisions and flows.

> Multi- scale systems*:* Multiple interconnected time and spatial scales. Decisions regarding energy systems comprise multiple interconnected scales, from very short ones (e.g. milliseconds) to years to even to over 100 years as could be considered for the case of infrastructure. As in the case of power systems both a continental wide transmission system coexists with small neighbourhood distribution networks.

> Uncertainties: What is specific about uncertainty in global energy systems in contrast to other systems? Are there any special approaches required? In this regard, scenarios are often used as a typical policy tool in energy systems assessment. However, one difficulty is that such scenarios usually do not come with any assessment of their probabilities. In this regard, sometimes people refer to a "central scenario" as the most probable. Advanced statistics (e.g. Bayesian methods) can be used to quantify uncertainty associated with a given scenario. Therefore, the problem is how to communicate the resulting uncertainty to politicians and the general public in a language that they can understand and engage. In this context, we need to ask: What are the various sources and types of uncertainty? What kinds of uncertainty emerge from various models and data dealing with energy systems? What is the role of social science in helping to anticipate or predict the behaviorand interactions of the new agents that form the new global energy system (e.g. prosumers, transnational corporate energy networks).

We should rethink whether the approach taken by climate change modellers whereby numerous climate models are developed and run by different research centres worldwide and in which divergent outcomes are used to derive a statistical measure of uncertainty is the best approach. In fact, it is not true that such models are so different in nature, as most of these models are based on rather similar assumptions and approximations (herd mentality) often deterministic and linear, as it is the case of the single-equilibrium, single rational agent assumptions used in most climate-economic models.

Modeling & simulation: proper models, simulation and large data management tools are needed to capture the global dimension of energy and electricity systems (both geographical and multilayer) and the high linkage between different players and systems. They consistency check and the validation prior of their application is a key issue.

In addition, models are usually validated using past data. One can always certain tweak model parameters to get a good fit to the observed behaviour. But this does not tell us if a prediction made by a model will be good. In other words models, are good for interpolation but not extrapolation. Hence, how to assess uncertainty of model-based prediction and in particular with regard to generating a better understanding of global energy system dynamics? The key is to understand sensitivities and to identify which model parameters are most important to understand what drives a system's behaviour, taking a complex perspective able to deal with non-linear behaviours, discontinuities, bifurcations, tipping points and phase changes, and rapid changes in boundary conditions (including changes agents configurations, e.g. from consumers to producers). We should avoid the view which tends to stick to the continuation of the present regime as if nothing would change. While there is the general perception that Agent-Based Modelling is the only way to address and integrate complexity in modelling, this is not true, as we need a portfolio of methods and tools to deal with such different kinds of uncertainties and problems. In this respect, we need to explore whether certain formal statistical methods (e.g. Bayesian statistics) can deal with the effects of disruptive technologies (such as e.g. shale gas) which have a potential to completely change the main model characteristics.

Questions and challenges to GSS APPLIED TO energy systems

Science-oriented challenges

- How can we better prevent a **globally systemic crisis** like the one in the 1970s?
- What are the **inter-linkages between** the vulnerabilities of power systems with the vulnerabilities of **ITC systems**?
- How to develop a **less vulnerable / more resilient energy system** in a globally interconnected world? What kinds of **regulatory innovations** at various scales of action are needed for that?
- What kinds of **specific tools, method and science-policy integrated processes** need to be devised to better represent and assess global energy system dynamics?
- What **integrated performance indicators and goodness functions** need to be constructed that relate to the whole energy system of systems?
- What kinds of **centralised/distributed algorithms** are required to address specific global challenges in the energy sector? Warning: avoid though reducing policy assessment and politics to algorithms.
- What trade-offs or synergies can be identified between various **optimisation procedures** operating at various levels and sectors?
- What kinds of **common formal languages** are required to integrate the various disciplines to address multiple problems and needs that regard the global energy system?
- What **kinds of evidence** we need to provide grounded insights about possible trajectories of the global energy system evolution?
- **How to extract sense from the large flows of networks information** in ways which are relevant for the understanding and the integrated assessment of global energy systems?
- **How to incorporate the social, political and behavioural dimensions in the modelling** of global energy systems?

- **What** is the role of other global systems, like **the financial and banking sector**, and the internet in the configuration of global energy systems?

Policy-oriented challenges:

- How better map out and understand the social, economic and environmental **consequences of unbundling?** Can GSS help to model and quantify the global multi-level effects, as well as the unintended consequences, of the unbundling policies in the energy sector? What is the role of prosumers in yielding extreme forms of unbundling?
- How to achieve **dynamic real-time pricing system** of energy flows at global level?
- What **benchmark examples** of existing experiences can already be used to illustrate the role of IT in fostering transformations and transitions in global energy systems?
- What would be the financial needs and social, ecological and economic consequences of a **Global Green Dea**l in the energy sector?
- What **kinds of new business models** are needed to better fit the various innovations, visions and requirements of alternative energy systems? e.g. globally distributed, based on 'servicisation' (not buying energy but energy services) and enhanced 'prosumers' (agents who are both producers and consumers).
- What implications have the present **world population growth** trends and demand for energy in the reconfiguration of global energy systems?
- How to better map out and deal with **global inequalities in energy access**?
- What **extreme global warming scenarios** (e.g. up to a 10º degree warming) would entail for the reconfiguration of the global energy system? In which way a complexity IT-based approach (e.g., using networks and big data information) can help better assess and to anticipate that?
- What is the role of military systems in the configuration of global energy systems (e.g. nuclear vs renewables)?
- How GSS can support **energy crises management**? (e.g. Japan)
- How **renewable**s can be introduced globally? What is the role of prosumers in reducing energy consumption and global energy impacts?
- What different potential **global transitions** in the energy systems can be identified and to what extent the implications, e.g. in terms of costs and benefits of these different transitions and pathways, can be quantified?

Public communication and engagement challenges

- What kinds of **incentives,** including the **non-economic** ones, can be most effective in supporting coupled IT-energy innovations and transformations?
- What kind of energy systems configurations can be envisaged so as to be more conducive to **learning, adaptation and flexibility** and in coping with global challenges?
- What is the role of IT, and in particular visualisation, in improving a '**global energy awareness and culture**' and supporting **'energy-smart citizen behaviours'**?

Concluding remarks

In the present globally interconnected world energy is generated, stored, transmitted and consumed -and its waste disposed or recycled- through a complex and dynamic *system of systems*. A central challenge for GSS is to focus on the multiple interactions of different scales of the energy systems: from smart micro-grids to super grids To what extent these two approaches can coexist? How these two apparently divergent trends and configuration relate to each other and need to be managed for a better coordination and efficiency?

GSS should be able to identify what kinds of factors are most relevant for the global energy systems and to what particular pressures are they more sensitive (e.g. not necessarily prices but perhaps to other variables outside the energy systems). For such a system to improve its long-term sustainability and performance a diversity of tools of analysis as of flexible and resilient operational arrangements are required, in ways that are able to address the multiple goals involved. In the context of emerging energy systems, 'global' should better be understood as 'multi-objective', 'multi-connected' (between various systems) and 'multi-functional'. In other words, while this 'global energy system of systems' is growing both in operational size and in interconnectedness, its multiple performances are also increasingly tighten up and depend on the performance of many other non-energy systems (IT, governance, financial, urban, etc).

In turn, GSS could also help to reframe the role of energy systems in the light of societal challenges. A global systems perspective could also be a key driver for Research, Development and Innovation and in particular by coupling IT into the development of alternative configurations of energy systems. For instance, GSS could support innovations and system-level synergies in areas like industrial symbiosis and industrial ecology (e.g. by transforming various forms of waste from one system to become energy for another system). Transformations in the global energy system will require coupling the synergies of multiple innovations occurring within the energy systems at various scales and processes with innovations being developed out them, e.g. with the IT and the urban sectors. While connecting the smart-grid with the smart-cities development may represent full suite of responses to complex problems that concern the sustainability and optimality of energy-information-transport systems, there are many other options and alternatives that need to be explored. To achieve so, a learning evolutionary approach is called for: individual motives, incentives and learning capabilities of the agents constituting the multiple systems need to be explored, together with their systems' interactions. In the future, a globally smart energy system, coupled with other systems, can only be composed by 'energy-intelligent agents' who know what is best needed to be done for optimizing their multiple decisions in ways that lead to a secure, sustainable and high quality operational global energy system.

On the one hand, GSS should also help to unveil the assumptions about agents behaviorused in the conventional energy modelling, e.g., moving toward the study of single individuals preferences to 'social practices' (clusters of social interactions, not just individuals). The way we represent real dynamics in energy markets does not often fit the supply-demand model. In this respect, we must avoid the risk of developing one single tool or model, but a diverse array or toolkit to improve our understanding of the complex energy system dynamics. On the other, GSS should be able to produce much better modelling tools on pressing issues such as the costs and benefits of climate mitigation and of the various pathways for a global energy transition, e.g., using agent-based modelling but also other methods while taking into account long-time series of energy trends. This should be able to enhance our capabilities for anticipation and of the systemic, unwanted effects of such agents' interactions as well as to understand what kinds of institutional innovations are needed at different levels (e.g. property rights of energy resources, or liabilities derived from energy systems). This could lead to a possible overarching theory to learn how to cope with the dynamics of energy systems of systems in a global scale. And at policy level, it could also help to identify certain policy system attractors and leverage points to support the various multi-level transformations, while trying to map out the possible unintended cascading effects derived from aggregation of single policy interventions (e.g. as in the case of the penetration of the electric vehicles or home insulation policies).

GSS is an open-boundary research, whose results cannot yet be anticipated - that, is its present nature is mostly goal-searching, not goal performing. There are indeterminacies about what we need to know and thus we are faced with many unknown-unknowns. In this situation, the GSS approach requires a community which is farsighted and creative, but also shows a greater capacity for flexibility and independence.

7.4. Ten selected posts from the GSS blog

Below a selection of 10 posts from the GSS blog, in chronological order.

Behavioural Change and Global Systems Science

November 14, 2012 by Paul Ormerod

Understanding how to change behavioris a major problem for policy makers at the moment. Just think of the problems which could be solved if we knew how to do this effectively. For example, climate change. To reduce emissions, behaviorneeds to change.

In financial markets, bankers have always wanted to make money ever since banks were first invented. But there has been a profound change in culture over the past two decades or so, which led directly to the financial crisis. It became acceptable for bankers and traders to behave exactly as pure Economic Man, without regard to the consequences of their actions on other people.

More generally in the corporate world, senior executives now feel able to pay themselves hundreds of times the wages received by ordinary workers. They deserve to be rewarded, but behavioral change has led to gross excesses. In the UK in the mid-1980s when the domestic gas industry was privatised, the Chief Executive was vilified for paying himself what was at the time considered to be a stupendous amount. How much was it? Half a million Euros a year. Most CEOs of major companies would now simply laugh if that was all they were offered.

Think of social problems such as obesity, drug taking and alcoholism. In each of these areas, behaviorhas changed. What was previously regarded as unacceptable behaviorhas now become permitted in the relevant communities.

Standard economics has an answer. It is not wrong. But it is at best a very partial solution to these major policy challenges. To change behaviour, you change incentives. Most public policy is based on this view, that people operate purely as individuals, and systematically compare the costs and benefits of different alternatives. On this theory, they then make the best choice for themselves. So policy becomes based on changing the incentives that people face, altering the costs and benefits of different choices.

Global systems science has the potential to revolutionise the range of tools available to policy makers. Network science has expanded dramatically over the last decade or so. We now know much more about how ideas and behaviors either spread or are contained across networks.

Peer effects, the copying or imitation of the behavior of others, are now a dominant feature of behavior in the interconnected world of the 21st century. Incentives still matter, but in many contexts they are of second order of importance compared to the influence of peers on the relevant social network.

Global systems science needs to make operational the insights of network theory. We can provide the practical tools for policy makers which will transform their effectiveness by understanding much better how to change behavior. We need to:

• Develop heuristics to identify in any given situation the relative strength of network effects versus individual selection on behavior

• Develop ICT tools to obtain good approximations to the underlying topology whenever network effects are a strong influence on behavior

• Develop strategies on how to alter behavior in these contexts

Global Imbalances: Equilibrating Exchange Rates vs Quantity Controls

December 10, 2012 by Leanne Ussher

Can we find an equilibrium exchange rate system (e.g. fixed or floating) that might reduce global imbalances or should we rely on penalties, caps or liquidity provisions to create sustainable balance of payments.

For example at the Oct. 22, 2010 G20 summit, Timothy Geithner argued that reducing current account imbalances would strengthen global growth and make it more likely to last. The U.S. pushed to commit each Group of 20 nations to keep its surplus or deficit to less than 4 percent of gross domestic product. But the manner in which this was to be achieved offered little change from previous measures amounting to deflation in deficit countries and no change in surplus countries.

Criticisms of such policies hark back to the reforms of global imbalances put forth by luminaries such as John Maynard Keynes and Nicholas Kaldor. Both economists were skeptical of the powers of flexible exchange rates to equilibrate imbalances. In particular, Kaldor in 1977 found empirically that appreciations of the Japanese and German exchange rates, and even rising labor costs relative to their trading partners, did little to change their increasing share of world trade in 1960s and 70s, typically at the expense of the US and UK. Looking at the history of currency realignments, the success of devaluations in reducing surpluses is variable at best.

Kaldor's instead proposed a solution that would focus on the terms of trade between manufactured goods and commodities – the raw materials essential to industry. Ordinarily, devaluation will raise a country's cost of raw materials (if such inputs are primarily imported), create inflation and possibly lead to rising wages. This would raise the cost of manufactured exports and lower competitiveness. During the period that Kaldor studied, he found that the appreciation of the Japanese and German currency compensated for rising prices of food, industrial materials and oil. This, along with Verdoorn's law (increasing returns in production and the positive feedback in market share and labor productivity) allowed these countries' trade surpluses to grow.

Consider today's currency environment, if China was alone in maintaining a low exchange rate relative to the US dollar, then they would necessarily lower the price of their own manufactured goods (i.e. the price of the 'value added' by its processing activities) in terms of basic inputs (food and raw materials). However this trade off between competitiveness and terms of trade is not occurring because there are many other emerging market nations that are also devaluing their currency, including those that primarily sell commodities, all are hoping to create a competitive edge and develop their manufacturing base through export-led growth.

Kaldor designed a trading system that would balance the manufacturing trade between the highly industrialized nations and prevent the industrially dominating 'go-ahead' countries from growing through unrequited exports, at the expense of other industrial countries, effectively stopping them from exploiting their own growth potential and ability to pursue policies of full employment. Kaldor felt that only with cost push inflation pressures and/or a limited supply of labor (although this was rarely binding due to immigration) would an export-led country have an incentive to ever raise their exchange rate enough to counter their competitive advantage in manufactured exports.

Kaldor's preferred solution was the institution of a new reserve currency, backed by a basket of commodities. He called this commodity reserve currency (CRC) his 'gadget' and once instituted he believed that it would be an apolitical, automatic stabilizer that would resolve global imbalances, promote even growth and effective demand throughout the world (Kaldor initially took this idea from Benjamin Graham and worked on it with Albert Hart at Columbia University in the 1960s and 70s).

In addition a CRC would create a bufferstock of storable raw materials and allow for the stabilization of their price index over the cycle. The stockpiling of these goods (located at regional futures exchanges and trading centers) would be paid for by the issuance of the reserve currency (redeemable inventory receipts for the basket). The targeting of a commodity price index could be done with open market operations – buy the basket and increase the supply of CRC when demand and commodity prices were low, or sell the basket and decrease the supply of CRC when demand and commodity prices were high. This new currency offered a standard of value that can grow or contract counter cyclically to world trade, and most importantly provide a source of stable income to commodity producers (including the developing world). Unlike the SDR this currency could be internationally traded by public or private participants and did not require liquidity or mass acceptance to make it valuable. It would be independent of national currencies, hence exempt from the Triffin paradox, and its supply was endogenous to rising world demand

This new reserve would exist alongside individual sovereign currencies which could peg or float to the international reserve. Importantly, each nation would be free to choose their monetary, fiscal, exchange rate and trade policy with their own citizens' priorities in mind.

In 1977 Kaldor thought his commodity reserve currency proposal was at least 20 years ahead of its time. Keynes back in 1943 was far more pessimistic.

"The right way to approach the 'tabular standard' [CRC] is to evolve a technique and to accustom men's minds to the idea through [individual] international buffer stocks. When we have thoroughly mastered the technique of these, which is sufficiently difficult without the further complications of the tabular standard and the oppositions and prejudices which this must overcome, it will be time enough to think again" (Keynes 1943).

Keynes thus took the pragmatic route and instead of finding an equilibrating exchange rate process he proposed the balancing of deficit and surplus reserves through member cooperation and agreement to automatic rules and penalties. His international clearing union (or world central bank) would impose penalties on trade surplus and deficit countries and offer strong incentives for surplus countries to spend their reserves held in excess of their quota. (I can offer details here if requested). Exchange rates would for the most part be fixed with capital controls, though adjustable to equate wage efficiencies across countries and balance trade. The International Clearing Union would finance commodity stockpiles to stabilize individual commodity prices and thereby create a counter cyclical international incomes policy to smooth the world business cycle.

Both the Kaldor and Keynes proposal required a new international central bank (or IMF) and both called their international reserve 'bancor'. Kaldor's was backed by commodities, Keyes's was not. Kaldor's was meant to be an automatic stabilizer primarily non discretionary in reserve expansion or contraction, while Keynes's was much more discretionary and required coordination, penalties, and lender of last resort functions. Both had endogenous reserve supplies, although Kaldor's was fully backed and Keynes's was not.

Kaldor thought that he had found a tool that would not only cure global imbalances but would create investment into renewable resources that could sustain the industrialization of the developing world in a steady and sustainable manner without the need for coordination.

It is easy to say that both plans remain futuristic utopian policies. But I believe it is important to understand the mechanisms of each and work out whether they can actually do what they promise, regardless of political viability. And then put them in the tool box for future reference.

Seven research questions on Special Drawing Rights (SDRs) as a reserve currency

The background of this post can be found in the GSDP workshop 'Towards a Sustainable Global Financial System', presentations and additional information can be found [here]()

The first such workshop took place in Potsdam, Germany, on December 8 – 9, 2012. It was dedicated to an assessment of the proposal for a sustainable financial system made by the governor of the People's Bank of China.

This is the first long-term proposal made by a major figure in today's global financial system, and it builds on an impressive sequence of intellectual and political precedents. In a nutshell, the proposal envisages a transition from the present, Dollar-based system towards a system anchored in Special Drawing Rights (SDR) emitted by a suitably enhanced IMF. These SDRs, in turn, can be defined not in terms of consumer price indices as is the case with today's currencies, but in terms of a price index for critical resources the world economy relies on. Relevant goods could include coal as well as emission permits for greenhouse gases. Ultimately, buffer stocks of related commodities may complement the classical instruments of monetary policy. Clearly, the proposal has major geopolitical, economic and environmental implications, all worth careful investigation.

The Potsdam workshop has been the first systematic effort at assessing that proposal. It was conducted in a sustainability perspective – a perspective all too often missing in financial debates. It is the starting point of a systematic inquiry on perspectives for a sustainable global financial system to be performed in the coming years.

December 10, 2012 by Ulf Dahlsten

First of all I would like to express my personal thanks to speakers and participants in the workshop on a sustainable financial system and developed SDRs. The presentations and the discussions were thought-provoking and they showed the need for more reflections and research, which most certainly will be taken on board in the white paper that is the planned outcome of the conference.

We clearly need to be more precise about the objectives the developed SDRs would meet. One goal for the developed SDRs seems to be to offer an alternative currency for cross-border exchange, the volume of which whould be mainly driven by the needs of the "real" economy and investments in "real" assets. However, already this seemingly uncontroversial goal raises immediate questions. What is the"real" economy and what is the value of "real" assets? If other goals are added, such as the balancing of current accounts and the stabilization of exchange rates the complexity increases further. In addition, if we among the goals want to include the role that SDRs could play in the necessary transition to a more sustainable economy and in the support of the development of the living conditions for the billions living in poverty we may reach a complexity level that is outside the reach of what now is possible. A "big-bang" solution may be attractive in the case of a new financial crisis, but as, for the time being, the "muddling through" scenario is slightly more likely, a more gradual approach could be favoured.

