**A Research Program for**

**Global Systems Science**

***Version 02*** *(March 6, 2013)*

“We reject: kings, presidents and voting.

We believe in: rough consensus and running code.”

(Internet meme by David D. Clark)

*Version 02 is the seedling for a living document. It is based on the seed, i.e. version 01, of February 1 (see the post “A Research Program for Global Systems Science” on www.global-systems-science.eu).*

*That version was based on the first open global systems science (GSS) conference (Brussels, November 8-10, 2012) and subsequent workshops, informal exchanges and on-going research by members of the emerging global systems science community.*

*Meanwhile dozens of researchers and practitioners have helped to expand version 01, via the blog, half a dozen workshops and direct exchanges. A preliminary result is the present draft. It is really a draft, and all kinds of comments, suggestions and structured inputs are welcome.*

*The precise date for the second open GSS conference will be determined in the coming days, but in any case it will happen in the week from June 10-14, 2013 (this is due to the calendar of Ann Glover, Science Advisor of President Barroso). As usual, details will follow on the global systems science blog.*

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# ICT and Global Systems

## What is Global Systems Science?

“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 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. 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 turmoils 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.

## 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 innovation, all functionalities in society change, and this task is also what GSS 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 question are of special interest for GSS:

* What can GSS bring to understand and deal with global sustainability challenges?
* When you look at the global level you need to couple different types of levels and systems, both temporally and spatially, all with different speed dynamics. We don’t really know how to couple all that, but we need to think what particular tools could address these complex questions.
* How can GSS identify various transition paths towards a more sustainable world society? 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?

*Some questions regarding ICT*

* What are the new capabilities that ICT as 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 a 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?
* …

## A living document

The present report constitutes a ‘living document’ which will continuously collect and summarise key insights produced from a consultation process on Global Systems Science which is being organised since November 2013, jointly by the European Commission and EU project Global Systems Dynamics and Policy ([www.gsdp.eu](http://www.gsdp.eu)) and will continue till the end 2013. The overall aim of this exercise is to produce an **Orientation Paper on Global Systems Science (GSS)** which can be used to support strategic science policies and capacity building in this domain. The content of the report is based on insights from workshops, conferences, informal exchanges, academic papers, policy briefs and focused blog posts at www.global-systems-science.eu.

In particular, the present version (v02) contains a first sample of views provided by members of the emerging 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 (Phoenix, AZ, February 25-26, 2013)
* Narratives as Communication (Brussels 13-14, March 2013).

In addition, the following workshops and conference are being prepared:

* Visions of GSS: Energy Futures (Brussels, 18-19 March, 2013)
* Urbanization, Resilience and Prosperity, Arizona April 15–19.
* Second Open Global Systems Science Conference (Brussels, June 2013).

In fact this allow us to talk about a kind of ‘ecology of questions’. Flourishing Global System Science will happen as a tension between big questions and small questions. E.g. big questions like how to bridge science and society (the type of conversations and processes needed for that). This cannot be resolved in the short term. What is needed is to produce a set of researchable small questions of which we can work. From this we should get four or five big questions and a much longer list of small questions, e.g. the role of particular ICT, on city system, medical systems, etc, on which we can work in the coming years. Openness and active collaboration between all of us here is a precondition for this to happen.

Draft proposals for single sections of 3-4 pages are especially welcome, but so are as are highly selective reference lists, smaller and larger materials, including figures, graphics, quotations, snippets, comments, and suggestions. Contributions are welcome at www.global-systems-science.eu.

# Policy Challenges

## Global financial markets

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,
* …

## Global climate policy

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 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:

* 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
* …

## Globalisation and urbanization

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, crowdsourced data, simulation models, and action research.

In particular, the Hence the following research questions are relevant with regard to the urbanisation and globalisation: What is the global systems 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?

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## The global energy system

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 centruy 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.

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# Knowledge Technologies

## Formal languages

Global Systems Science deals with complex, dynamical systems and their interrelations on a potentially global scale. It relies heavily on Complex Systems Science (CSS) and mathematical tools and models from non-linear dynamics. It deals with large amounts of data and agents, and multiple, interacting networks. It involves social, economic, ecological, biological, and information systems. They may be non-deterministic and non-equilibria in kind. Emergent behaviour may be an important feature of them. Besides the tools of non-linear, dynamical mathematical models, algorithmic game theory and agent-based modelling, GSS stresses the importance of policies, policy makers and citizens and their roles and participation in dealing with global challenges. It also suggests the use of narratives, games and art as means to interface with scientific models and connect decision-makers and the public to scientific results and forecasts.

Given these aspects of models, methods and their application we may ask what is the role of formal languages for GSS. The present note concerns a particularly important kind of formal languages: logic and logic-based languages and systems. We describe five 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 claim made by GSS practitioners 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. By the way, this suggests that GSS is not purely descriptive and "value-free" (though its methodology may be!).  Let us then take the case of *policies* that are somehow integral to GSS.

The notion of a policy denotes 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 nor 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, but also abductive reasoning is relevant. 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), and other non-monotonic reasoning systems, are highly suitable for representing defaults, typicalities and exceptions and for dealing 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. They can be combined with ontology languages and other logics for reconstructing knowledge (databases, KBS etc.). For example in the Ontorule project, some logic-based languages are used for formalizing business rules provided by Audi Design. These may be considered as high-level policy rules. In GSS, logic languages could 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.

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 AI 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 by 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. GSDP 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. The recommendation pursued in that project is to focus on languages based on dependent type theory, itself derived from a logical approach known as constructive type theory (CTT). They suggest that DSLs may be valuable not only as a programming environment for implementing mathematical models, but also for the science-policy interface discussed above. However, they do not analyse this interface in any detail or indicate what kinds of concepts might form the basis for a high-level DSL in this context. 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 (STIT, deontic logics). 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.

Note that logic may be good for the ABMs but even the same concepts may be good for the science-policy interface.

*3. Logical concepts for modularity.* Another issue raised by the GSDP project is how to improve comparability and modularity of models. They single out agent-based models 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.

*4. Logic for GSS methodology.* Logic forms a crucial part of traditional scientific methodology and there is no reason to suppose that GSS is in this respect any different. The fact that systems studied may be non-deterministic, that behavior may 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. It is clearly as yet only very 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, we are dealing here 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.

*5. Logic for reasoning about GSS and global challenges.* The role of logic in 3 and 4 above is partly determined by the fact that logic typically forms the metatheory of the mathematical sciences. While the different disciplines 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, if we want 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 or other formal methods.

## High Performance Computing

Once high performance computing (HPC) mover 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 assessments 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.

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## Big Data

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 crowdsourcing – 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.

## Models and Narratives

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 can 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.

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 artciulating 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.

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 learnt from the past and for the future so to adapting and creating adequate models to do all this –and its associated narratives.

In particular, the analyses of framings and narratives should help to unveil how do 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 behaviour change 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.

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# Conclusion

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 apply 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 this kind 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 aweare how this should help GSS practicioners 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.

# Appendix: People involved in the GSS discussions so far

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