I have taken with me seven research questions from the workshop. They are in no way the only questions that can be raised and other participants may have other questions they have brought with them home, but I would like to share my seven questions with you for the purpose of promoting a common understanding of the challenges ahead.

1. What are the realistic alternatives to the USD as a reserve currency?

It is clear that China does not wish the RMB to take over the role as global reserve currency as they are - and probably rightly so – afraid to be caught in the Triffin dilemma and become unable to tackle the domestic interest problem. They may end up having no choice in the matter as history has shown that the switch from one reserve currency to another can be surprisingly fast.

Many see the development of three regional reserve currencies – the USD, the Euro and the RMB. But would this be a stable sloution? It is unlikely, as Carlo Jaeger discusses in his blog input. We need to look more into it and may add some insights from research in other areas to the subject.

The third alternative is a new global reserve currency and given that the other solutions have some drawbacks, this is a solution worth looking into.

2.Who creates the SDRs for commercial use?

Base money are created by central banks, but the overwhelming creation of commercial money is done by banks. Who would create the SDRs, which Governor Zhou is proposing to be used for commercial purposes? If banks would be allowed to create them, what would be the requests for reserves? There is a big difference between banking systems today as the UK is demanding 0 % in reserves, the US in principle 10 % and China above 20 %. What would be the optimal liquidity reserves in SDRs if banks are allowed to create them?

3. How could a smooth and gradual transition look like?

Governor Zhou's proposal is sketchy on this point. He just recognizes the attractiveness of a gradual approach.

5. Would we need capital controls?

The truth is that financial markets with private creation of money have been inherently unstable sinch the 17th century with the exception of the decades after Bretton-Woods. Perhaps we need to reintroduce some controls to reduce speculation and focus the system on the main objectives.

6. Stabilize exchange rates

The status of the USD as rressrve currency is automatically pressing the USD upwards. The introduction of SDRs would relieve the USD from that pressure and rebalance the the exchange rates. A question: Would even a reintroduction of Bretton Woods in some form or the other be a possibility?

6. Do we need to balance the current accounts?

Keynes saw a rebalancing of current accounts as a major objective of his clearance union. As the exchange rates can be expected to be adjusted at the introduction of SDRs this problem can be expected to be reduced, and especially if a new "Bretton Woods" is introduced.

7. How about the store of value?

The Chinese are expressing concerns about the risk that the US is going to solve its debt problem by printing money. Given the gridlock in the US Congress it is a worry that seems reasonable. The USD was a reserve currency when Roosevelt unilaterally disconnected the USD from the gold standard and it was a reserve currency when Nixon decided to print money to pay for the Vietnam war. The USD as a store of value is a shaky proposition given the present debt levels. The SDRs could perhaps if connected to the real economy (in a wise way) offer a better store of value. A concern is that commodity markets are highly volatile and manipulated due to speculation and cartels.

A comment on the agenda for a Global Systems Science

February 5, 2013 by Rich Rosen

As I stated at one of the Berlin workshops in December, my favored methodological approach when confronted with a set of interacting complex systems is to try to break them apart, and create SCENARIOS from plausible ways in which the systems might interact. To somewhat oversimplify the approach to Global Systems Science described in this agenda, I don't think one can have any realistic hope of creating one big model to represent the likely interactions among several complex systems such as the economy, the energy system, the ecological system, the food and agriculture system, the global patterns of land-use, etc. It is even hard for me to conceive of developing a successful model to simulate the future of even one such system. So the reason I would propose to focus Global Systems Science around the creation of interesting future scenarios (like the four the Tellus Institute has recently updated) is that the components of these scenarios are not overly "hard-wired" together in ways that we can not really justify. Also, the scenario methodology will inherently come with the types of narratives which the agenda correctly describes as quite useful.

Another reason for supporting a scenario creation approach to global systems science is because the global data by region for almost all the key parameters needed to support creation of one big simulation model (agent-based or otherwise) is terrible. The poor quality of most data does not make it amenable, in my view, to the kind of intensive analysis described in the agenda, so I would also drop that approach. When one creates complex scenarios for interacting complex systems, our experience is that a lot of data for various regions of the world has to be made up, based on comparisons to other regions.

To me, the key requirement for creating interesting scenarios for the future of our planet is intelligent and creative analysts who can actively consider futures that others dismiss. Anyway, the key goal of Global Systems Science in my view, is to lay out a plausible set of scenarios that can be used to guide the world to a better future. So to me, trying to simulate the future based on a set of equations in a model is somewhat besides the point. The key set of questions we need to ask and answer is how we can change human behavior and both the individual and collective level to change the relevant set of complex sub-systems in the ways we want to change them.

Starting a GSS Reading List

February 13, 2013 by Carlo C. Jaeger

When some time ago I asked Ralph Dum what he considered a good example of a global system, he said: "The Internet". That answer made a lot of sense to me and is one of the reasons I engaged with GSS.

There is a rather famous paper by Papadimitriou called "Algorithms, Games and the Internet" claiming that to understand the Internet we need "a fusion of algorithmic ideas with concepts and techniques from Mathematical Economics and Game Theory". Again, that makes a lot of sense to me. The reason being that "The Internet has arguably surpassed the von Neumann computer as the most complex computational artifact (if you can call it that) of our time". It "is unique among all computer systems in that it is built, operated, and used by a multitude of diverse economic interests, in varying relationships of collaboration and competition with each other." And for sure this multitude of interests cuts across nations to span the whole globe. So that paper looks like a good start for a GSS reading list. And for those who like less technical stuff, here is a gentle introduction to "The Price of Anarchy", a subject presently studied with the tools suggested by Papadimitriou. Remarkably, the Internet community engages in this analysis because it wants to pay that price, while understandably preferring to keep it low.

I'll start a very preliminary GSS reading list by adding some references based on conversations with Sander van der Leeuw about readings for the worksop: "GSS – territorial versus functional patterns" (Arizona State, February 25/26).

Consider the beautyful Internet meme: "We reject kings, presidents and voting. We believe in rough consensus and running code" (it started at www.ietf.org/proceedings/24.pdf, p. 543). That pretty much captures the spirit of the professional networks that are increasingly shaping the technologies humankind lives with. These networks are an important example of what sociologists call the functional differentiation of society – as distinct from the segmentation practiced by our ancestors in the couple of hundred thousand years before they settled down, but also from the hierarchical differentiation that became paramount in the territorially based ways of life that shaped the past couple of millennia. Some background on this is provided in a pretty influential paper on Social Differentiation.

One reason functional networks are important in today's world is that they provide people with identities that generate bonds crossing the boundaries set by national identities. Amartya Sen has argued that this kind of multiple identities is what we need to reduce the risks of violence in a globalized world. We better think hard about these risks as they may well become, in Churchill's words, "A Gathering Storm".

A key topic to consider when looking at the relation between global functional networks like the world of computer scientists, programmers, etc. and the territorial structures of nation states is the dynamics of global urbanization. Cities are places where a multitude of functional networks intersect. Sander has already begun to spell out how the GSS research program might look at worldwide urbanization (see his post "Towards a Global Systems Science of Urbanization"). To get a sense of how this fits with the broader scope of GSS as a whole, see his "Lessons from the Distant Past". And when thinking about a GSS research program, we can build on the agenda for scientific research that Young et al. have designed with regards to "The Globalization of Socio-Ecological Systems".

A key practical challenge with regards to that globalization is how to develop a reasonable "Governance of Finance". How daunting this challenge might be becomes clear when looking at the "Global Network of Corporate Control". As the global financial crisis of 2007 has shown, the state of the art in economics is hardly sufficient to deal with these networks. The fusion of algorithmic ideas and game theory advocated in the first paper on our list, therefore, is best seen not as refining existing ideas here and there, but as the kind of intellectual adventure that opens truly new horizons. "Shaking an Invisible Hand" offers an entry to that journey.

Global change, Disasters and Governance

March 7, 2013 by Sani Yang

Disasters seriously undermine longer term sustainability and the increasing environmental risk caused by global change has widely attracted attention.

What kind of scientific support can we provide to global change policymaking? Several aspects that we may think of:

Can we further explain the mechanism of environmental risk under global change? Do we understand global change and the evolution process of environmental risk as a global system? Is the "dose-response" theory for narrow-sense environmental risk still working? Do we need new for more general environmental risk?

Can we propose integrated models to describe the environmental risk in the world? (Hey, models again! It is imperfect, it is subjective… but we need tools to 'commercialize' the value we have. People are easily and heavily influenced by charts and figures, isn't it?) E.g. new models which can reflect the characteristics of the cascading effect/domino effect/disaster chain effect?

If we have new risk assessment models, can we design institutional design ased adaptation strategies for integrated environmental risk governance?

When the problem is simply too big

March 14, 2013 by Colin Harrison

Last week I went for the first time to Mexico City to take part in a technical conference at the Universidad PanAmerica (UP). The USA newspapers have been full for many months with stories of murder and kidnapping and so I approached the trip with some apprehension. I am delighted to say that my expectations were enormously exceeded. No doubt there are many dangerous areas in Mexico City, but that is true of many cities around the world. As a photographer I was enchanted with the colours and the light in Mexico City and our hosts at the UP were amazingly well organized, gracious, and generous.

The one big problem we faced however was that of getting around in this city of 20 (25?) million people spread over some 2000 km2. The conference used a 20 seater van or a 50 seater bus on different occasions and we seemed to spend 2-4 hours per day crawling through the congested streets. More independent participants used the MetroBus, a very popular (and overcrowded) Bus Rapid Transit system, or walked. But mostly we suffered in the very nice van.

So it would be wonderful to wave a Smart City wand over this and magically solve these problems. Surely this level of congestion must be having some impact on Mexico City's further economic development and it definitely has an impact on the quality of life of all economic classes. But transportation is only one of many substantial challenges that the city faces. Despite efforts by the city to prevent it, many (millions?) people live in unauthorised developments where they receive no services, including fresh water and sewage. And this in a city that has had repeated epidemics of Avian Flu.

I can barely imagine what it must be like to be a senior administrator in the city government who is confronted with these totally unmanageable and highly inter-connected problems. So what does GSS have to say about problems of this scale and complexity? Or can it only deal with the easy stuff, such as London?

Your thoughts?

How should GSS enable policymaking to better 'host' the future in the present?

March 18, 2013 by Angela Wilkinson

Global Systems Science needs a deliberate and reflexive element of actionable supranational or 'global' foresight that recognises the contingent nature of an unpredictable future as a motivator for change in the present. Today's big policy challenges benefit not just from looking back to see established patterns, but in looking forward and imagining different possibilities. They are also increasingly associated with new approaches to change, not just developments in systems thinking and complexity science. For example, the momentum in collaborative futures, transition management, resilience management, sustainable inclusive and green growth initiatives, etc. each, in their own way, recognises the limits of established economic theory (neoclassical economics) and indicate a search for new approaches to appreciating, addressing and 'managing' change in the context of irreducible uncertainty and complex systems dynamics.

Connectivity has become the key driver of vulnerability and value creation, and created a 'perfect storm' of complex systems, higher decision stakes and inherent social/values conflicts. The future as probable, possible and preferable are as pertinent today as they were 20 years ago, but the methods to engage the role of the future in the present continue to evolve.

Big Data and (better and/or new types of) model-based analysis and simulation might seduce some towards renewed predictive confidence of new economic theory. Yet there is no 'God given' perspective of complex socio-technical-ecological systems. Forging shared and more systemic understanding of international/global system is one thing, enabling and sustaining the collective, cross-scale action involved in changing established systems dynamics is another. Navigating between narratives, forging new common ground, and attending to the evolution of strategic vocabulary – open questions of systems boundaries and framing contests. Then there is the question of ethics – the contingent future as a design challenge and who is designing what and for whom?

It requires attention to the quality of judgement not just the availability of data – a sensitivity to narratives, to framing contests, to making space for conflict and to managing disagreement as an asset within science and within policy making processes. It requires rethinking the science-policy interface – GSS to support a better quality of strategic conversation and experimentation not just a better quality of analysis and predict and decide approaches.

Developing 'global' foresight relevant to new global polycentric policy context is core to the effectiveness of GSS and requires a multi-method modern futures toolkit in which rigorous analysis and intuition, numbers and narratives, hard and soft systems thinking have a role to play but not at the exclusion of the other.

And given the future is not neutral but the playing field of power, what is the policy arena for GSS 'foresight' – EU Commission, national governments, EU speaking to other OECD national governments, multilateral institutions? How can GSS contribute to enabling 'whole system' governance and help with institutional innovation that is currently locked out by rigidities of established policy domains, ministerial structures and lack of interdisciplinary and trans-disciplinary science. What sort of science do new practice communities organising around global and systemic risk, sustainability, resiliency and transition management need/are they able to use? How can policymaking reorganise to attend to cross-scale dynamics (not top down vs. bottom up) and connected challenges (rather than issue-by-issue basis)? How does policymaking enable new value creation not just risk control?

Example – which Narrative or Narratives: Global Financial Crisis

Is the global financial crisis really over as far as the EU is concerned and has it really been contained because of the heroic efforts of central bankers? Or is this global systemic risk still cascading into other spheres of life – the real economy, society, politics?

If we fix the financial system and growth is put back on track, what are the implications for a global environmental crisis? How do we know when we have avoided the choice between

more ‘global’ economy vs. better global environment?
Who decides what a ‘good’ dynamic of stability looks like and can it be achieved without attention to structural inequality, as well as global to local environmental changes?

Some GSS professional network initiatives

Adapted from 3 posts by Gertjan Storm:

Professional networks thrive, seek a balance between knowledge and action and appear to fill a void in addressing public goods-issues (networks organised as an “org”):

- networks become more sophisticated also thanks to “interaction” among participants and with “science”, and to increasing demand in society and the private sector, for sustainability solutions
- support for networks from public authorities seems to emerge at the level of EU member states
- “despair” about the pace of change is allowed for when looking at the governance processes in the EU, taking the need for action based on an assessment of the risks and uncertainties of the main global sustainability issues as the point of departure, as compared to actual EU-decision making.

The initiatives, linked to the GSS-issue of “Climate Policy and Global Financial Markets”, provide the following perspective:

1) ”2Degrees-Investing Initiative”, launched in December 2012 as a “think/action tank”: www.2degrees-investing.org provides the launch document. The documents ends with a number of messages of support, including a message from the president of GLOBE EU, and a one by me. 2Degrees-Investing Initiative is also participating in the GLOBE EU “group of experts”.
3) “Rating Agencies and the Ecological Transition”: a seminar to be held at the French National Assembly, hosted by the Parliamentary Sustainable Development Commission (Paris, February 2013). France is currently preparing a “Transition Ecologique”-action plan. The purpose of the seminar, organised by “European Partners for the Environment” I advice, is: “The objective of the European workshop is to redefine the performance and value concepts at the level of States, local authorities and businesses in order to lead to new assessment methods, generate innovation and creativity. We will focus on Social and Environmental Rating Agencies as well as Financial Rating agencies, and their respective role in the ecological transition of rated enterprises and authorities (Regions and Cities)”.

3). “A transition to a low-carbon economy in the European Union” as an initiative of “GLOBE EU”, European Parliamentarians members of the global parliamentarian association GLOBE, remains on the table and will have to regain momentum towards a session with a number of ministers of Finance, in Autumn 2013. The two preceding processes will support this initiative.
In a broader setting global trends in accounting and reporting, disclosure and fiduciary duty and the relevant international processes dealing with the issues, constitute a further potential strong movement in favor of a much more operational approach to address sustainability issues.

The actual and latent "demand for scientific inputs and interaction" in the professional networks provides a relevant link to the GSS-project and to the forthcoming round of debate and networking in Brussels, in June 2013 I am looking forward to !
The contribution of Angela Wilkinson (March 2013) highlighting "How should GSS enable policy making to better 'host' the future in the present?" should be referred to here:

"…. Global Systems Science needs a deliberate and reflexive element of actionable supranational or 'global' foresight that recognises the contingent nature of an unpredictable future as a motivator for change in the present. Today's big policy challenges benefit not just from looking back to see established patterns, but in looking forward and imagining different possibilities…".

I see Angela's contribution as one of the important comments i have tried "to absorb" for the purpose of further debate and action
GSS relevant professional network on Forests:
Looking for "… highly interconnected challenges, "system of systems".." as framed under "Vision" on the project website, "Forests" provides a relevant and pertinent example from a professional network i wish to share.

The need for action arising from the analysis of issues under the heading of "Forests", makes for a strong case to consider "… to support policy-making, public action and civic society to collectively engage in societal action …. " by way of the provision of "scientific evidence", referring to the framing of the "Vision".

A specific case i am involved in supporting on a voluntary basis an initiative, relates to the following elements, elements of "REDD+" from the UN-REDD+-site on the one hand, and of ongoing processes of deforestation and resource exploitation in forest areas and the consequences for indigenous peoples on the other, brought together in the following three observations after the question described here:
"Reducing Emissions from Deforestation and Forest Degradation" as a relevant and potentially significant contribution to global climate mitigation: can climate action as developed and defined in the framework of UN-REDD+ be reconciled with the rights of indigenous peoples?:
1. Sustainability at the global and local levels: is "convergence" in attaining objectives in the areas of climate, biodiversity and ecosystems, especially also water, and in the domain of the rights of indigenous peoples, achievable and feasible, and under what conditions, with the following two elements:
2. The example of a concrete and significant problem area, i.e. Ecuador, and of the initiative of Norway to finance a REDD+-programme in Colombia, Ecuador and Peru (proposed funding 150 million $).
3. The immediacy of action and of outcomes needed for the sake of indigenous peoples as a human rights issue is a key question to be addressed (see also "environmental democracy" as defined in the Aarhus Convention and the possible extension of the geographical scope of "Aarhus" to Latin America, as supported by 14 countries in the region).

Design, narratives and public stakeholder engagement

June 2, 2013 by Stefano Mirti

As a contribution for the on-going conversation on the relationship between design, narration and social media, I would like to start from a series of general observations. An introduction to the theme. A series of empirical thoughts developed in years of working at the cross-over between design, new media and narratives.
We all agree that design is mostly a narrative exercise (or if you prefer, story-telling). The writer tells his stories with a novel, the musician tells his stories composing music, the designer tells his stories making objects, spaces, buildings. But then, if we start to use new and social media, are there changes and transformations?

Here below, 12 points to start a conversation.

The community is the message (originally published on Abitare 532, May 2013).

A few days ago a friend asked me: "But why should I learn to use social media?" This is a question that doesn't have an answer. It's as if someone were to ask me: "Why should I learn to play the saxophone?" The question is put in a peculiar way, but it is possible to come up with a series of sensitivities and insights that we can gain and understand thanks to intense involvement with new social media. Here are 12 points with which to start a conversation.

1. New media?

New media don't exist (and conversely neither do old media). To put it another way: all old media were once new, and all new media will become old. The Bic pen is an extraordinary medium. It was incredible and perfect in 1950, and it still is today. VHS and cable radio have led different lives. In short, whether the medium is new or old is not the heart of the matter. It all depends on how you use it (and what are the goals you want to achieve).

2. Generosity

This is the first and most indispensable ingredient. If you're not generous, nothing (significant) will ever come of using social media. There is the importance of doing things for the pleasure of doing them, without a fixed purpose: the more you give, the more you take away. There is (really and truly) no possibility of taking without giving. And then if all this takes on the form of a community, a vast array of possibilities opens up before us.

3. Digital flâneurs

Walter Benjamin had his own universe of reference. It was made up of details, things on the margins, aimless strolls, Parisian shopping arcades and a thousand other more or less invisible ingredients of daily life. Here it's the same. God is not just in the detail, but this detail is in general – and apparently – insignificant. Here too, though, if you find that detail is able to fascinate other people, at that point, a breath-taking film begins.

4. Where does the money come from?

It doesn't. Or if it does, it comes through absolutely unpredictable mechanisms. It should never be forgotten that becoming famous on Facebook is like becoming rich in Monopoly. Try and invent a project to develop with a digital community: if you manage to reach this level you're already doing pretty well. Hardly anybody, in truth, succeeds in making much money. For convenience's sake, let's forget about money.

5. Deductive?

No. Inductive. The Web (and with it the digital media) is made up of millions of extraordinary unsystematised (and unsystematisable) fragments. You start out from one of these fragments and climb back up to empirical systematisations. Again, when you learn to carry out this process of "climbing" with other people, you gain a strength that would have been unthinkable in previous environments.

6. Humour

Humour is a fundamental ingredient. This was already true for an exclusively analogue world, but it has become indispensable in a digital planet (especially in the social version). If a sense of humour is not present in large doses, it's all a waste of time.

7. Visual imagination

The landscape does not exist. What does exist are spectacles of interpretation that we put on when we look around us. In our heads the oil refineries of the Po Valley start to take shape after we have seen Red Desert. The cinema, photography and television have changed our visual imagination. The same thing is happening with new and social media. The revolution is first and foremost one of imagery. It is a subtle change, and one that proceeds and advances in an invisible manner. But it is already here.

8. The 1% Rule

In the worlds of the Web there is this very simple formula: 90-9-1. In a given digital community (be it Wikipedia or a Facebook group), out of 100 participants there will be 90 who use the medium in a passive way, nine who are sporadically active and one who generates almost all the content. Being in that 1% allows you to invent new heavenly bodies to which the remaining 99% want access. This is an element that should not be underestimated.

9. Experts They don't exist.

At best, there are people who try and try again, making mistakes over and over again: in this long and tedious process they acquire a quantity of information that is useful to others too. The on-line community is the antithesis of technocracies dominated by elites of experts. Ennio Flaiano said some 30 years ago "today even the fool is a specialist". Well, the digital community does not allow for specialists.

10. Hierarchies

It is often said that digital communities are horizontal, and that there are no hierarchies. This is not true. The hierarchies and dynamics of power exist, and are perhaps even stronger than the usual ones, but they are simply implicit, unspoken. Understanding the invisible mechanisms that regulate the life of one of these communities is an exercise that offers us an insight into many facets of the here and now. The fact that the majority of these goings-on are negative does nothing but add value to the exercise.

11. Watch out!

A digital layer has appeared in our lives. But this does not mean that the early analogue layers have disappeared. On the contrary: they may be even more important than before. It's just that they now have to reckon with a new presence. In general, those who are able to make the most appropriate short-circuits between the analogue planet and its digital satellite are the ones who can get the best out of both.

12. The community is the message

McLuhan taught us that “the medium is the message”. Perhaps what we are seeing here is another step in a different direction: the community is the message. From this point on we should be aware that we are in those territories marked hic sunt leones on mediaeval maps. Leones et dracones. This creates a curious sensation…

Obviously not all these ideas are of my own. They are the fruit of experiments and activities carried out with different communities.

For a series of reasons, they have asked me to summarise them. But having got this far I cannot fail to mention the community of Gran Touristas and that of Whoami. Without the unbounded energy and enthusiasm of these people, I would not have been able to report anything at all. Then I should cite all the people with whom I exchange tweets and Facebook posts (not to speak of photos on Instagram). The list would be too long, but you’ve got the idea.

Once we set a possible manifesto, here two projects developed upon the above defined conceptual grids:

Here, the Whoami school project I’m working on (or: sharing knowledge via an on-line / off-line gaming system):

http://www.whoami.it/

Here the trailer for a design course via MOOC (Massive Open On-line Course): https://moocfellowship.org/submissions/design-101-or-design-basics–2

7.5 Results of the EC- FET consultation process on GSS

See:
http://cordis.europa.eu/fp7/ict/fet-proactive/fetconsult2012-topic09_en.html
total contributions: 165

> GSS addresses new ways of supporting policy decision making on globally interconnected challenges such as climate change, financial crises, or containment of pandemics. The ICT engines behind GSS are large-scale computing platforms to simulate highly interconnected systems, data analytics for 'Big Data' to make full use of the abundance of high-dimensional and often uncertain data on social, economic, financial, and ecological systems available today, and novel participatory tools and processes for gathering and linking scientific evidence into the policy process and into societal dialogue. GSS will develop further the scientific and technological foundations in systems science, computer science, and mathematics.

Posted by Pnina Vortman on 2013-04-17 11:59:06

One of the areas which ICT should focus on is the Food Sustainability and Aghriculture Transformation using ICT. The agriculture which is on eof the oldest traditional industries is changing with the introduction of soil sensors, plant sensors, and remote sensors (aerial imaging). We need to grow much more food every year to feed the world, but the required resources such as water and arable land is limited, which mean we need to grow much more using the resources we have available. So, I see the role of GSS in creating policuies which will enable to share data and create agribusiness knowledge centers using "big data" platforms to integrate data from multiple sources, derive conclusions, and establish policies. There are many interested parties who will be able to benefit and as a whole, all of us will benefit. Farmers, governments, enterprises, and SMEs will be able to access data and generate new insights and knowledge as well as develop methodologies to optimize and reduce the required resources (water, fertilizers, pesticides) as well as improve the yield, the quality, and the nutrition value of agriculture products - grain, oil seeds, vegetables and fruits, animal proteins, meat, dairy, and packaged food. I work in IBM research for many years, and during the last 4 years I lead Smart Water and Agribuesiness across IBM research.
Posted by Soroosh Gholami on 2013-04-11 18:52:18

Contribution of a Global Systems Science to the challenges we are currently facing -- Global Systems Sciences is intended to provide a more holistic view of the challenges we are facing and aims at policy making with global implications. This holistic view is most needed since modern science has been narrowed down into very specific fields for in depth understanding. Solutions provided by one area of science for a specific challenge in the global system may have devastating effects on other areas. This can be discussed in the sense of global system’s dimensions and those of them we actually understand. Our understanding of the surrounding environment is limited and we are left with no choice but to make decisions based on our limited knowledge. However, our decisions impact the global system in its totality (all dimensions) which result in unpredictable (by our limited view) and sometimes devastating outcomes. Although narrowed-down science provides in depth understanding of the system as individual parts, it does not help us in making global decisions. The reason is the scale which our decisions can impact the global system today. In the past, a decision on pandemics, food supply, or economy impacted the local surroundings of the decision makers only. However, our technological power has scaled the impact of our decision up to the level of global system. Thus, the limited vision of various science fields (which is even more narrowed-down these days compared to a century ago) coupled with their significant impact on the global system may ultimately result in problematic situations. The holistic view of GSS observes more dimensions and therefore helps in making less hazardous decisions. In conclusion, for the challenges we are facing such as the financial recession and global warming and for the challenges which may threaten our very existence in the future such pandemics, food supply, and energy, GSS can provide a more universal view (with more dimensions included in the process of decision making) and ultimately better policies. However, the effectiveness of GSS is still a question as the relation between various fields of science and their impact on one another are still unclear.

Posted by Ilona Heldal on 2013-04-11 17:03:57

Motivation: To handle global systems compromises have to be made. For example: It is tough, nearly impossible to set and describe boarders and limitations discussing global systems. Since our resources and possibilities to act are limited, we need to handle these in our activities and argumentation. Challenges: To handle limitations and argue why and how is still important to consider a 'global systems' and not only the (limited) systems and also to consider the influence of time. I can imagine that some limitation can be tested and evaluated as well. Expected Impacts: Increase safety and trust in systems and contribute to more transparent communication. The focus units and the action arenas can be examined in a systematic way. Example: There are several motivations to upgrade the dedicated systems for public safety communication from analogue to digital. This is a tough, considering the many involved organizations (e.g. ambulance, police, fire departments, etc), their different interests, and sometimes conflicting roles. By making clear the limitations of the system (e.g. limited bandwidth, developing proper new devices, interoperability, and involved actors) and being aware of the consequences of these (also the effect of the limitations) some countries upgraded their systems earlier while some other countries had endless discussions about limitations and necessary compromises. For example, Finland upgraded the public safety system earlier. They also had to make compromises, but discussing these and making the quicker decisions they gained several benefits. Their benefits are not only technological, but also social e.g. the public safety organizations in Finland can use a robust communication system today. The point is that adopting global systems compromises needs to be done, e.g. which interests are NOT considered from the beginning. Doing the compromises in time long-term benefits can be gained. However, much more support is needed today to know how to handle these limitations and the compromises in a systematic way.

Posted by Maxi San Miguel on 2013-04-09 18:23:12

-What is new in global challenges? ICT creates the new interconnection and at the same time it makes available the big data needed to understand the interconnection -What GSS can bring in? i) Attitude: a way of thinking global ii) Concepts and their quantification: resilience, sustainability iii) Theory for the big data era: Theory is an important part of our understanding of the world. GSS needs also theory: unifying concepts -GSS and the study of urban systems: i) Integrated complex systems approach ii) Interactions: physical and symbolic interactions within a city as well as interactions between cities iii)

Multilevel dynamical networks: Multilayer(transport, economy, health, business) and functional and territorial networks iv) Spatiotemporal multiscale structure.

Posted by Franziska Schuetze on 2013-04-09 10:17:55

To me the importance of GSS lies in analyzing the interrelation of problems in usually separated research fields and in policy making. Investigating contagion in financial markets is important and urgent, but GSS should also work on extending this line of thinking into other fields of the economy, such as energy. With annual revenues of the largest energy corporations being as large as the annual production of countries such as Portugal, Norway or Argentina, we can expect these to have a large impact on the global economy. Networks of energy companies might have a similar systemic importance for the economic system, e.g. how would a shift in trade flows (e.g. shale gas development) or a next oil price shock (probably no gas price shock) cascade through all value chains using energy as input factor and their network and entire sectors? Under which circumstances can this trigger a crisis of the “real” economy, the way the financial crisis did after 2008. Another related question is the connection between the economic and the environmental dimension, which is often left out: How can the same amount of investment in a specific (les environmentally harmful) sector or network of products lead to much lower overall emissions and resource use than in another (due to the amplification of the effect through the value chain) but still have a positive effect on macroeconomic indicators such as GDP and employment? ICT and social media can be used in this respect to make this knowledge on the interconnectedness of problems and consumer and policy choices more accessible and transparent. It makes global knowledge and experience sharing possible and can therefore potentially lead to better coordination at a global scale. ICT can also help to find out if for example a decentralized electricity system can work as efficient and at a similar cost compared to a centralized system. However, for this, the electricity system needs to be analyzed in a more systemic way, including generation, storage, transportation and demand side management throughout the value chain. Clearly the thinking here needs to go beyond single technology considerations. There is a huge opportunity for GSS to engage in these kinds of interrelated and multi-layer research questions and to help us understand and manage the current problems in a more advanced manner.

Posted by Jeffrey Johnson on 2013-04-09 07:26:26

GSS explicitly addresses policy. There is no theory to connect the vernacular language of policy makers to the formal representation of 'data' and its processing inside machines. E.g. the gap between policy and formal systems and computer proof is enormous. I think some work may have been done in Law. Fundamental science is required as the basis of automatic processing of Big Data which, by hypothesis, cannot be processed by hand. * GSS assumes that meaningful information can be abstracted from Big Data. Although people talk about semantics it seems to me that much of what we see in machine intelligence is syntax. Any 'meaning' in ICT implementations is induced by interactions with humans. Therefore Human Computer Interaction (HCI) is a very important research area in GSS. 'Policy Informatics' explicitly assumes human-computer systems. The technical performance (including failures) of such systems involves the behaviorof the human side. I don't think we have any models for this in in big complex multilevel social systems such as government. * GSS involves simulating the behaviorof big complex messy social-physical systems (e.g. TRANSIMS for land use and transportation). However the policy process itself is a social-physical system. Do we have anything approaching 'meta-simulation'. * GSS requires a new way of thinking about big complex messy systems. The culture of policy and its notions of 'correctness of argument', 'validity of evidence', etc. is very different from the culture underlying physical science (physics etc.) and ICT. There is a huge educational requirement for the ICT community to understand better the 'logic' of social systems.

Posted by Pablo Garcia Tello on 2013-04-09 02:14:43

Project ideas: 1- Synergy between "Big Data" experts: Large Research Infrastructures (i.e. CERN, ATLAS, etc) in collaboration with industry, etc...this can generate an enormous potential based on finding common know-how grounds. 2- New computational challenges and proposed solutions for handling the ever increasing "Data Deluge" (both software and hardware based). 3- How to make the step from data crunching to useful information.

Posted by Ion Cojocaru on 2013-04-08 23:51:12

Technological and scientific bases of the so-called Global Science Systems are important, but more important is the way of education, development and evolution of the dead world objects and organisms of mineral, plant and animal life. The life of organisms from birth to death goes through certain stages set by nature. Nature foresaw for life as a whole and for each period of life individually a predetermined duration, which can not be bypassed or slip. The theoretical length of these periods corresponds to the theoretical length of the mineral, vegetable or animal life of the body and can be described via relevant laws of the basic sciences. Individual actual length of these periods is different for different entities of mineral, plant and animal life and is always less than the theoretical lenght: it is reduced due to inherited defects, and due to the influence of negative environmental factors.

Posted by Christian Heimgartner on 2013-04-08 22:33:27

One core aspect of global systems is transport: transport of persons, goods and also information let interact the different elements of the world we live in and let so become this world as the stage of our lives a global system. As an effect of urbanisation and therefore increased density of land use and transport and due to the fact, that capacities of transport systems at the end are not unlimited, the intelligent management of traffic has to be seen as a major task with regard to sustainable development. Only if the traffic flows in the transport systems could be maintained on a reliable level, the global system of the world we live in could be kept on a sustainable level. Now to avoid brake downs of the transport system in general and also in a long term perspective, the traffic management has to be seen in a global manner, linked not only to the transport systems users and the infrastructures, but also to main drivers of the overall transport development as for example land use and living styles. So to establish Intelligent Transport Systems to promote sustainable development, Global Systems Science is certainly a key approach.

Posted by Sander van der Leeuw on 2013-04-08 18:44:53

I would just like to alert the organizers of this consultation, in case they are unaware of this, that there is an ongoing, quite intensive and in-depth discussion of various aspects of the Global Systems Science problematique on the following website:http://blog.global-systems-science.eu/. It seems to me that those comments do need to be taken into account in this discussion, especially because there is on that site more place for longer contributions.

Posted by Merijn Terheggen on 2013-04-08 16:42:02

Most of us in scientific and professional communities have a thousand times more knowledge in our minds than we've ever shared online or in papers. The collective knowledge of human kind contains the information that forms the building blocks that potentially can shape the answers that GSS seeks. The challenge is to unlock these building blocks so that the larger connected patterns that answer the important questions of our time can be identified. Of key importance is therefore the understanding that these patterns only exist as superseding combinations of smaller components that might not mean a lot individually. The total is bigger than the sum of the parts. This seems to indicate that any ICT solution that aims to identify global complexity patterns in an addressable form, needs to be able to combine a plethora of unstructured 'informal' elements into a larger picture. Although structured scientific analysis and organization of knowledge has brought us great things, it has not yet sufficiently addressed large scale global complexity problems like climate change, financial crises, and so forth. GSS as a next generation systems science has the opportunity to embrace ICT powered unstructured knowledge mapping and virtual networks that help scientist identify important patterns from a deluge of data. Wikipedia articles are an example of a knowledge mappings and represent what a certain collective of people knows. The articles are focused on providing a single consensus view of any topic. The editable article format however provides limited abilities to capture unstructured knowledge that connects larger (global) issues. Social networks like Twitter provide a very initial form of informal unstructured knowledge interaction but lets recognizing patterns to the user and don't provide a framework that iteratively and continuously works toward identifying important global patterns in a way that allows for addressing the most important issues. Next generation systems that support GSS need to work on the intersection of ICT (web wide scale), Math (distributed argumentation networks), and Social Sciences (trust, credibility, and authority algorithms as an analog to peer review) in order to adequately capture the multiverse of perspectives of the crowd and distill a clear picture that can move us forward.

Posted by Leanne Ussher on 2013-04-08 15:56:29

It has been claimed that these imbalances are the cause of asset bubbles, financial crises and reflect unfair exchange rate policies. Calls have been made for a global readjustment of exchange rates or a new international monetary order to ‘rebalance’ trade and capital flows in order to remove inherent instabilities in the global economic system, and to put international finance into its place of handmaiden to international trade rather than its captain. Global imbalances can be measured in terms of a network where countries are nodes and directed links are trade or capital flows. Net flows create imbalances in trade and capital. Network analysis of trade flows and their simulation under different international monetary systems and economic models provides a method in which proposals can be evaluated and through which economists and heads of state can communicate with each other: trying out different policies within the same network and simulating their outcomes.

Posted by Kat Austen on 2013-04-08 13:09:18

Making all the data open to the public > Development of interactive tools for people to interrogate the large datasets available > Online pedagogic tools for understanding statistics gleaned from large datasets, allowing their validity to be interrogated > Research into the means to look at "quality" in data that can be mined as well as more easily quantifiable properties - looking at the complex range of factors behind statistics > Asking the question: is there anything that can't be understood by asking the right questions of a more complex dataset? And if so, how can we capture that too? > A look at the philosophical implications of searching for this new truth in GSS > Building all the interactive tools with high aesthetic values to promote understanding and engagement, and research into the aesthetics of this kind of data delivery

Posted by Giuliano Andrea Pagani on 2013-04-08 11:58:10

A global system science (GSS) approach is the right way to address complex and multi-faced themes such as energy and the electrical system. The energy landscape of the future is: uncertain (demand, supply, and resource availability), user-oriented (the users start to play a role as producers and in the market), and data prone (monitoring of the electrical system and user consumption and facilities). At the same time, users expect the same level of freedom in using energy and security/reliability of the infrastructure (e.g., the power grid). GSS promises to put together all the disciplines (e.g., engineering, sociology, economics, computer science) and ingredients to address the key questions of energy transition towards sustainability.

Posted by saini yang on 2013-04-08 10:00:42

With multi-dimension big data, GSS can provide wonderful platform for interdisciplinary research in tradition or merging areas. It can also be the incubator of new tools and engines for complex problems or wicked problems, such as climate change, ecomonic crisises and pandemics. One specific example is large scale disaster. Under globlization process and climate change, the frequency and intensity of large scale disaster are both increasing with the impact of large scale disaster more global. With GSS, it will be extremely beneficial to analyzing the global economic, political and ecological impact of catastrophe and initialize the step towards global integrated risk governance.

Posted by Saini Yang on 2013-04-08 09:57:46

With multi-dimension big data, GSS can provide wonderful platform for interdisciplinary research in tradition or merging areas. It can also be the incubator of new tools and engines for complex problems or wicked problems, such as climate change, ecomonic crisises and pandemics. One specific example is large scale disaster. Under globlization process and climate change, the frequency and intensity of large scale disaster are both increasing with the impact of large scale disaster more global. With GSS, it will be extremely beneficial to analyzing the global economic, political and ecological impact of catastrophe and initialize the step towards global integrated risk governance.

Posted by Marco Aiello on 2013-04-08 09:15:15

A rapidly evolving energy sector needs new tools for modeling, analysis and especially designing its components and its overall behaviour. These tools do not come from one single discipline, as it was traditionally, but are at the interplay of several areas including engineering, computer science, economics, sociology, and more. Global System Science promises to be the right umbrella under which novel, global, interdisciplinary approaches to enable the future sustainable scenarios for the energy sector will foster.

Posted by Alessandro Moschitti on 2013-04-07 20:50:49

Big Data refers to huge amount of information, expressed by heterogeneous sources: web logs, sensor networks, social networks, Internet text, phone call records, astronomy, genomics,… - It offers incredible opportunity to understand past, present and future. - A major criticism is that systems' dynamics can change in the future making useless past observations. - One solution relies on using powerful methods for very accurate discovering and analyzing of patterns and data correlations. - Examples of such approaches: (i) supervised machine learning methods, e.g., for classification and re-ranking of information; (ii) advanced representations, ranging from sequences to syntactic/semantic structural relationships; and (iii) powerful approaches for automatic feature engineering, e.g., structural kernels for modeling the relations between patterns.

Posted by Ciro Cattuto on 2013-04-07 20:26:32

One possible way to think about Global System Science (GSS) is that GSS aims at achieving a paradigm shift in societal-scale decision making. This paradigm shift will unleash the full potential of the rapidly evolving relationship between data, models and decisions, which is ushering society into an era of data-driven science for decision and policy making. Back in 2009, John Wilbanks wrote in his contribution to the seminal book "The Fourth Paradigm" (Microsoft Research, 2009): "Data-intensive science, if done right, will mean more paradigm shifts of scientific theory, happening faster, because we can rapidly assess our worldview against the 'objective reality' we can so powerfully measure." The key aspect he pointed to -- our unprecedented capability to assess our worldview against measured reality -- has a relevance that is not limited to scientific investigation alone, but rather represents a cornerstone for Global Systems Science: in fact we could say that GSS is about realizing the full impact of this vision for societal-scale decision making. The process of assessing our worldview against reality will be affected both in terms of the empirical evidence we will use and in terms of the methodologies we will deploy to build and maintain our worldview, i.e., the methodologies we use to model, predict, and decide. The main driver for change is the fact that, increasingly, the digital representation of the world will track the world: Digital traces of human behaviours, made available as a byproduct of the ICT infrastructures underpinning society, will provide raw evidence at unprecedented levels of scale, coverage and resolution, in a machine-processable form. However, these massive databases and data streams will hardly speak for themselves: turning big data into actionable knowledge will require the ability to detect relevant signals, to incorporate them into data-driven predictive models, and to validate such models against empirical evidence on the consequences of the chosen course of action. Methodologically, this will require an interdisciplinary stack, with ICT-based societal observatories at the bottom; data mining, statistical analysis, machine learning and complex systems modeling on top of that; and a top layer where knowledge from models is turned into decisions or policies that can be effectively explained to the involved stakeholders, and thus turned into actions. The type of models that GSS will need are data-driven, predictive, and explainable. This will require the integration of best practices across the full spectrum of relevant disciplinary domains, assimilating and moving beyond minimal models from complex systems science, beyond data-less agent-based models, and beyond black-box machine learning. Global Systems Science seeks to develop the foundational knowledge that will enable the creation of data-driven predictive models that can support transparent and accountable decisions at the societal scale. Key challenges will include: - learning, selecting and validating such data-driven models - managing the tradeoffs between approximating high-resolution observatory data on socio-technical systems, and creating generalizable representations of those systems - formalizing and handling the tradeoffs between the predictive performance of a model and its human-readability - solving the challenges of turning sensitive and personal data (e.g., information from electronic healthcare records or mobile phone traces) into privacy-preserving interventions that fully respect the citizens' fundamental rights and interests - discussing the evolving notions of accountability for decisions taken by using the models developed within the GSS vision.

Posted by Sibylle Schupp on 2013-04-07 20:09:17

Being a computer scientist, it is no question to me that computations contain faults---especially those large-scale simulations that are behind global systems---today, and dramatically more so in the future. I wouldn't care much about those faults if I knew for sure that they have little impact only. But it is largely unclear which faults are benign and which ones may distort the result of a simulation in a relevant way. A fundamental task towards a SCIENCE of global systems, thus, is to provide methods for understanding the impact of faults.

Posted by David Tuckett on 2013-04-07 08:50:33

Understanding the relationship between individual (micro) decision making and its aggregate consequences in conditions of uncertainty (ie when there are no plausible grounds for constructing probability distributions because we simply do not know) is one of the major tasks decisions makers face - to understand developments and develop policy on relating to economies, finance, climate and most of the major decisions facing us. In the light of events we (should) have come to the hard realization that we understand much less about these things than we thought and need a much broader range of disciplines to do better. One area that is very ripe for development is that of understanding the way people gain the conviction to act when they cant know for sure what to do - a topic which requires understanding at the neurological, psychological, economic social and political level and which can be greatly aided by the development of computer algorithms to analyse very large data-sets in close to real time and to run simulations to test theories. But advance in my view will depend on avoiding the perils of mere data mining or the imposition of atheoretical thinking and need to be preceded by a great deal of well informed interdisciplinary clarification. It requires the disciplines mentioned to be well understood and intelligently integrated so that hypotheses and findings are well specified. In this context, complexity theory, broadly conceived, is the way to explore how aggregation occurs and with what consequences. Narratives have huge power. Understanding how they form, cohere and gain conviction and confidence in aggregates - or lose it - is a priority area.

Communication of policy without understanding how it is understood in multiple ways that combine unexpectedly will often be very dangerous.

Posted by Justyna Zander on 2013-04-07 05:03:57

I would add the notion of Cyber-Physical Systems (CPS) and the implications that it brings, as of NSF, NIST, and other reports recommendations (USA). (1) Focus the attention on CPS collaboration and open architecture. (2) Focus on the completely new design methodologies required for capturing the unexpected but required interaction of CPS during deployment (3) Focus on increasing modeling and simulation importance in this context (4) Design prediction-based search engine for big data search and extrapolation

Posted by Stuart Anderson on 2013-04-06 23:10:13

This area seems pretty much co-extensive with the proposal made by the FuturICT consortium to the FET-Flagship process. I believe Dirk Helbing had pulled together a very convincing group to carry out this complex, ambitious, programme. FET-Flagship rejected the proposal but it seems the problem remains a FET priority.

Posted by Irina Efimenko on 2013-04-06 01:29:22

1) Cost-effective and easy-to-spread infrastructure (for distant and poorly equipped regions and communities). Let us take telemedicine as an example. Its idea (at least, one of them) is in giving access to high quality medical services to people who do not have possibility to use them in an ordinary way (e.g. for communities living in distant regions). However, nowadays telemedicine services often require high quality and rather expensive channels and hardware which are not available in distant and poor regions, thus becoming "services for rich" though they could be services for poor, i.e. only enhancing the gap. 2) Coalition vs. competition. Infrastructure to support win-win partnership between countries (incl. those between "strong" and "weak" players) within a framework of outsource and distant techonologies. 3) Developing scenarios of cross-country communities survival based on natural metaphors (such as ant hills, etc.). Formal models and decision support systems based on these models. 4) Data mining technology (incl. those integrated with sensors of various nature, e.g. installed in public areas) of behavioural, neuro- and other patterns to predict and prevent violence (using big multimodal data). 5) Methods and tools for cross-disciplinary knowledge engineering.

Posted by Colin Harrison on 2013-04-06 00:52:14

It is a central belief of western civilization that we are capable ultimately of understanding the world. Our understanding is not at any given moment complete, but exists to a certain degree. Moreover we believe that this degree will improve over time. Since the 1960s, weather forecasting has been added to the long list of areas of the world that were once viewed as beyond human understanding and yet have proven to be understanding at levels that are not complete or perfect, but that are nonetheless useful. Others include the solar system, the ultimate constituents of matter, the many systems of the human body, and so forth. With respect to our understanding of how cities work, we find ourselves today in somewhat the same position as those pioneers of model-based weather forecasting. The historic weather ships off the coasts of Britain, if one may equate Jane Jacobs provisionally to a weather ship, are being complemented by floods of information from a vast array of sensors in the natural and built environment, by government and industrial statistics, and by the chatter of the social networks. Moreover we can now draw on some fifty years of increasingly realistic and accurate methods of representing, visualizing, analyzing, and simulating complex natural and human phenomena. This body of expertise is gathered under the heading of Global System Science for Urban Systems. We therefore feel emboldened to hypothesise that it may be possible to develop a Science of Cities by harnessing Global Systems Science to help us to gain insights from the floods of urban information. Karl Popper defined the status of a theory as “falsifiability, refutability, or testability” . Until now this benchmark has been beyond our reach, since we had neither the means to observe, nor the means to structure (taxonomy) and analyse (test) our hypotheses. But the advent of the Internet of Things and more specifically Smart Cities brings us within grasping distance of the benchmark of a Science of Cities. Why should we want a Science of Cities? Because by the end of the 21st century the vast majority of human beings will live in urban rather than rural areas. In this century we will construct as much urban capacity as has ever previously existed on the planet. Finally the cities that we build in this century together with those already existing will probably serve global society for many centuries. It is time that we had a Science of cities to enable us to get the design, construction, operation, and management of our Cities right so that all citizens, wherever they may live, may have the best opportunity for a safe, healthy, prosperous, and sustainable life.

Posted by Bridget Rosewell on 2013-04-06 00:30:53

Traditional policy making has shown itself to deal poorly with problems where dynamics and long term implications are important. This is a question of what can be held constant in any policy problem, and how the interaction between different domains of action can be captures. This is important in financial services in dealing with risk, for example. As the Chair of a Risk Committee in an EU bank, I think that a better understanding of the interaction of different pressures is important, and Global Systems Science helps to do this. An another area where GSS is important is in infrastructure consideration. Much long term investment has long term impacts where an understanding of dynamics, and of the distinction between a necessary and a sufficient action is crucial. GSS can address these topics in a more integrated way by being able to consider in a stronger intellectual framework the feedbacks which constrain and alter policy choices

Posted by Piotr Dziurdzia on 2013-04-06 00:00:21

To analyze large data, for instance in the financial, economic, ecology structures, a kind of expert system should be taken into consideration that would employ artificial intelligence, neural networks, etc. Moreover, development of new “engines” for searching and managing huge data bases will be needed.

Posted by Adam Sobczyk on 2013-04-05 23:56:58

This is the great idea. In my honest opinion, the solid bases for the problem modelling and simulating should be prepared in the scope of this particular project. In explanation, interdisciplinary scientific platform should be prepared, concerning the active engagement of the scientist from different domains. I think also that many of the phenomena from the real world are already well modelled and possible to be analyzed by specialist in the domain of ICT (especially: electronics and telecommunications) thanks to numerous similarities between the typical problems occuring in the real world and the problems that are being approached in communication networks (for instance: latencies, congestions, lack of resources etc. - with their common impacts on the behaviorof the telecom. network which performs very similar to the real world). Maybe one small example at the end: there are numerous, very important examples for the similarities between the real world and the telecom. nets. Few of them are Erlang as well as Engset rules. They were not defined on the basis of the observation of the telecom. nets. They were defined on the basis of the observation of the military logistic problems (transport, delivery) during the world. So, the observations taken from the real world and from the telecom. nets live in parallel in absolute compatibility. I think it is high time to take an advantage from that fact.

Posted by Paulo Garrido on 2013-04-05 23:42:57

"GSS addresses new ways of supporting policy decision making on globally interconnected challenges such as climate change, financial crises, or containment of pandemics" and, I add, unemployment and trade imbalances. Unemployment and trade imbalances are intertwined problems because as posited in previous post, full employment is in principle achievable from a systems perspective by overt financing a universal employment program and simultaneously requiring that in this program minimally useful socially recognized production is achieved. This is feasible, positive for economic activity and realizes the recognized human right to meaningful and favorably remunerated work. Yet, if one thinks of such program being extended to a majority of countries, questions of trade imbalance appear. It is not possible for a country to be a net exporter / importer if another country or group of countries does not become a net importer / exporter. Now, net exports are a real loss for the exporting country and net imports are a real benefit for the importing country. That this is so, is confirmed by the economic history in the Eurozone where creditor countries have been transferring real product through net exports to debtor countries and where resentment among creditor and debtor countries has been mounting. That this resentment from creditor countries is justified seems obvious. Being both European countries or just being both countries is no justification for purported transfers of wealth from one country to others, unless this is fair payment to settle incurred debts or the country wants to raise its reserves in foreign currencies. If full employment with recognized useful production at favorable remuneration indexed to the country productivity propagates over countries, then it is to expect that it also acts as a driving force to balance trade in the long run. This can also be taken as a line of research and development for GSS and its applications for human societies.

Posted by Paulo Garrido on 2013-04-05 23:07:59

"GSS addresses new ways of supporting policy decision making on globally interconnected challenges such as climate change, financial crises, or containment of pandemics" and, I add, unemployment and trade imbalances. Unemployment is used here to mean unwilling unemployment, a situation where the United Nations declared human right to meaningful favorably remunerated work is not realized. Realizing this human right means in general full occupation. Being occupied a remunerated work producing goods and services does not mean necessarily employment, as it can be done as an individual professional or in partnership with others, a desirable situation that many people can prefer in a friendly economic environment. Yet, the actual economic environment is not for friendly for individual or in partnership economic activity to be capable of enabling full occupation, providing to all willing meaningful and favorably remunerated work. That would be a very favorable development, as it would increase personal and social responsibility over the traditional employer-employee work relation with their traditional problems of managing responsibilities and distribution of income in organizations. One can take such a situation as a goal to analyze and pursue, but in actual, practical terms one must acknowledge that realizing full occupation requires full employment. Yet and again, in the actual economic environment, within the prevailing culture and institutional set-up of economic activity, full employment cannot be generated by the private sector, as the profit motive together with the unrelenting growth of technological productivity tend to bias decision to minimize labor use. This may not necessarily mean less favorable remuneration for workers, although it is often the case, but necessarily means eroding employability and employment, unless economic growth or development offsets the reduced use of labor per unit of product sold. Systemically this tends to reduce income, reducing demand and stopping or reversing overall economic growth, and to increase unemployment. An increasing number of unemployed people is a social problem. To fix ideas, let us imagine the extreme situation where unemployed are left to their own savings. This is of course a recipe for strong social unrest and / or turning representative political systems into authoritarian ones with all their negative national and international possible implications. In the second half of the twentieth century, so-called developed economies learnt to deal with such dangers by instituting support to the unemployed through what is called unemployment benefits. These and relatives support has, in particular since the onset of the financial crisis in 2008, averted the worst-case scenario depicted in last paragraph. Yet, unemployment is a growing problem worldwide affecting mainly the young generation. As economic perspectives deteriorate, so deteriorate prospects of solvency, participation in production and youth parenting, pushing birth rates below replacement. This does evoke crisis and not a good future for nations where this happens and if left to its own dynamics will hurt economic activity in the medium term. For a systems scientist or technologist, unemployment and growing unemployment is an absurd problem. It is n absurd problem because after all, thinking in real terms, out of letting unemployed to starve and dye, they must be kept alive, so real products must be supplied to them in exchange for nothing, whichever is the monetary income that makes this. So, if this is the case why not to have them in a position where they can produce something useful for societies? Given the inability of the private sector in today's terms to generate full employment, public action must explored. Full employment can be easily obtained in a nominal way by governments through a universal employment program, offering whichever work positions are required at a minimum salary. (In the case of the actual Eurozone, the ECB should finance such program, as governments cannot. The minimum salary would be targeted as a fraction of national income per capita. This observation is relevant to Eurozone situation, but the potential impact of GSS considered here is wider and relevant for any country). In general, for those covered by the universal employment program, this should be seen as an employer of last resort and a transitional situation. One of the aims of such a program should be to have the maximum number of people out of it into private sector or public sector in higher paying situations. The positive economic effects of full employment obtained this way are undeniable. The government offered universal employment amplifies to the private sector as this must offer salaries above the minimum, this minimum establishing a universal minimum income. As income hits a floor, so does demand, recessionary effects cease and economic growth and development resumes. It is also undeniable that such positive effects require that in general people in the universal occupancy / employment program, albeit doing the least remunerated work, do real meaningful work, recognized as such. Designing and organizing such a program so that it meets this requirement is a challenge. What people should be paid to do? How what they are actually doing should be assessed? Answering these questions requires ICT engines applying GSS not only for the purpose of simulation to manage macro-economically the effects of full employment but also for its operational implementation. In fact, the deeper problem behind is to manage efficiently and in the public interest public organizations. Two basic aims for such ICT engines appear as providing full transparency of public organizations operations and expenses and increasing the quality of decisions. Such engines would be powerful factors for the success of the program in particular − and for public organizations setting high standards of quality of service. This may be taken to set goals for GSS research and associated ICT applications developed.

Posted by Lorenzo-Mateo BUJOSA VADELL on 2013-04-05 22:52:36

This topic should drive us to a careful consideration of Protection Data Bases and the fundamental right to the privacy, although the international cooperation on that matter is needed, for example to prosecute the international criminality.

Posted by Mahmut Arikan on 2013-04-05 22:42:40

GSS is inevitable to build sustainable global community. Large datasets bring ICT and political issues. These issues should be addressed by 1) defining new standards (data acquisition, storage and processing), 2) involvement of different research and development groups (non-commercial and commercial organisations), 3) and creating awareness in the community. New information rising from GSS will improve our forecasting and reshape our policies and communities. PS: Lost the initial post.

Posted by Mahmut Arikan on 2013-04-05 22:07:34

From my perpective in order to meet challenges rising from large data analyses. We need to 1) define (new) standards to collect, store, process, share large datasets and present output results 2) make sure these standards are well accepted and up to date, 3) create and promote means to work together with different groups/research centers (non-commercial and/or commercial sector especially SME to bring innovative ideas), 4) combine, if possible, different datasets to improve validation of the results 5) allow public audience to visualise and understand possible consequences of the findings and support policy makers to reshape their decisions. In the long run, GSS will improve our forecasting capabilities and also give us to new insights how actually independent systems might be triggering and/or interacting with each other on a larger scale such in case of climate changes, environment problems and hazards.

Posted by Catalina Spataru on 2013-04-05 21:44:50

In my opinion, existing research in this area is limited by methodological and inter-disciplinary fragmentation, with each often restricted in scope, and focused on a single domain. There is an urgent need to bring together people from various disciplines and define a common dictionary (language) which can be utilized universally in GSS. Global System Science could be the key and the future of a transdisciplinary science, with the neccesary translation vocabulary from one discipline to another, breaking down the barriers between mathematicians, engineers, social scientists, economists, computer scientists, etc. Through such a science we recognize the existence of difference levels of reality which is driven by different types of logic, involving the acceptance of unknowns, unexpected and unforeseeable. Regarding models, we need to update models and include also people and their interaction with the system as part of the system. We need whole-energy socio-technical-economic systems models. In energy for example different people behaviorin use of technologies is not yet explored. It is not only about technology, is also about how people use the technologies. Moreover, within these models we need to integrate methods used in physicology and assess collaborative behaviour. Collective opinions can influence decisions, so what is needed is to identify methods to translate this information for policy. Currently most people think that climate change is caused by CO2 emissions and this opinion resulted in various actions at individual level to community level through legislation. A similar strategy can be adopted for ICT, but in reverse. However, what we don't need to forget is a model is a precise representation of a system dynamics used to answer certain questions. So whatever model we choose it depends on the questions that we wish to answer. So, there could be multiple models for a single physical system. Regarding "Big Data", the big challenge of GSS is "Big Data" availability. The bureaucracy in many countries in Europe represent a barrier. Until a method is applied to disolve this barrier and have an "Open-Data Procedure" then a "Big Data" Framework to link and archive data monitored in the real world will remain a dream. We need organizational factors aligned with goals, relevant learning and training, exchange of knowledge. GSS needs to have well designed goals to succeed in the "market" of the new concepts, otherwise it will remain just another fancy concept. Dr. Catalina Spataru, Senior Researcher, UCL Energy Institute, London

Posted by Bogdan Kwolek on 2013-04-05 20:55:40

Analysis of large datasets can be achieved through, among other thins: (i) enhanced reasoning, hypothesis creation and validation, evidence marshalling, uncertainty refinement via 3D immersing the users in data and using interactive, integrative and iterative visual/sound interfaces; (ii) visual clutter reduction and visual encoding of data quality methods that deal with scale, multi-type, dynamic streaming temporal data flows to avoid misinterpretation by the analyst; (iii) data structures and effective analytic algorithms and unstructured data reduction techniques to facilitate interactive visualization with human in the loop of multiple, linked spaces.

Posted by David Pearce on 2013-04-05 20:43:35

One objective of GSS is to make policies and policymaking an integral part of the scientific enterprise. To further this aim it may be important to develop domain-specific policy languages. These need to capture reasoning about defaults, norms, exceptions and typicality and so may best be developed using logic-based languages where these features are already efficiently handled. While such high level policy languages should be able to implement guidelines, rules and policies, they also need to interact with real-world data coming from mathematical models and external data sources. A related issue raised by GSS is how to support the involvement of stakeholders and a wider public in policy and decision making processes, with dialogue and debate possibly supported by social networks and platforms. In this process it is important to emphasise the role of good science and sound methodology and ethics in ICT design and their value for policymaking, and to bear in mind that the tools of crowd-sourcing and gamification cannot replace scientific theories and justified reasoning steps. Decisions still have to be based on scientific evidence and the reasoning steps that justify policy decisions have to be ultimately grounded in criteria of rational acceptance. Argumentation theory and logic could provide useful tools in this context. GSS mixes science, technology and policy. How do we measure progress in GSS? Which, if any, of the indicators of progress in science or in technology might be applicable to GSS? An analysis of this problem is fundamental to obtain a clear grasp of the nature of GSS and to provide means to evaluate the success of projects that develop new ICT tools to understand global systems and help to design and implement policies.

Posted by Heather Ruskin on 2013-04-05 20:14:52

It would be good to see some focus on data value and quality, data distillation and similarly. Much data is better than little data, but much bad data is still bad. Some focus on evaluation and value for purpose would be good.

Posted by Eeva Jernström on 2013-04-05 20:00:55

The importance of holistically assess and estimate the effects of actions on one of the global challenges further on the other – e.g. the effect of increasing the amount of renewable energy on the availability of renewable raw materials for other applications. Reliable, global assessment of raw materials –mineral, water, renewables - is key and base for such simulations and data processing. This kind of approach should be used for evaluations of the fit of the new technologies and solutions to sustainability expectations and how well they fit to solving global interconnected challenges. The results would at their best speed up implementation of new technology and processes and also be used to checking and redirecting of research and development efforts.

Posted by Panos Patsouris on 2013-04-05 19:45:32

Three project-concepts: The first two will run concurrently. The third project will have as input the conclusions and analysis of findings of the two earlier projects. The project-concepts are as follows: 1 Critical research on the foundations of Big Data and its predecessor sub-disciplines and approaches. 2. Critical analysis of the real needs in moving from Raw Data – to- Actionable Knowledge for the different entities (Organizations) and gap analysis that would permit to conclude what is missing to reach a satisfactory GSS. 3. Extrapolating the two (2) above projects in view of exploring, detecting and providing the scope and size of the (a) demanded know-how, (b) required models and their nature and (c) expected workable outcomes. Feedback and feedforward mechanisms also must be established since along those interactions one may produce more findings than in the projects themselves.

Posted by Marco Raberto on 2013-04-05 19:27:46

Please, let me draw your attention to a key approach in agent-based modelling and simulation of complex socio-economic systems. I would name this approach as stock-flow consistency modelling or balance-sheet accounting approach. Every economic agent have to be characterized by a proper balance sheet reporting the stocks of different assets and liabilities; any economic interactions involving an exchange of real or monetary flows must correspond to a related variation of balance-sheet stocks. A critical validation criterion can then be the stock-flow consistency both at the single-agent level and at the aggregate one (many agents, sectors, the entire economy). This approach allows to detect very insidious modelling or implementation mistakes and to understand critical aspect of our modern economies, like the endogenous nature of credit-money and the endogenous source of bubbles and bursts. One of main weaknesses of mainstream economics is indeed to discard stock-flow consistency, while the Great Recession is basically a balance-sheet recession.

Posted by Piotr Sulikowski on 2013-04-05 19:21:09

Examples of ideas which could fill in this topic * developing methods for rapid analysis of large amounts of data * establishing systems for gathering and analyzing anonymized medical data worldwide for the better understanding of health, disease and optimal treatment selection

Posted by Krzysztof Biernat on 2013-04-05 18:07:45

There are many in the world of scientific databases where availability is limited and due to having to pay fees. Without going into the need to ensure the safety of the GSS, you can consider creating virtual research institutes affiliated with each other. The composition of these institutes could enter teams from different countries of the world in the ongoing research topic. This gave an opportunity to progress in research, and the research would not be duplicated.

Posted by Yougui Wang on 2013-04-05 17:27:53

A reliable approach to rating the raters; 2) Self-organization in markets and emergence of collective intelegence; 3) Reconstruction of macroeconomics based on better understanding of production process of goods and service and circulation process of money.

Posted by Iiro Harjunkoski on 2013-04-05 17:13:30

I would expect this to deal with many parts of technologies - New efficient data storage and compression technologies, completely new paradigms - More efficient analysis and correlation technologies - Ways of accessing data anywhere & fast - Classification of data and purposeful automatic causality identification - Cloud for everyone, i.e. ease & speed of access to related applications across systems - Social networks activating hidden talent pools (compare Linux development) Application areas can be immense... However a risk is that too complex systems give false responses (bullwhip effect) that calls for also cautious and critical uses.

Posted by Bruno Gaminha on 2013-04-05 17:12:14

A project under GSS could enable the intensive collection and treatment of massive data that would allow the scientific community to address some of the central topics in our society: how do economic agents coordinate their actions, how they form their expectations and how do they forecast and anticipate the future evolution of the economy and deal with uncertainty. A project under GSS would allow the understanding and the capture of the opinion dynamics over networks and clarify the role that global, regional and local economic governance can have in framing the economic expectations.

Posted by Sarvapali Ramchurn on 2013-04-05 16:35:32

I believe the management of large datasets and the analysis of such datasets will only be possible if novel mechanisms are implemented using distributed intelligence ideas. This means distributing computation but also the self-organisation of systems through the use of AI and multi-agent systems techniques. By so doing, we will be able to combat the computational and space complexity of Big Data problems and work out solutions using distributed capabilities on various types of hardware ranging from data centres, through normal PCs, to mobile phones.

Posted by Domenico Delli Gatti on 2013-04-05 16:31:36

I would like to bring the attention of the policy makers and the wider public to the issue of vulnerability and resilience of economic networks (for instance, the network of borrowing-lending interlinkages among firms and banks; the network of customer-supplier and trade credit interlinkages among firms) to shocks (aggregate and idiosyncratic). Vulnerability is a possible source of a financial crises and recession. Resilience maybe a criterion to design the most appropriate (possibly optimal) topology of such networks. The problem of regulation is strictly associated to this issue. Regulation of the individual firm or bank is irrelevant if it abstracts from the interconnections among firma and banks.

Posted by Saskia van den Muijsenberg on 2013-04-05 16:23:33

Research into resilient ecological systems, pattern recognition and translation for societal use - understanding other biological high-information systems like neural networks in our brains, high-power computing in locusts, etc. - even when it's clear what the most beneficial decision would be for the larger system, many times more short term decision making prevails (penny wise pound foolish). To prevent this from happening there should also be attention for preventing perverse incentives and perhaps different organisational structures

Posted by Zi-Ke Zhang on 2013-04-05 16:06:56

Now we come to the era of big data, which allows us to analyze, model and predict our life. However, although everybody talks about big data, how to realize and use real big data INDEED still remains a huge challenge. The GSS project now provides a promising way to think about the how to utilize the various sources of data, especially the daily communication and transaction data which contains both casual and serious user actions. Therefore, it is expected to conduct useful conclusions and methodologies to influence many disciplines as well as their unsolvable fundamental questions via precisely quantitative analyses, and finally, help us understand the human society.

Posted by Zi-Ke Zhang on 2013-04-05 16:04:46

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Posted by Mario Rasetti on 2013-04-05 16:04:24

Global Systems Science: a shared research vision It is increasingly obvious that to tackle the most challenging problems humanity is facing, such as the impact of climate change, living in a networked society, or facing the recent financial crisis, we need 'open boundary' research. 'Open boundary’ refers to a research that in its pursuit of novel solutions to challenges in science, technology and society unites the most promising expertise from a variety of disciplines and stakeholders without accepting a priori constraints from existing disciplinary or institutional arrangements. If flexibility and independence are major characteristics of open boundary research, critical mass could be achieved only by identifying commonly accepted, emerging research needs. 'Global Systems Science’ can be such an area. Here 'global' means that the systems and problems to be faced cut across manifold scientific expertise, different policy sectors and societal interests; they are borderless and can no longer be handled by one given country or by one sector of policy. Integrated cooperative efforts are required from across various scientific disciplines as well as from the shared synergy of policy makers and citizens, at individual and collective levels. More and more research needs to pay special attention to, and critically reflect on, the interface of science and technology with policy and societal stakeholders to succeed in making a relevant contribution to societal challenges. Novel approaches are needed where current modeling paradigms will be extended in a way that is both scientifically credible, i.e., rigorous, visionary, innovative and at the same time useful to those taking policy decisions and to all strata of society. The world we live in is more and more interconnected: tumultuously growing urbanization and population (with the related fast spreading new diseases and demands: housing, food, security), commercial exchanges, global migrations (induced by poverty and climate changes) are intertwined with an entangled world of 'techno-social' systems, where infrastructures composed of different technological layers are inter-operating within the social component that drives their very use and development. The growing complexity of such systems hides unanticipated opportunities as well as potential dangers. As a result of it, society demands an ever-increasing predictive power to anticipate, evaluate and correlate risks, and a deeper understanding of the systemic complexity of the world the new technologies are generating. Characterizing and modelling interdepending social systems is a challenge that can be faced only resorting to complex systems science and big data science. Indeed, contrary to the systems conventional science deals with, global systems knowledge is not based on repeatable experiments and a shared phenomenology, but just on data. It is 'data driven'. Data Science goes well beyond the technical challenges of gathering data from on-line systems and real-world sensors or coding computational frameworks for data analysis. It also goes beyond the classical statistical analysis. The focus is on identifying empirical laws emerging from massive data sets and on the "How?" question, i.e., on conceptually new scientific methods for synthesizing these correlations. Data Science wants to recognize the picture that is hidden in the massive deluge of data streams, to predict its occurrence, and to control it. But it also wants to proceed to the "Why?" question, linking these findings to theoretical concepts, to understand their origin and their impact. Such scenario aims to be a basic step towards turning 'Big Data' into an 'ICT Big Science' goal, coupling methods and data with theories and models. The goal is indeed that of endowing ICT with novel, more efficient tools to better play its role in the process of turning data into information, information into knowledge, and eventually knowledge into wisdom. The ever-more blurred boundaries between the digital and physical worlds will fade away, as ICT becomes an integral part of the fabric of nature and society. Two facets strongly emerge: one mathematical, oriented towards formal structures; the other computation oriented, based on the new idea of going perhaps even 'beyond Turing' to define novel computational paradigms. There is a deep philosophical question behind all of this, that was seriously addressed by Vint Cerf (the 'father' of Internet, inventor of the TCP/IP protocol) in a recent President’s column of the ACM: whether or not there is any "science" in computer science. Any time computing concerns analysis and modeling, that imply the use of formal methods, it is of course reasonable to say that there is a rigorous element of science in it. Computability, complexity, theorem proving, correctness, completeness, … are abilities that fall into the category "scientific". However, as computing is not a static, but rather a dynamical process, there is a need for stronger scientific tools to predict 'behaviour' in abstract computational processes. Modeling itself is a form of abstraction used to represent programs or systems with adequate if abstract fidelity, suitable to be rigorously analyzed. Judea Pearl’s (2012 Turing award) idea of 'causal reasoning' in conditional probabilities is translated in graph-like models linking the various conditional statements of a program in chains of cause and effect. This introduces into play a sort of intrinsic, natural time variable (reminding us of the 'arrow of time' proper to statistical physics – the link being provided by entropy) and hence the ground for a true dynamics. Pearl represents such scenario by diagrams that make it possible to construct analytic equations that not only characterize the problem, but make its solution computable. Pearl’s use of diagrams has an analogue in Feynman’s representation of quantum interactions. Both are abstractions of complex processes, which aid our ability to analyze and make predictions about the system behaviour, and may prove as powerful for computer science as Feynman’s were for quantum physics. Abstraction is a powerful tool; it eliminates unimportant details while revealing structure; a way of facing the problems that recalls statistical mechanics (dealing with fluctuations and noise induced by interactions) and chaos theory (concerned with the dynamical effects of nonlinearity), where unexpected patterns emerge despite the apparent randomness of the processes. In 2008, the editor of Wired Magazine, Chris Anderson, wrote an editorial titled The End of Theory. He was referring to the idea that computers, algorithms and big data might potentially generate more insightful, useful, accurate, true results than scientific theories, which traditionally craft carefully targeted hypotheses and research strategies. This certainly revolutionary and provocative notion has today entered not just popular imagination, but also the research practices of corporations, governments, journalists and even academics. The idea is that data, by themselves, shadow as they are of information trails of people, machines, commodities and even nature, can reveal secrets to us that we were once unable to dig, but now have the power and prowess to uncover; with no need of resorting to an underlying conceptual structure. I argue that this is not the case: brute force cannot fulfill the current scenario of Big Data analysis. Our ability to understand and make prediction about complex processes by analyzing data, rests on our cleverness in creating more efficient high-level query languages that allow details to be suppressed and 'theories' (not only models) to emerge. A number of consolidated areas of strength such as: • Computational Modeling in Complex Realities • Data-driven Societal Science • Information Dynamics • Web and Internet • Computational & Digital

Epidemiology • Mathematics of Complex Systems need to be exploited, in order to give credible, reliable answers to a world where every day 294 billion e-mails are sent, 20 billion text messages are exchanged by mobile phone, 250 million photographs are posted in Facebook, and every year 1 billion cars take the road and 2.5 billion people travel by plane. The "Big Data revolution" may allow for the ignition of a transformative science cycle for Global Systems through: ➢ Collection, acquisition and integration of human dynamics data from the individual to the societal scale. ➢ Development of computational infrastructures enabling new efficient processes of production of knowledge from data. ➢ Development of mathematical and data-driven models endowed with a high level of realism, able to offer novel quantitative understanding and predictive power in the area of socio-technical systems.

Posted by Alexander Makarenko on 2013-04-05 15:10:45

Our Institute for Applied System Analysis at National Technical University of Ukraine (KPI) have a more then 20 years experience in system analysis, mathematical modeling, nonlinear analysis and applications of IT in the field of complex large scales systems investigations especially of large socio-economical-natural-technical systems. So it may be proposed the next issues for including for GSS: 1. System analysis of large socio-technical, socio-economical etc. systems and processes with special role of emerging and developing IT influence on society evolution 2. Mathematical modeling of such topics 3. Research for understanding and governing sustainable development processes for local and global systems 4. E- servises and society development 5. Strong and weak anticipation in society 6. Complexity research focused on society problems

Posted by Lydia Vamvakeridou-Lyroudia on 2013-04-05 14:51:42

Important points - Interdisciplinary (not multi-disciplinary) reserach groups, in the proper sense, with social sciences and economics included in the physical sciences/engineering groups and collaborating actively - Social actors/stakeholders need also be included at all steps -More research on advanced (mathematical) methodologies for modelling complex systems needed, based on such existing methodologies, as systems thinking, systems dynamics, cellular automata, pattern recognition etc. -In particular systems thinking should include modelling on social and economics elements, interacting with technical and psycical components - The general theme of societal "adaptation" (e.g. adaptation to climate change, to hazards, to conflict impacts, to energy/food crisis etc) needs to be researched in this interdisciplinary context -Policy impacts need also to be investigated in the context of complex systems thinking -Innovative methodologies needed for including well documented artificial intelligence techniques from other fields (e.g. evolutionary algorithms) to systems thinking. This does not existing today in interdisciplinary global science modelling. -Urgent point: Research needed for quantifying and reducing "uncertainty". It is now the main problem for all modelling and scenarios involving climate change impacts. Not enough has been done on this. So advanced "uncertainty modelling" methodologies are needed.

Posted by Matus Medo on 2013-04-05 14:18:08

While a basic description of a system is often possible with a simple model, big data naturally leads to high-dimensional models depending on many parameters. This makes the validation task particularly challenging: validation methods not only need to scale well with the data, they also need to scale well with the number of parameters. Furthermore, common incompleteness or noisiness of the data makes model selection more difficult - how best to evaluate a model and how to penalize for the number of parameters when the data cannot be trusted completely? These fundamental data and statistics-related issues need to be addressed in order to GSS yield credible results.

Posted by Kostas Pavlou on 2013-04-05 14:16:03

Re-exploring and re-record the desires and needs of people as a cause of crises or/ and pandemics
Posted by Elke Henning on 2013-04-05 14:07:14
The study of problems as diverse as global climate change and global financial crises is currently converging towards a new kind of research – Global Systems Science. GSS builds on economics as well as on climatology, on history as well as on geography and on a variety of further disciplines. However, it is no attempt to renew the failed pursuit for a single unified science. It simply integrates insights and methods that are useful in studying global systems and develops them further for that purpose. GSS needs to emerge including substantial advances in information and communication technology (ICT). The use of computer models, digitized data, and global virtual networks are vital for GSS, and GSS can provide a key domain for socially useful ICT developments. Within the project Global Systems Dynamics and Policy (GSDP) a series of workshops on GSS have been organized around these issues during the last years. The latest contributions can be found at http://blog.global-systems-science.eu/.

Posted by yicheng zhang on 2013-04-05 14:00:13

I want first of all to emphasize the extremely timely importance of GSS. I was involved in one of WP of FuturICT during several years, and from all sides of the the society and the economy people realized how important the systemic thinking is crucial for the society and how painfully it is missing from traditional segregated displines. With the sinking of the the flapship, the huge challenge now rests on GSS's shoulders and this is the only credible opportunity (as I see it) that EU can promote the particular type of research of Complexity. 1) Why GSS is different from broad complexity studies. Today complexity is too broad and lacks of focus. GSS goes under the same umbrella but it should clearly stands out from the sometimes murky ground. GSS as I see it must be real-world application oriented as compared with pure academic curiosity. I believe GSS should make itself a sufficiently distinct name by grouping scientists and practitioners who share the basic premises. 2) some of FET past calls gave impressions to be hurried (to out, casual observers), and out of patchwork, often suiting the prevailing political winds of the moment. GSS in the horizon2020 may provide better more consistence and focus. The advantages for GSS is that the community is more mature and many new tools become the standard. The GSS calls hopefully will be organized into some key themelines and successive calls can be planned so that the efforts of one set of calls will be relayed by newer calls to advance further, to reach higher goals than on the per-project basis. 3) GSS being global, should be more globe-oriented, should be unashamed to call for cooperations regardless of geoplitical boundaries. Newer economies like India, China, and BRICS should be involved, this way GSS may reach its full strength. EU should not pay to save the world, many other participants can and will co-pay for the ambitious goals. I quote one example of ecommerce giant of Alibaba, after 1 year collaborating with NESS, decided to build a brand new research center aiming to target information economy. The new entity aims not to solve its own problems, but modelled after Santa Fe, to seek general excellence (rahter than corporate profits) 4) Since ICT will be still a key element in GSS, ICT and information economy should be one of the key focuses of GSS.

Posted by Jorge Louca on 2013-04-05 13:58:10

I would expect that a project under GSS would address new models for complex social systems analysis, particularly: * knowledge generation and propagation models in social networks; * the relation between the design of socio-technical systems and the dynamics of knowledge generation networks. New models can be designed and tested through intensive data collection and analysis from large-scale communication networks.

Posted by Jorge Louca on 2013-04-05 13:54:09
I would expect that a project under GSS would address new models for complex social systems analysis, particularly: * knowledge generation and propagation models in large-scale communication networks; * the relation between the design of socio-technical systems and the dynamics of knowledge generation networks.

Posted by Ilia Polian on 2013-04-05 13:43:29
It is of utmost importance to understand and control such properties of global systems as safety, integrity and security. Global systems can be seen as generalizations of complex systems or systems-of-systems to stronger encompass non-technical artifacts, and these issues are not completely understood even there. Conceptually, global system will depend on emergent and unpredictable, non-deterministic behaviour, while traditional understanding of safety, integrity and security is to a large extent based on a solid degree of determinism. The relationship between these conflicting targets is an interesting issue, both philosophical and pracitical.

Posted by Jørgen Staunstrup on 2013-04-05 13:40:10

It is suggested to extend the proposal to also include research on trust. It is a huge challenge to increase the trust in the findings of GSS e.g. by exposing assumptions, making models transparent and exposing uncertainties. The issue of “trust” must be included in the design, development and user interfaces to the technology used for GSS.

Posted by Peter Geczy on 2013-04-05 13:02:40

Large-scale systemics, or GSS, is certainly a viable domain. Ever-increasing amounts of data from numerous sources present various opportunities and challenges – where both need to be appropriately addressed. Large quantities of data contribute to information overload, and present processing and analytic challenges. However, they also allow us to tackle (large-scale) longstanding problems formerly inapproachable. This domain should strive at exploring both sides. Furthermore, it should positively correlate with other domains, such as ‘Knowing, doing and being’ and ‘Constructive symbiosis’.

Posted by Rezia Molfino on 2013-04-05 11:45:03

The Global Systems Science is an interesting subject that could involve all engineering sectors. The prediction, the anticipation or the description of a situation could be explained such as a classical engineering or physics problem. We propose to explore particular cases (e.g. natural catastrophic events, transport logistics) in order to define particular formulas and mathematical models to be used as decision base. Thus from the particular to the general strategy and approach could be no many steps.

Posted by Christoph Glasner on 2013-04-05 11:21:55

The use of GSS for gas hydrates as a fuel source of the future and for the simultaneous storage of carbon dioxide in the (depleted) mining areas.

Posted by Fred Heuer on 2013-04-05 11:12:49

"A requiem for large scale models" is the title of an article of the USA think tank Rand Corporation which I read a long time ago. But I was and am convinced that large scale computer platform based models tend to collapse under their owm weight. The weight of too many weak assumptions, of too much lack of reliable data, and of a too great lack of real knowledge. Instead this GSS should focus on relatively simple, separte models on subsystem level, as -for example used by the so called "CLub of Rome". This approach has less risk of black box phenomena and the crucial system relationships tends to be easier to communicate and validate.

Posted by Robert Baber on 2013-04-05 10:48:32

The language and terminology used by politicians, the media and the general public when discussing the environment, ecology and energy is dominated by terms such as “energy consumption”, “renewable energy”, etc. These terms are scientifically meaningless and wrong. This incorrect terminology interferes with the analysis of the problems involved, effectively preventing us from discussing these issues meaningfully and from arriving at solutions. Scientists and engineers know that energy is always conserved; it is never created and never destroyed or lost. It need not and cannot be “renewed”. Instead, a given quantity of energy is converted from one form to another or, if in the form of heat, it can flow from a body at one temperature to another body at a lower temperature. The amount of energy does not change. The thing that changes, the real issue here, is not energy, it is entropy. Currently, only scientists and engineers are in a linguistic position to discuss the relevant issues meaningfully. Politicians, the media and the public cannot currently understand such discussions. If these issues are to be discussed meaningfully by politicians, the media and the general public, the appropriate basic knowledge and the linguistic basis must be extended to them. This need gives rise to several important questions: • What scientific knowledge must be transferred to the public, the media and politicians so that they can participate in meaningful discussions about energy, the environment and ecology and so that they can contribute to solutions to these issues? • How can the necessary concepts (e.g. entropy) be described and expressed in a generally understandable form, suitably simplified, but not oversimplified? Which examples would be most effective? • Which concepts, terms and consequences of the second law of thermodynamics would be the most useful for discussing energy, environmental and ecological issues? • How can those concepts, terms, etc. be best presented to the public, the media and politicians? What publicity would be necessary, appropriate and most effective? • How can these concepts, terms, examples, etc. be most effectively included in school curricula?

Posted by Robert Baber on 2013-04-05 10:46:27

As Europe continues to shift from oil, coal, gas, etc. as sources of its energy supply to solar, wind, etc., the overall environmental effects will change, presumably significantly. Some of these effects will be viewed as positive, some as negative, and others as mixed in terms of quality of the overall impact. We need to identify and quantify these effects in order to plan this transition and to ensure that the resulting overall system is efficient and effective. A few of the questions to which we need answers are: • Extracting ever more energy from wind will change wind patterns. o What local, regional and large scale effects on wind velocities, air temperature, pressure, humidity, the distribution of various exhaust gases in the atmosphere, etc. will these changes have? o What consequences will these effects have on all aspects of weather patterns (e.g. precipitation), both in the short term and in the long term? o What corresponding changes should be made to weather and atmospheric data gathering and reporting systems? • Fields of solar panels to collect solar energy will reduce the land available for agriculture. o To what extent and how can this reduction be minimized (e.g. by mounting solar panels on the roofs of existing or newly constructed buildings)? o Can solar panels be designed so that the incident rays pass unhindered through and only rays reflected and refracted back from the surface below are converted to electricity or other forms of energy? • Reducing the combustion of oil, coal and gas will reduce both the extraction of the raw materials and the emissions of exhaust gases into the atmosphere accordingly. o What geological effects will result from the reduction of the extraction of raw materials? o What economic consequences will result from the reduced extraction of raw materials? o What consequences will the reduced emissions of exhaust gases have on weather patterns, air quality, etc. locally, regionally and overall? What overall thermal (entropic) consequences will result? o What consequences on human health (and associated costs) can be expected? • What macroeconomic consequences of the energy transition can be expected? • What is a reasonable fraction of Europe’s energy supply that should be provided by solar, wind, etc. by 2020? 2030? 2040? • How can the consequences of these changes be best accomodated by society?

Posted by LAURENTIU ASIMOPOLOS on 2013-04-05 10:11:58

From my point of view (as geophysicist and mathematician) the Global System Science has great importance for development the knowledge’s about the physics of the Earth, geophysical fields (gravity, electromagnetic, etc.), solar-terrestrial interactions, etc. Also, are very important all data of knowledge of deep structures of the Earth. All this VERY BIG DATA on the planetary scale can contribute to the development of innovative methodologies (modeling with many parameters, solving of specific forward problems) in geological sciences with application in many directions: climate-change, environmental problems, natural hazards, unconventional sources of energies, etc.

Posted by Silvano Cincotti on 2013-04-05 09:47:06

Over the last few years, the greatest concern of the global political agenda has been to find a way to overcome the crisis, to prevent future crises by making the global economy more resilient, to explore the possibility of broad societal transitions to sustainable patterns of production and consumption and therefore to look for effective policy instruments and even for new theoretical economic frameworks. The governance of local and global economic systems is therefore a topic of paramount importance. In order to successfully understand and govern this change, it is crucial to focus our attention on the increasingly integrated market economy and finance, which essentially drive other important global issues like the climate change, food security and energy management. Global systems science is the viable way to support the progress and advancement of the techno-economic-society with a complex and global approach to decision making. In particular, by considering behavioural and societal aspects when designing economic policies, by collecting (via social media mining) and integrating in the model citizens' sentiments, beliefs and opinions, by developing appropriate economic policies and regulatory frameworks. Addressing these objectives will increase the transparency of the policy making process, help citizens to engage, improve the credibility and effectiveness of policy institutions and allow to understand the emergence of the complex interplays and feedbacks among economic sectors, citizens' expectations and policy makers decisions.

Posted by Wiesław Bartkowski on 2013-04-05 06:43:39

From my perspective (as HCI expert and interaction designer) I would like to add: [-] To involve people we have to make systems which fulfill a real needs of user and are easy and pleasant to use. Knowledge from Human - Computer Interaction can help to do this. It also help to design interactive data visualization and new ways of data exploration. [-] We have to think out of the box. From my experience combining Art & Science is best way to achieve this goal. [-] We also have to teach people about models and processes. You learn best by play and making experiments. Teaching computer programing is a great way to do this. You can play with models, you can make experiments, and finally you learn how to think. Teaching computer programming is often seen as a not good idea, but it can be great idea if You as a teacher remember that you teach for play and exploration, but never for making next professional computer programmer.

Posted by Andrzej Nowak on 2013-04-05 05:15:30

The researchers in complexity science have gained considerable understanding of the dynamics of single processes occurring in social groups and societies. In any real social system, however, many interdependent processes (e.g. information flow, social influence economic processes etc) occur at the same time. Moreover often social processes also depend on physical and biological processes occurring in the system. The ability to model any the real social system requires understanding how this processes affect each other, and how they interact to produce real social dynamics. The challenge for Global System Science can provide understanding of multiple processes operating in the same social system and thus provide realistic models of processes occurring in societies. Social dynamic in the large part is the dynamic of sociality negotiated meaning, social construction of shared reality. Although this process is described qualitatively in the social sciences, new tools are needed to look at the big data from the perspective of socially constructed structures of meaning. Social sciences have created a large body of knowledge concerning processes occurring in social groups and societies. This knowledge has mainly quantitative character. On the other hand, the new ICT based research based on the analysis of large data sets has generated quantitative models, but the researchers lack the knowledge of existing social theories concerning the same phenomena .The challenge is how to integrate existing quantitative knowledge of the social sciences with the newly generated quantitative knowledge coming from ICT research. Understanding psychological mechanisms (e.g prospect theory)underlying economic processes and dynamics of financial markets represented a big advance in economic theory. Economic and financial processes, to a large part, however, are sociological processes. Understanding the nature of these processes is that challenge for the global system science.

Posted by Daniel Keim on 2013-04-05 00:28:31

One important subtopic in GSS is the integration of the human in the decision making process. For this purpose the combination of advanced automated simulation and analysis capabilities with interactive visualization techniques will be essential. The research area Visual Analytics is exploring the technology of how to make this combination most effective. Research in this area will be instrumental for a success of this program.

Posted by Agnieszka Rychwalska on 2013-04-04 23:55:40

The GSS should also pay special attention to the social aspects of the new solutions for policy decision-making on global challenges. Existing research on e-participation shows that to make meaningful reconnection between ordinary people with politics is a real challenge. Therefore GSS, especially when talking about social dialogue, should include better understanding of people behaviours and motivations in the process of decision making mediated by ICT into the set of its objectives.

Posted by Andres Gomez-Lievano on 2013-04-04 23:48:35

GSS stands as an important step in understanding our increasingly interconnected world: 1) Its priority has to be the collection of quantitative data, and of fostering that recollection so that all countries share their information in a centralized way. 2) The information has to be easily accessible and public. 3) The analysis and approach to understand this data has to be multidimensional in nature, and the construction of aggregate measures (such as GDP) should be avoided, since those measures hide the important details. 4) The principal focus of analysis should be cities, instead of whole nations and countries, which are arbitrary constructions.

Posted by Herbert Gsottbauer on 2013-04-04 22:58:36

--- GSS solutions for reducing the growing gap in income and education between different social classes within the society of a certain country --- GSS solutions for reducing cost and increasing quality of the public health system --- GSS enabled tools and methods of facilitating societal dialogue on globally interconnected challenges

Posted by Robert Van-Es on 2013-04-04 22:15:34

As the architect of a collective of consultancy firms from the UK, Belgium and Netherlands, collaborating to provide multi-disciplinary services to innovative SMEs, I assist SMEs to successfully navigate along the routes of implementation, marketing and project management. The collective works closely with specialist IT companies and Software houses to support multi-dimensional business analytics and intelligence to visualise decision grade information from operational, market and external data sources. The visualisation and implementation of enterprise intelligence is used to guide agile enterprise transformation and change projects - all activities are underpinned by business extended analytics for routes to innovative project development and implementation, and routes from concept to commercialisation. In this respect the collective partners in a collaboration will demonstrate developments that can support any or all of the following: • Project innovation analysis, • Constructing a structural model (Enterprise Architecture) • Analyse business scenarios • Construct exploitation views • Determine management criteria • Construct inspection and monitoring dashboards This has an important bearing on: • extensible meta-models (core elements), • structural models (including total structured, semi structured or unstructured data) • exploitation models • IT dashboards, and squawk boxes • tool boxes, methods and i-Visuals The above, combined with Enterprise Intelligence and Application Data (live) leads to Implementation, consisting of: • Extraction of raw resource information from systems • Extraction, translation and loading of data • Analytics and exploitation • Alerts by squawk box – leading to human intervention • What-if scenario modelling • Decision support and predictive behaviorGlobal Systems Science also necessitates security considerations (including cyber) to protect data and industrial intellectual property. Security and operational integrity at all stages of the system lifecycle is underpinned by continuous inspection and monitoring (CIM) while planning and scheduling of systems development follows along the lines of the Critical Path Method. In our case collaboration with a larger enterprise has led to further acquisition of collaboration contracts, providing specialised SME support, such as Patent-Box Regime and R&D Tax and Project Accountancy. Together, it allows delivery of "one-stop-shop" services to innovative SMEs from concept to commercialisation and total transformation and change projects for larger organisation, e.g. Ministry of Justice. It proves that collaboration between large and small enterprises works to the benefit of all as it decreases overhead cost and increases ROI. Collaboration between large enterprises and SMEs for the utilising the latest development through joint innovation and development, and joint "Routes to Market" allowed for increased [EU]cross border commercialisation of innovative goods and services. The core of the one-stop-shop collaboration scheme (heavily encouraged by the EU) revolves around the Collective's programme navigator, who is the conduit between EU funding , E.E.N., Technology Strategy Board and iNETs. It allows also allows (funded) project participants in closely controlling planning and scheduling of funded projects, whilst engaging in board and stakeholder participation, views and interests, and consequently lean project implementation, and project management office implementation support.

Posted by Liesbet Geris on 2013-04-04 21:58:23

The Virtual physiological human and its representation in the form the Digital Patient are defined as a technological framework that once fully developed will make possible to create for each citizen a computer representation of the health status that is descriptive, integrative, and predictive. It is descriptive because is provide a unified access to all information about the patient health determinants, including those related to life style, such as physical activity. It is integrative because it automatically combines all the available information so as to provide better decision support over large amount of information. It is predictive because the integrated information is used to inform individualised simulations able to predict how specific aspects of subject's health will develop over time, as a function of different interventions. • All medical professionals (nurses, GPs, hospital specialists, etc.) could use Digital Patient technologies for prevention, diagnosis, prognosis, treatment planning, monitoring, and rehabilitation purposes. Once the Digital Patient technologies will be fully deployed, every hospital in Europe will generate every day a huge amount of integrated clinical data about real individuals. This “one million Digital Patients” database could then be used in what-if simulations to inform public health decisions; the goal is the so-called ePublic health, where policy decisions are taken on the basis of reliable computer simulations of the different scenarios.

Posted by Efstathia Kolentini on 2013-04-04 21:23:59

-Projects with large scale simulation capabilities (i.e, EU energy market simulations) -Projects to indicate indicate new policies and trends (i.e, Associations panel to the state of the art technologies information exchange)

Posted by Oleg Smorygo on 2013-04-04 21:14:14

Today, humanity is legally structured according the “geographical” principle with the well-developed regulations in the economy, law, policy, etc. Until recently, such structure corresponded more or less to the structure by religious and cultural principles, and no remarkable “structural” challenges existed. At present, the restructuring by different principle is being established – due to the rapid development of transportation and communication technologies, gradual equalization of living standards. The role of “vertical” boundaries decreases, and interactions according the “horizontal boundary” principle are being established. There is the necessity in the detailed studies of the novel global “social environment” formation principles as well as the establishing legislative, political, economic, etc. rules and regulations

Posted by Tibor Normandy on 2013-04-04 21:09:12

Citizens with the current extraordinary computing power (including all aspects of cloud computing) in “hand” for every individuals, there is an immediate possibility, therefore expectation, to develop new generation of expert applications to support individuals and institutions to drastically reduce ICT related basic, predictable tasks, raise efficiency for the benefit of the whole society. • Institutions, decision makers, politicians should get new generation of support from complex modeling, simulation and next level of SWOT analysis tools for high and cross level objectives. Significantly reducing risk of neglecting or misrepresenting factors, affecting GSS issues. Start to build the next level of systems top on the document, retrieval, processing, and data-mining modules with the support of for example Information field theory (IFT). Some of the challenges is to convert, maintain integrity, redundancy, control, authorize access the big-database. New “tools for computer-aided policy” will be required. • Burden should be and can be drastically reduced on individual citizens loaded by the exploding amount of information maze, - using different aspect and cross-section of the ‘big-data’ and without jeopardizing the individual control, the loss of useful information and the ability to present or hide different results at will. Setting, analyzing specific needs, able to consider short term, emotional and long term effects on different level of groups, national or union wide.

Posted by Antonio Lucio on 2013-04-04 20:59:50

My experience in local governance processes on mobility (especially the Mobility Round Table of the Citof Madrid, 2006-2011) has shown me the important role that GSS can play in that field, interacting with participation. The GSS can, should, be a factor that will strengthen the role of participation (largely understood as "shared knowledge") in governance processes both metropolitan planning and project specific and neighborhood scale performances. The project Eunoia (http://eunoia-project.eu/) trying to approach these issues.

Posted by Sergej Zilitinkevich on 2013-04-04 19:20:34

PROPOSED: Revised paradigm and innovative methods for modelling geophysical and astrophysical turbulence with application to challenging problems of climate change including solar-terrestrial aspects. • Turbulence is an inherent feature of the atmosphere, hydrosphere and Universe. It essentially controls our environment and climate change. • Geo/astro-physical turbulence is strongly affected by combined effects of gravitation, rotation and stratification of density. • Besides regular mean flow and chaotic turbulence implied in the classical paradigm, geo/astro-physical turbulence involves self-organization, internal waves and inverse energy cascades. Comprehensive revision of its theory and modelling are necessary to respond to climate-change and other environmental and astrophysical challenges. • The time is ripe for this research due to the newly revised turbulence paradigm; new knowledge of interconnections between turbulence, chemical processes, aerosol dynamics and cluster dynamics; advanced DNS and LES methods of modelling geo/astro-physical turbulence; new understanding of the self-organization of turbulent convection; new energy- and flux-budget (EFB) turbulence closure theory.

Posted by Andrea Brandt on 2013-04-04 18:20:42

GSS is a very interesting topic to develop. The data are provided in all kind of systems in different kind of aggregation levels. Target should be to define stable use cases, search automatically in all data networks for fitting information in real time, translate them into a uniform language and model and provide them at the same moment at the fitting interface. Overall you always compare the predicition with the reality and improve the use cases and technical implementation out of it.

Posted by Viviana Cigolotti on 2013-04-04 17:38:09

Energy sector could be an interesting area of application, thinking to several aspects: societal, technical, financial, environmental; thanks to that, energy should be a topic under GSS. - smart grids, distributed generation, integration of renewables into the grid: data and control systems, data analysis, data aggregation -LCA as support for decision making

Posted by Patrik Jansson on 2013-04-04 16:01:53

I am particularly interested in the potential contributions of Computer Science and Mathematics to the the challenges of Global Systems Science. I see great opportunities in develop systems, theories, languagues and tools for computer-aided policy making with potential global implications. Some more concrete examples I would like to work more on include Sustainable Energy, Climate impact research and Economic modelling where prel. work is detailed in the following blog posts on the GSS blog:

http://blog.global-systems-science.eu/?p=1260 http://blog.global-systems-science.eu/?p=1257 http://blog.global-systems-science.eu/?p=1233

Posted by Terry Barker on 2013-04-04 16:00:17

GSS is an emerging field of academic research and empirical applications. The topic has become central to global economic governance, with the rapid globalisation of the world economy over the last 30 years and the appearance of a global shadow banking stricture and the rapid growth of offshore tax havens. • The extraordinary solution to the financial crisis of September 2008, after the Lehman bank went bankrupt, showed how many government adopted a similar approach to bailing out broken banks, rather than letting them go bankrupt too, so transferring private debt and private risks to the public sector and leading to stagnation and unemployment in many countries, particularly in Europe. These bail-out solutions were clearly a global solution to the problem, but one that has been shown to be deeply flawed, particularly since it compromises the basis of capitalism, namely that bankrupt companies, especially banks go bankrupt and therefore cancel their debt. • My interest in GSS is to develop an alternative global solution that requires that global banks go bankrupt in an orderly manner when their assets, valued on a mark-to-market basis, are less that their liabilities. This will have to be done by nations coordinating their policies and laws.

Posted by Markku Kulmala on 2013-04-04 15:33:26

It would be crucial to have supradisciplinary, multisacel efforts to solve interlinked global grand challenges. I suggest to establish and support the Pan Eurasian EXperiment (PEEX). The vision of Pan Eurasian EXperiment (PEEX) is to solve interlinked global challenges influencing the human wellbeing and societies in northern Eurasia, such as climate change, air quality, biodiversity loss, chemicalisation, food supply, energy production and fresh water in integrative way recognizing the increasing important role of the arctic and northern boreal ecosystems. The PEEX vision includes to establish and to maintain a long-term coherent and coordinated research activity and research and educational infrastructure in PEEX domain. PEEX will use an integrated observational and modelling framework to identify different forcing and feedback mechanisms in the Northern parts of the Earth system, and therefore enable more reliable predictions of future regional and global climate. Due to the already seen impacts of climate change on the society and the specific role of permafrost and boreal forest regions this context, PEEX initiative emphasizes the fast actions needed for establishing PEEX domain, the next generation research infrastructure in the field of boreal and arctic research. PEEX is targeted to provide fast tract assesments for the climate policy making in a global scale and mitigation strategies for the Northern PanEurasian region. PEEX will be built on collaboration by EU-Russian and Chines parties, involving scientists from various disciplines, experimentalists and modelers, and international research projects funded from by European- Russian- Chinase funding programmes.

Posted by Greg Fisher on 2013-04-04 14:09:24

Prediction and resilience Global systems pose different policy challenges. The basic policy approach at present is to try and understand a system, predict it and then control it. The financial crisis exposes the serious limitations of this approach. In global systems with feedbacks, systematically accurate prediction may be very difficult or even impossible. So the policy model of predict and control is becoming extinct. We need to focus policy on designing systems which are resilient. We cannot avoid instabilities, these are inherent in complex systems. But we can improve dramatically the resilience of social and economic systems, their ability both to absorb shocks and to recover from them.

Posted by Carolina Collaro on 2013-04-04 13:40:48

GSS will contribute to a better integration of local-global dimensions with better scientific knowledge.

Posted by Joseph Sventek on 2013-04-04 13:34:56

The ability to sense, process and control systems which generate enormous amounts of data is key to successfully building and understanding socio-technical systems in the years to come. The lifecycle from Data to Knowledge encompasses many phases: capturing and filtering numerous types of data, storing it, managing associated resources, modeling stored data, developing/exploiting data management systems which facilitate querying the data, executing analytic tasks (information retrieval, complex event processing, machine learning) to mine and infer new knowledge from the diverse types of data and, finally, exploiting the knowledge obtained to control our world. Managing this lifecycle in a truly integrated way currently exceeds our technological capabilities. Each of the above phases pose research challenges, especially in the face of high data volumes, stringent real-time processing requirements, and determining the latent knowledge within the data; solving real problems through integration of solutions across the phases significantly increases the research challenge.

Posted by Ilme Hinkel on 2013-04-04 13:26:41
A globally cooperative and interconnected challenge concerning European migration and citizenship could be the establishment of effective systems and measurements to combat human trafficking (e.g. sexual exploitation and human organ trafficking).

Posted by Devdatt Dubhashi on 2013-04-04 13:00:35

We are involved in several national initiatives in Sweden that fit very closely with the themes of GSS: - We lead a 2.5 million Euro project "Data Driven Secure Business Intelligence" funded by the Swedish Foundation for Strategic Research. This project, which is conducted with close collaboration from industry, has two principal themes: (a) efficient, large scale data mining from open source information such as social networks, blogs, open repositories and (b) retaining privacy and security while doing so, using techniques like differential privacy. Both these aspects would be of great relevance to GSS. - In collaboration with Virginia Tech, we have started developing synthetic population resources for Sweden intended to be used with high performance computing systems in application such as design of urban futures, transport and epidemiology. This work would fit into a wider Europe-wide context under GSS. - We are part of an international consortium "ICTBioMed" whose goal is to develop ICT infrastructure for sharing and mining of medical data, see http://events.internet2.edu/2013/annual-meeting/program.cfm?go=session&id=10003014. The ICT infrastructure envisaged has a somewhat generic character which would be directed to other application domains such as those envisaged in GSS. - We are involved in a "Big Data Analytics" initiative coordinated by the Swedish Institute of

Computer Science (SICS), whose goal is to consolidate and develop Big Data technologies and research in Sweden, and how it connects to such initiatives in Europe and the world.

Posted by Maria Lodovica Gullino on 2013-04-04 12:14:41

AGROINNOVA of the University of Torino (Italy) carries out basic and applied research in the agro-environmental and agro-food sectors. Multidisciplinary proposals tackling ecological systems within GSS topic could address the following field of research: - (referring to the containment of epidemics and biosecurity aspects): "One health" paradigm providing the rationale for an integrated approach of human, animal and plant life and health and environmental protection for the enhancement of breakthroughs in biomedical research, for epidemiological studies and ultimately for public health policy decision-making. - interconnections among climate, energy and agriculture.

Posted by Paul Ormerod on 2013-04-04 11:06:19

The basic model of agent behaviorMainstream economics still assumes that agents make decisions independently, and have fixed tastes and preferences. In the increasingly connected world of global systems, these assumptions are less and less valid. A key task is to develop new models of rational behaviorwhich are better suited scientifically to the interconnected world This is a key task, because a great deal of policy advice is still based on the concept of economic 'rationality'. Such policies are proving less and less effective, because, increasingly, this is not how agents behave 2. Systems, evolution and resilience To understand why instability is inherent and the mechanisms which link efficiency and instability To use history to understand how social systems (in the broadest sense of the term) evolve. Understanding the ability or otherwise to predict such systems Getting beyond the price mechanism so as to deal with discontinuities in markets and other systems, including understanding sustainability An efficient system has little resilience, and apparently robust systems be subject to fragility and cascades of failure 3. Big Data and predictability Develop methods for prediction – this is needed We must characterise predictability and its limitations Conduct and construct effective large scale experiments, inluding use of machines Develop visualisation techniques to explain results Apply specifically to crime, collective mood, prediction of trends, financial markets Analyse the consequences of the reactions to published predictions, both positive and negative feedbacks

Posted by Michael Gipp on 2013-04-04 05:02:28

Emergent properties are global-scale behaviours which arise in a manner not-at-all-understood from the interaction of a myriad of local subsystems. Interestingly, small changes at the local scale may bring about structural change at the global scale, which has been described as innovation. The notion of innovation in complex systems is critical because it implies that new behaviours are possible, so that the study of all past behaviours of such a system is insufficient to describe all future possibilities. My interest has been deducing the existence of innovation in complex systems on the basis of observations. How do we know we are witnessing something new? I have been using an approach involving the construction of finite state machines from phase space portraits reconstructed from observational data.

Posted by Borut Paul Kersevan on 2013-04-03 19:01:33

The concept of using the available large-scale computing capacity and 'Big Data' mining to simulate, analyze and predict the behaviorof highly interconnected systems with high social impact is in itself a promising topic. An underlying premise to this proposal will I think need to be addressed, namely how to facilitate access to the large-scale computing as well as the data of interest: -> There is certainly a lot of computing capacity available in e.g. High Performance Computing centres but there is no unified, simple, scalable and on-demand remote access to these resources. -> Likewise the abundant 'Big data' is in fact composed of data scattered across different locations depending on the type and source of this data, to collect the data from these diverse sources into actual 'Big data' a unified, simple, remote and on-demand access is to these is needed. Furthermore, active collection of further data or the simulated counterpart for the targeted (GSS) system of interest might demand the availability of global (EU) data storage solutions. Last but not least, the data are often sensitive, either in terms of privacy issues or in business terms and thus also need appropriate protection/authorization, which needs technically to be addressed on the global (EU) scale in terms of a common solution. Solving these issues is I think a prerequisite to address the GSS questions successfully by the participating EU-wide science community and would also be very beneficial for any sharing of 'Big data' or access to distributed computing capacities within the global heterogeneous science community.

Posted by IRENA SIELAMOWICZ on 2013-04-03 18:18:42

GSS addresses new ways of supporting policy decision making on globally interconnected challenges such as climate change, financial crises, and also distancemonitoring of different structures and devices. The ICT engines novel participatory tools and processes for gathering and linking scientific evidence into the policy process, data collection.
Posted by Sybille Lammes on 2013-04-03 17:24:51

This topic would benefit from a more critical stance on what big data are and how we interpret them as developed in STS and new media studies. . It could be more inquisitive and reflective about what quantity and quality means in this setting.

Posted by Santiago Luis on 2013-04-03 17:22:30

-continuous validation of data received and used and simoultaneous validation of the algoritms (and logics) used to handle those data is a key challenge, in particular in areas (i.e. climate change) for which scales can variate from very large (temporal series, number of data) to very small (i.e. temperature variations)

Posted by Martijn Huibers on 2013-04-03 15:08:40

The energy sector is also becoming a very interesting area of application, interconnecting societal, technical, financial, ICT, and environmental aspects. I think this should be an explicit topic under GSS. - smart grids are emerging, consequently a vast increase in data and control systems. How to optimally define / control / regulate / financially operate it is however both complex and unclear. -

distributed generation means bidirectional energy and data flow from a plethora of diverse sources (previously unidirectional from a few major sources) - combination with traffic data for impact assessment and smart charging of electric vehicles, and vehicle to grid for buffering renewables - online and offline data analysis is needed for optimisation of energy flows, investment costs etc. - aggregation of generation and load data on various levels is important to combine with demographical data of users in an electricity grid, for relevant scenarios and their consequences (e.g. investments). - etc.

Posted by Pablo Vega on 2013-04-03 14:57:14

The creation of freely accessible information by crowdsourcing is emerging in the Crisis Management environment. This topic could be addressed taking into consideration: - Technical limitations to the processing of crowdsourced informatino - The difference between data created by crowd specifically to support the crisis response and the data created by the crowd in a different context, but potentially resuable - The techniques to validate this data and use inside professional information management systems

Posted by Simon Dobson on 2013-04-03 13:54:58

This is a very promising topic, and one that could form the basis for more cross-disciplinary proposals. These often don't do well in "normal" calls: my experience in reviewing has been that, unless a call mandates interdisciplinarity, proposals in single areas typically score better (because the multidisciplinary proposals are often not equally innovative in *all* their component disciplines). I'd also like to see some component of managing uncertainty here. Most of the large problems are characterised by their uncertainty, but the programming and analytic models we use, especially when talking about sensing, warning and actuation, deal poorly with pervasive uncertainty. There's scope for some basic research here.

Posted by Fredrick Awuor on 2013-04-03 13:52:59
ICT4D in developing nations i.e., e-Agriculture, e-governance, e-learning/training, women empowerment through ICT 2. ICT policies and frameworks

Posted by Livio Baldi on 2013-04-03 12:03:33

Overlap with "Knowing, Doing and Being" that should provide basic tools and with "Time for Time" for predictive, look-ahead control system. Required are: - massive data storage systems - fast data processing - data base compatibility or automatic translation systems - interconnected communiation networks - algorithms and technology for data mining, data analysis - pattern recognition - also possibly control system mimicking natural processes.

Posted by PRAT Nicolas on 2013-04-03 11:38:40

In order to use GSS, the availability of the data is very important. The OpenData movement has to be promoted and maybe defined by rules in order to have a common definition on how to manipulate the OpenData, to have homogenous data with the same signification and the the same tool to manipulate them. The number of OpenData server is exploding but with no rules on data structure. Urgent action has to be taken to organize this enthusiasm, and in order to get massive and coherent data.

Posted by Sanna Kaasalainen on 2013-04-03 08:14:23

Novel processes and tools on this front require an interdisciplinary approach and synergy. This is evident, e.g., in the last sentence of the text: further development of these sciences needs co-operation and joint efforts of systems/computer scientists and mathematics - Reducing uncertainty in data comes from advanced multi-data approaches and their successful interpretation, which needs advanced mathematics. This is because multi-data interpretation and upscaling (in the case of, e.g., global environmental change) needs advanced mathematical modelling, to turn accurate local approach into globally valid systems - Furthermore, linking scientific evidence into policy and decision making should also involve research from multiple fields

Posted by Lars-Göran Löwenadler on 2013-04-03 01:00:24

In the area of transport, lots of data are collected regarding transport efficiency, environmental impact and safety respectively. Data bases are established to meet certain needs in these areas, but how to utilize them for balanced conclusions from the perspective of the society, the transport companies or individual aspects is not clear. * I see a need for developing / establishing strategies of how to propose criteras for the large scale assembly of data to meet the needs of the users in the final end.

Posted by Andreas Buecker on 2013-04-02 22:15:10

+ GSS bear a great potential. However global governance of climate change, the financial crisis or social justice is strongly influenced by cultural premisses and dynamics. Therefore theoretical approaches to the interrelation between data analytics and cultural aspects of global governance need to be discussed carefully.

Posted by Bruce Edmonds on 2013-04-02 20:38:01

Much GSS research seems predicated that we can safely ignore much of the micro-macro detail involved in society's systems, and thus is squarely in the realm of wishful thinking. Big data will not solve this problem if it involves simply conditioning global models. There is a disconnect between global simplistic models and the participatory end with users/stakeholders providing a very different view, resulting in their input being frequently constrained to fit into the data slots designed by GSS. Rather, I suggest, a new synthesis between different techniques is needed allowing in the greatest possible variety of data and methods, including: qualitative micro studies of behaviour, agent-based modelling, multi-dimensional data sources (where many aspects are simultaneously covered), data-mining techniques to detect meso-level patterns and hypotheses, multi-levelled modeling approaches, etc. in addition to those mentioned in the brief abstract.

Posted by Ivo Opstelten on 2013-04-02 20:06:06

Currently, energy consumption in buildings can vary with a factor 4 or more, between design on paper and performance in practice. The difference is attributed to both building-related and user-related characteristics. The building related causes can be attributed to building quality construction, building system commissioning and building system alterations (deliberate or not). Sub-optimal operation can have very large energy use and indoor quality consequences. The identification of causes and appropriate response scenarios rely on multi-parameter data analysis linked to 1) building/system maintenance activity 2) adaption to user behavior3) influence of user behaviour.

Posted by Clive Robinson on 2013-04-02 18:42:27

Given that the target user for these systems is the policy makers and the affected populations who may not have technical knowhow to understand these concepts or the results, effort should be put into methods and models for simplifying interfaces and presenting results in a simplified manner

Posted by Adel Taweel on 2013-04-02 18:07:20

Future, day-to-day or long term, decisions are not in complete isolation from the past and/or from the ones made in the past. In some domains such are critically affecting human lives, costs, interdependencies between their own aspects or between domains. Inference methods from Big data have the potential and can be key to unlock the future to making the right decisions for such, in terms of the efficacy, survival and existence - these can be critical in some domains such as healthcare. - Making decisions can learn from lessons from the past to help better make better decisions by predicting of the uncertain future. Prediction methods, based on past evidence from history data, can be key to unlock to change our future to the better from making the right decisions, through answering difficult questions to reduce uncertainties, to foreseeing potential forthcoming problems, in many domains including healthcare and economic/finance. - Would big data help understand human behaviorin ill and healthy humans and their complex social aspects to support more independent living as we get older? This is becoming essential not only to support human living but also to create methods to sustain our living.

Posted by Patrizio Pelliccione on 2013-04-02 17:21:40

ICT engines behind GSS should use of an experimental approach, as opposed to a creationistic one, to the production of dependable software. In fact, software development has been so far biased towards a creationist view: a producer is the owner of the artifact, and with the right tools she can supply any piece of information (interfaces, behaviours, contracts, etc.). GSS promote a different experimental view: the knowledge of a software artifact is limited to what can be observed of it. The more the observations will be powerful and costly the more the knowledge will be deep, but always with a certain degree of uncertainty. Indeed, there is a theoretical barrier that limits, in general, the power and the extent of observations.

Posted by Marco Trentin on 2013-04-02 17:00:44

One of the most popular topics discussed on the papers or by politicians, is energy. My opinion is that this is not the biggest problem we have to face with today: from now till the next 100 years, the biggest one will be the clean water availability. Water is not like energy, that can be obtained by several ways. A man cannot certainly survive without water for more than two or three days, but he can probably survive without energy for more than 7 days. There are not enough information on this topic; no information mean no actions, and no action means conflict. Together with my Company I'm working on this topic to contribute to the solution of this problem.

Posted by Maciej Jarzebski on 2013-04-02 16:46:52

Global Systems Science: - direct (meetings), indirect (supported with new technology) cooperation between European with American, Asian, African and Australian scientist - global sustain development - supporting creation global scientific network to solve interdysciplinary problems (i.e. with new technology implementation)

Posted by Iuliana Netoi on 2013-04-02 16:31:25

-The project will research the impact on environment after extracting schist gas so that be known if it worth going on with the actual schist gas extracting technology.

Posted by Angelo Caruso on 2013-04-02 16:24:07

In my vision Global System Science could be the key of a much better dissemination of knowledge through the open discussion of systemic maps. Complexity of current social system is becomic quite large and human mind needs supporting tools to understand the causal loops between variables. So, at the same time we prepare deep models to simulate for scientists, I'd propose to evangelize a sort of "modeling and discussing language" for laymans, to help improve our grasp of complexity and ability to find more systemic (and effective) solutions to our social, political, economic... issues. I see GSS as a real participatory tool necessary for everybody to survive in a complex interconnected world: unfortunately evolution didn't provide it, so we should acquire it culturally.

Posted by Minna Palmroth on 2013-04-02 14:00:09

With a European Research Council Starting grant, my team is developing a computer simulation that will be able to describe the near-Earth space weather environment accurately for the first time in the world. The simulation is huge - requiring peta or even exa-scale computations, and thus it requires innovative parallelization techniques. The simulation is six-dimensional, where computations are made in the ordinary three-dimensional space containing a three-dimensional velocity space. Due to the large volume to be simulated and the very complicated feedbacks between different domains in space weather (upper atmosphere, ionosphere, magnetosphere, solar wind), the simulation easily fits in here: 1) It gives a holistic view of a highly interconnected and complicated system, 2) it can easily fill any supercomputer in the world, and 3) it provides bigger data than is normally thought due to its six dimensions. For this simulation, we have had to develop very innovative techniques so that it can be run in reasonable time within Europe's largest supercomputers. These techniques also keep the supercomputing know-how within Europe. The code could be utilized here in many ways: By developing it further, it would advance European parallel computations and space weather research. One interesting topic is how to model energetic particle precipitation to the high-latitude upper atmosphere, a phenomenon that is currently not know at all by first principles, but which evidently has weather and/or possibly climate impacts. By utilizing its novel techniques, the code could also advance other fields that require massive computations.

Posted by Antonio Fernandez on 2013-04-02 13:56:22

In my view there are several challenges that are fundamental to GSS and in which I believe we could contribute, like, - Developing algorithms and techniques to process huge amounts of data (Big Data). - Modeling agents' behaviorfrom available data. - Analyzing and modeling interconnected systems as networks that evolve over time. - Predicting the future evolution of the systems.

Posted by Herman Russchenberg on 2013-04-02 11:48:00

Successful policies for societal adaptation to the effects of drastic or gradual regional climate change require empowered and committed citizenship. - This can only be achieved on the basis of reliable information, coming from the combination of observations and models at higher resolutions than currently possible. - The way forward: the development of dramatically higher resolution models, technologies and observation networks. - Challenges: 1) joining and interlocking advanced scientific observation systems and participatory sensing, 2) modelling small scale and diverse phenomena, 3) high power computation skills for global coverage to anticipate change.

Posted by Rolf Kubli on 2013-04-02 10:49:51

This general theme touches topics related to the FuturICT and similar visions, aiming at enabling global ICT-based decision support. Unfortunately, the main challenges in this context are not primarily of a technical nature, but rather political, educational and cultural. From a public research funding perspective, I would expect to see concrete examples covering methods and conclusions reached from specific Big Data analysis, as well as speculative multi-disciplinary investigations, for example: • Studies, concepts and approaches to improve the general understanding and acceptance of System Science and the interpretation of its findings. • Architectures and methodologies for linking simulation models of adjacent and of less-related disciplines (e.g. meteorology, hydrology and biology) • Benefits, limitations and improvement of collective intelligence. Thorough understanding of the (mostly hidden) algorithms imbedded in large-scale technical, commercial and social information systems will be of paramount importance for the evolution of decision processes in society and economy. • Looking into analogies, commonalities and differences of current large scale information systems as compared to the growing knowledge we have about the overall system-level architecture of the brain. Historically, artificial intelligence advances came from computer science and great engineering, not from biology. Even today, biological and technical information processing are far from a synthesis or convergence. It will therefore be worthwhile to compare biological and technical approaches to deal with complexity, stability, reliability and more. To be clear, not with the aim to build the human brain (this is already covered elsewhere :)), but to investigate certain aspects top-down, from an abstracted, system-level perspective.

Posted by Gérard Bréard on 2013-04-02 09:52:45

I totally support these approach. The question mark could be how to share the rational and the non-rational before to introduce a mathematics logic. Statistics could an option but that means that we have a good understanding of the process to use the right law !

Posted by Carla Marchioro on 2013-04-02 09:42:50

There is a need for a better treatment of large set of data: in several cases "numbers" are generated and used without a critical assessment.

Posted by Henryk Palus on 2013-04-02 09:00:10

I wanted to draw attention to the importance of data analytics for 'Big Data'. Often it is not just a problem of computing platforms, large-scale databases but also new methods of data clustering and classification.

Posted by Robin Williams on 2013-04-01 22:46:51

The University of Edinburgh has been investigating the socio-techical character and implications of Information and Communication Technologies for over 25 years. The Institute for the Study of Science, Technology and Innovation has fostered cutting edge interdisciplinary research from leading scholars and research groups from the Schools of Social and Political Science, Business, Informatics, Law, Art, Engineering, Public Health. This includes participation in EU studies from FP4 onward. Our work on computer systems in policy formation we highlight the need to address ** Socially Robust GSS ** Though the increasing availability of big data offers powerful tools for addressing complex societal challenges attracts considerable attention, the recent history of the financial sector reminds us that computer-based models do not necessarily lead to good decisions. Indeed inappropriate reliance on computer-based models without knowledge of the limits of applicability of the underlying mathematics or data can lead to new kinds of risk and systemic failure. Despite considerable attention to its potential benefits in selected areas, there is little systematic understanding of how big data can contribute to more robust, effective and accountable decision making. Other issues arise concerning the uneven access to data and to advanced analytics between individuals, private organisations and the state.

Posted by Glória Pinto on 2013-04-01 16:45:52

In regard to Global Systems Science the key discussion should not be the computer capacity, data volume, but more about correct and comprehensive interpretations of data that could be explore by different partners.

Posted by Miroslav Hladik on 2013-04-01 14:35:24

In regard to GSS the key discussion should not be only about the computer capacity, data volume, but much more about data handling and interpretations. It is essential to find the appropriate algorithms, which could be applied in the relevant simulations e.g. Monte Carlo, Heuristic algorithm e.g. problem P versus NP, new interpretations of Game and/or Agent Theories in Economics, Psychology and Sociology. In the respect to this stand point, it is no wonder that metrology, climatology are missing the tools to forecast atmospheric anomalies and scale of the analysed data will hardly help. If some problem solutions like P versus NP, Navier-Strokes existence and smoothness are too difficult to formulate now, they could be reformulated for the special purposes.

Posted by Gabriela Aronovici on 2013-04-01 14:02:57

FET research should establish more extensive research collaboration with non-EU partners to create new global economics models based on equity, reciprocity and competition, modeling the behaviorof complex techno-social systems and providing ICT tools to manage the emerging threats in financial markets systems.

Posted by Jose Piruat on 2013-04-01 09:43:19

Global Science scientific projects must be developed under a collaborative work between countries acting as a network of observatories/laboratories which obtain data that will be further processed in an integrated manner. On this regard, participant research groups should be geographically distributed. - There should be also a broad distrubution in terms of disciplines participating. Data collection, analysis, modelling of situations, validation of results, etc, will encompass a collaborative network of experts in different fields. These will range from experimentalists to computer scientists. - In GSS, social agents must be implecated at the highest level, as translationality of results, e.g. from biomedical research to public health, require active partcicipation of tha administration and other civil organizations.

Posted by Iordanis Arzimanoglou on 2013-04-01 08:31:11

The idea is to use GSS to educate decision makers to rely primarily on scientific data and not on personal interests, as the only likely means to harvest fruits from their decisions in the long run. In particular for politicians this is, understandably, extremely important in the Western world. Furthermore with the power of the knowledge hidden in GSS, we can vision a society with leaders in a variety of fileds possessing the necessary expert's knowledge and international experience required to perform such a task. Thus, GSS may a be a tool to eliminate mediocres and inappropriate people from influential senior management positions in world, state and corporate organizations, a situation that currently exists and impacts on society, economy, health care, environment etc - GSS could also be a platform tool for the public to check and monitor decisions made in various fields of common interest because it is not relistic for the average individual to possess the necessary knowledge to do that.

Posted by Peter Cowling on 2013-04-01 07:46:03

We can harness the extensive engagement that (especially young) people have with digital games - creating new genres of computer games whose objective is to enable game players to understand the very difficult policy trade-offs that are needed to address global issues. We might imagine an example where a game required a choice between building a new hospital, defending against an actual or potential enemy, and reducing net CO2 emissions by planting trees. -- We need to engage the policy makers who understand the issues, the digital games companies who know how to create game experiences that people want to play, and the systems and computer scientists who understand how to bring these two together. -- Given that (according to an article in Forbes magazine) the average child has played 10,000 hours of computer games by the age of 21, and the broadening demographic of games players, the potential is enormous for increased understanding and ultimately for long-term, large-scale policy change.

Posted by Narantsetseg Purev on 2013-03-31 17:33:07

GSS is applying in all social-economic sectors. So the creating and developing scientific and technological foundations is crucial matter for intensive global development. The IT, reliable data providing and processing, systems science and economic-mathematical modelling are importance for successful business expanding in wide range.

Posted by Amer Smailbegovic on 2013-03-31 12:11:41

Make effective use to use developing and emerging new technologies in the realm of non-destructive, data acquisition technology (i.e. active and passive spectroscopy, fluorescence etc.) to perform decision-making analysis and input for data systems - Enhance automated analysis protocols of acquired data to take advantage of isolating key identifying parameters of the "Big Data" (e.g. signal processing) useful in delineating and tracking a particular observable.

Posted by Andrzej Goworski on 2013-03-30 18:35:14

Scientific Editing: Promoting an open form of reviews in scientific journals.

Posted by Oliver Mayer on 2013-03-30 13:58:03

Today we use these systems to identify and predict threats we see (climate change). How could we use such systems for positive prediction: We want to do X what will be the effect Y?

Posted by filippo Addarii on 2013-03-30 13:57:49

I would add global governance amongst the global challenges. Global governance - the set of rules and forms of cooperation between all the States and non-State actors in the world - is actually a structural condition to tackle all the other challenges. In particular, the EU is the blueprint and test bed of future global governance. I would include global governance as a field of exploration for GSS. What 's the impact of ICT on the emerging global governance? How GSS can help understanding and foster global governance?

Posted by Alfonso Niño on 2013-03-30 13:47:59

According to my interest in the development and application of complex networks principles and tools I would like this section to address: A. Complex networks in big data analysis B. Design of efficient large networks modeling software in distributed environments (Grid, Cloud)

Posted by John Collins on 2013-03-29 18:17:14

It would be worthwhile considering the implication of the 'internet of things' - including people as the 'things' in GSS.

Posted by Jesus Marco de Lucas on 2013-03-29 17:58:37

Our group could contribute on: -Development of simulation systems based on a very large [> O(10^6)] number of agents and integration over a GIS system -Distributed NN oriented to very large datasets -Smart Visualization

Posted by KHALED BAAZIZ on 2013-03-29 16:04:18

storage and fast loading of "big data". - simple and intuitive visualization of complex patterns. - Real-time data correlation and tendencies of change forecast

Posted by Martin Connolly on 2013-03-29 14:25:00

I would consider the following under this topic: 1) The use of Big Data Analytics and Data Science to process the raw data from sensors and other smart devices. 2) How the data, information and knowledge generated can be integrated in Information Systems, the Cloud and Social Networks. 3) How these systems can be secured - at the device level as well as data in transit and stored data. 4) The impact of GSS on Business Processes. 5) A focus on applications in each of the areas cited above i.e. financial crises, climate change, disease containment.

Posted by Vincent Heuveline on 2013-03-29 13:48:57

The following topics are to my opinion very important for GSS and would fit very well in this topic: - Uncertainty Quantification (UQ): based on deterministic and/or stochastic mathematical and numerical models assuming huge distributed datasets. - Visualization techniques in the context of "Big Data" which allow for decision maker but possibly non expert to catch and understand the most important features and dependencies assuming large, complex and interconnected system.

Posted by Vit Sipal on 2013-03-29 13:34:10

Cyber-security is a huge topic that is a pre-requisite of the GSS. Briefly, GSS makes only sense if there is enough "cybersecurity" even at the lowest level of individual data sources. For the big data analysis it is important, to know that the data (however uncertain) comes from a reliable source. In future we can expect that systems analyzing big-data will gather data from a large number of sensors without human in the loop. For such systems we have to be secure and prevent impostors to send corrupted data. Corrupting even a small number of data links between sensors and data fusion centres can lead to a wrong allocation of resources leading to a system failure or to an increase of system vulnerability. For example: - a relatively low number of fake fire reports received from a smoke sensor compromised by an impostor can cripple the emergency infrastructure which will send its assets to the wrong locations and leave the entire infrastructure vulnerable to a real threat. With the internet and wireless sensor networks such large attacks can be performed in a much more sophisticated manor with less resources than ever before.

Posted by Andrzej Kos on 2013-03-29 13:30:54

Selection all kinds of information having influence on global processes. New system of different information collecting and recording using universal notation. - Analogy between global system created by human being (e.g. economy) and natural global systems. - World wide computer network as a main source of important information on upcoming global crisis.

Posted by Quentin Compton-Bishop on 2013-03-29 13:16:12

The University of Warwick is a partner with NYU in the Center for Urban Science and Progress (CUSP), set up to carry out applied global systems research in cities and urbanisation. I suggest therefore: - Urban informatics, with greater emphasis on applied research

Posted by Stefanos Vrochidis on 2013-03-29 13:01:19

The low cost of sensors (video cameras, environmental stations, kinetics, wearable EEG, eye-trackers, GPS, etc.) and the fast communication technologies in global networks allow for the generation of multimodal content and data streams that actually describe a variety of factors (such as environmental conditions, human physical conditions, human psychological status, etc.), which if considered at large scale directly affect social, financial, health and ecological problems. Innovative projects should target crowdsourcing approaches to deal with: a) modelling of multimodal sensor information with respect to the social, financial, health and ecological dimension of important problems (crises, disasters, pandemics) considering cognitive and affective human response. b) large scale sensor multimodal and multimedia data semantic integration c) scalable semantic reasoning techniques for decision support d) large scale visualization to complement decision support

Posted by Nazareno Claudiani on 2013-03-29 08:39:50

"Big-data" availability and resume is a basic progress towards participation, dissemination and equal opportunity. In mediterranean Countries, Italy as first, burocracy and public offices procedures and languages come from a long history of particularism, privileges and city revalry. Therefore, a strong engagement towards simplifying and "Open-data" processing should be addressed, for getting an easier approach to Public Offices and Services. It's a matter of real standardisation in a common understanding framework and esay-to-approach citizen services. Such standard procedure purposes have to be "transported" upon ICT layers, already existing and off-the-shelf available, capable of implementing such simplification - standardisation - data availability needs.

Posted by Nijaz Deleut on 2013-03-29 08:15:17

"Short Sharp Science: Global greening as plant life moves northwards" - Across the entire northern hemisphere, ice and snow are retreating in front of an invading green "army" as warmer climate turn once-freezing tundras into temperate shrub lands (www.newscientist). Also, "The Role of Boreal (Taiga) Forest and Carbon (C) Sink Fluxes and Mechanism" should be better understood.
Posted by Pedro Silva Girão on 2013-03-29 07:21:39

Many policy decision making are presently more dependent on good models than on data. Economic Science is full of examples. Emphasis on models development can avoid resorting to simulations requiring large computational resources.

Posted by Alexis Tsoukias on 2013-03-28 21:21:53

As director of LAMSADE (Laboratoire d'Analyse et Modélisation de Systèmes d'Aide à la Décision) a joint laboratory of the CNRS and Université Paris Dauphine (www.lamsade.dauphine.fr) I am following the whole set of research activities addressing decision support issues both from pure theoretical and from an application point of view, the later being mainly oriented towards the design, the implementation and the assessment of public policies. We are launching a new interdisciplinary research area aiming at establishing an international community: Policy Analytics. The main idea can be described through: - policy making is a set of complex decision processes structured in "policy cycles"; - we need to create a new methodological frame within which develop a new type of analytics fitting the specificities of policy cycles; Specific research challenges within such a direction include: - Preference Learning - Scenario Planning - Argumentation Theory - Support Problem Structuring and Formulation - Reformulation of Decision Problems - Innovative Design of Policies More details can be seen in: A. Tsoukiàs, G. Montibeller, G. Lucertini, V. Belton, "Policy Analytics: an agenda for research and practice", to appear in EURO Journal of Decision Processes, inaugural volume 1, 2013, downloadable as Cahier du LAMSADE, N. 335 at http://www.lamsade.dauphine.fr/sites/default/IMG/pdf/cahier_335.pdf

Posted by Metin Turkay on 2013-03-28 20:33:16

I have been actively involved in developing data analysis and optimization methods for understanding complex systems. I have the following background that would be useful for the 'Global Systems Science': - I developed a novel approach to classification of big data into multiple classes and applied it successfully to a variety of problems including climate change, environmental impact analysis, renewable energy technologies and disease identification using biomarker data. My theoretical approach is at the interface of systems science, computer science, and mathematics. - I am involved in energy and environment interaction analysis at the national level to shape policy decision regarding energy policy, energy mix and carbon footprint. - My laboratory (http://systemslab.ku.edu.tr/) is involved in a number of high-profie projects at the national and European level. I expect the following topics to be addressed under this topic: There is an urgent need to develop a holistic approach for addressing complex systems related problems. Such an approach should include the domain specific experts, systems scientists, computer scientist and policy analysts. Incorporating, analyzing and representing big data in an user-friendly manner and derivation of policy related results supported by data analytics are important concerns. - Conceptual aspects: The definition of the holistic approach with its important conceptual components and their interaction is a prime requirement. This step requires a discussion platform to bring together experts with different backgrounds. I would like to contribute to defining the core concepts of the holistic approach. - Methodological aspects: I would like to contribute to shaping this approach in general and participating in data analytics with deeper technical participation. - Use Cases/Validation: I would be very happy to participate in use cases to validate this approach in assessing the environmental effects of energy use and demographic changes in healthcare management. I believe that my background and experience in several national and European projects would be great asset to the project. Sincerely, Metin Turkay

Posted by Ionut Purica on 2013-03-28 19:43:28

The increased complexity and the high dynamics of today processes require the application of new models - sometimes imported/adapted from one domain to another - such that to gain new insights into predicting behaviorand through this to be in a position to better understand/shape the future. Nonlinear decision models, econo-physics, are but two of the possible examples of such outcomes.

Posted by Andres Garcia on 2013-03-28 19:20:50

It would also be good to devote some efforts to data capturing, not only on ways of interchanging and analyzing data. The reliability of the obtained results is never higher than that of the data used in the process. Technologies such as Wireless Sensor Networks (WSN) or rather Sensor Networks in general, can be a good starting point. New ways to make reliable sensed data available to others through, for instance, the internet can open the field to the development of new interesting applications.

Posted by Robert Moldach on 2013-03-28 17:27:55

While considering GSS future applications, specific attention should be addressed to public health challenges which namely in the EU countries focus on the unparalleled combination of ageing population, growing expectations and the proximity of healthcare spending limits. > Large scale predictive modelling should bring innovative solutions how to better prepare healthcare infrastructure to the epidemiological needs and how to maximise the socio-economical benefits based on the preventive medicine rather than acute treatment. > As a result, GSS focus on healthcare should extend the well being of nations, support active living and ageing, as well as provide control tools making it possible to better manage healthcare spending against outcomes.

Posted by Leonardo Camiciotti on 2013-03-28 17:09:07

Science and society are experiencing a challenging and revolutionary transition and this indeed requires the approach GSS is following in order to achieve a sustainable socio-economical progress. Technology development is constantly adding intelligence to the world and by definition rather than introducing simplification this increases interactions and turns it into a globally connected system. Therefore dealing with complexity and handling it with a scientific and organic approach in order to produce positive impact on society is the challenge of this era. Digitization, the Internet and the World Wide Web are producing a “knowledge burst” and creating a digital mirror of the real world in the fields of healthcare, energy, education, public administration, logistics, finance, tourism, etc. not forgetting the emotions and life snapshots flowing through the social networks. On the one hand this

digital mosaic, composed of fragments called digital data, describes reality; on the other, it stimulates, influences and conditions it – and much faster than any other social transition previously experienced. This gives un unprecedented opportunity to analyze data, decipher and cross-mine them, finding emerging and recurrent patterns, discovering hidden behaviours, possibly casting predictions to prevent crises. This is called the Big Data revolution, which will provide policy makers, companies, institutions, governments and citizens with new tools to interpret reality, take decisions and build a society capable to function as a complex, intelligent and balanced organism. In order to exploit this opportunity there is a need for: - Building models in order to: o manage and leverage complexity o extract emerging patterns and hidden laws by properly mixing different and apparently uncorrelated datasets. - Educating a new generation of category of data scientists able to create meaningful mosaics through the mastering of digital data - Developing proper scalable technology infrastructure (e.g. computing and storage technologies, new visualization techniques and tools, etc.) in order to make the described Big Data asset accessible, understandable and exploitable.
Posted by Maria Paola Bonacina on 2013-03-28 16:39:09

Large-scale computing platforms and 'Big Data' cannot be handled by brute force computation. Therefore, the success of GSS requires that the ICT engines behind it features * new automated reasoning algorithms for expressive languages, * new search techniques for the search spaces implied by uncertain data, and * new paradigms of distributed reasoning and communication.
Posted by vincenzo gulla on 2013-03-28 15:47:26

-large scale data are certainly useful to understand the social and economic behaviortrend of populations and countries but could be even more important to draw the social-health trends in order to allow decision makers to detect and implement just in time solutions . As a matter of fact today we are facing an fast elderly increment in all the developed countries. Alarms have been launched in due time in each country but no realistic method to face the lack of future work power , economic failure and quality of life decrease has been put into action. - The synergy of data over wide -scale computing with simulation facility where social, ecological and population data trends are manipulated in combination with the "game theories" could produce powerful decision making tools . -the milestone to develop a GSS dashboard integrating data to simulated and predict future global trends

Posted by Thilo Stadelmann on 2013-03-28 14:44:21

The current focus of data science and big data analytics is to build "data products" to boost business. Under the call for "Global Systems Science" I would like to see proposals that apply the tools, techniques and methodologies developed there to the case of modeling and predict complex behavioural patterns like climate, public opinion or market bubbles.

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9 Participants to the recent GSS meetings and workshops

This list contains the people who have attended to the following GSS workshops and meetings:

- First Open Global Systems Science Conference (Brussels, November 8 – 10, 2012)
- Towards a Sustainable Global Financial System (Potsdam, December 8 – 9, 2012)
- GSS workshop on Models and Data (Brussels, February 7 – 8, 2013)
- Urban development and GSS (Brussels, February 13 – 14, 2013)
- GSS – Territorial versus functional Patterns (Arizona, February 25 – 26, 2013)
- Narratives as Communication (Brussels 13 – 14, March 2013)
- Visions of GSS: Energy Futures (Brussels, 18 – 19 March, 2013)
- Urbanization, Sustainability and Prosperity

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