Report on European Research Landscape

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1. Overview

1.1 The report

The report presents major considerations concerning complexity science in Europe, with special focus on:

- the challenges complexity science is facing;
- its potential impact on society; and
- the activities needed to meet the challenges.

The report is based on communications established among the countries participating in the Complexity-NET and also with selected participants from other countries, in particular France, Germany, Bulgaria and Romania.

1.2 Summary of the Workshop

The report contains outcomes from the complexity landscape workshop in Budapest, November 1-2, 2007. The workshop agenda included presentations of (1) highly cited results accomplished within complexity science and (2) activities that already exist to support complexity science research and training. An expert panel gave its views on the issues and benefits of complexity science and all the participants contributed to a thorough analysis of the strengths, weaknesses, opportunities and threats in the complexity science research landscape in Europe.

2. Complexity Science and its Applications

2.1 Complexity Science

Complexity science studies *multidimensional problems* involving many variables interacting with each other and with the environment in complicated ways. It addresses the *behaviour of the system as a whole* and aims to understand the dynamics of ensembles and the evolution of subsystems composed of many interacting parts, whose "global" behaviour cannot be understood by studying only the properties of individual components. Complexity focuses on systems which are far from equilibrium and cannot be treated in a "traditional" way, as they exhibit remarkable properties of *self–organization and emergence of coherent structures over many scales* that cannot be explained by the behaviour of their individual elements.

This definition enables us to describe and understand the concept of complexity science, without being too exclusive. Rather than attempting to provide a more precise definition which may then prove to be too narrow and limiting, this report focuses on revealing the challenges complexity science is facing and also the major opportunities it has.

Over the last few decades complexity science has fundamentally changed our understanding of complex systems and provided a number of tools and methods to explore and handle complex systems.

Some of the benefits of complexity science, as discussed by the expert panel (made up of the speakers at the workshop) are:

- complexity research allows a broader viewpoint in comparison to other disciplines
- complexity science can address real world issues that are important to the general public and have relevance to everyday life
- complexity science can be useful in fields such as biology which are full of multi-scale phenomena
- complexity science can be used to provide solutions to global issues such as energy, environment, pollution and financial markets

- complexity science can deliver on a practical basis and the benefits should be promoted in industry

2.2 Applications of Complexity Science

The challenges the world is facing are very complex; from climate change and natural disasters to humanitarian catastrophes; from waste of limited energy resources and raw materials to environmental pollution and the spread of dangerous diseases; from sudden breakdowns of communication or transport networks to outbreak of economical and political instability. Today, results from complexity research allow us to explore a number of real world complex phenomena, the way they develop and organise, and the basic principles behind them. Complexity science, interdisciplinary by nature, provides a broader viewpoint and yields insights unavailable by more traditional means. Some prime examples of the applications of complexity science were given in the presentations at the workshop, the links to which are found in Appendix 1 (Keynote Speakers).

Major areas of complexity science, which have provided results of high relevance for the European society include:

Complex social and infrastructural networks, including the dynamical structure of such networks, how they are formed, their characteristic features, and the challenges of governance, damage control and self-organisation. Complexity science provides new ways of assessing risks for political or economic instability, and new models imitating interactions among humans leading to conflicts, war and recession, or conversely to peaceful, constructive relations and economic growth. Also, in business, the importance of loyal employees and customers are known to be crucial. Regarding the infrastructures, the breakdown of these, from sudden loss of communication, electricity or water to traffic jams and delayed delivery of health care may all be consequences of a lack of understanding of network dynamics.

Biological complexity, including a multitude of complex systems on very different time and space scales, from biological evolution and the spread of infectious diseases at global scale to studies of brain function and gene expression at micro scales. Inspired by biology and physiological functions (brain, kidneys etc.) complexity science may even help in designing and constructing entirely new materials with desired emergent behaviour and maybe devices that respond and adapt to our needs.

Environmental complexity, regarding dynamical structures emerging in systems relevant for a better understanding of weather and climate changes, including fluid motion and pollution dynamics, of relevance for predicting the impacts of human activities on ecological systems, or of relevance for a better understanding of biomaterial in the ocean. This area also includes studies of natural disasters like earthquakes, hurricanes and forest fires threatening the sustainability of our world.

Complex control and optimisation processes, regarding nonlinear and adaptive control and optimisation methods that can improve processes and the use of resources, save energy and raw materials and reduce pollution, and at the same time improve yield and quality in industrial production. In economy, complex optimisation methods are applied in finding profitable investments and improving risk control based on a dynamical analysis of technical indices.

It should be noted that complexity is the central theme of some of the most recent and innovative developments in the fields of non-linear science and statistical mechanics, even if the research is not always recognised as ‘complexity science’. Furthermore it is important to remember that complexity is a fundamental science in its own right. It contributes to our understanding of nature, in the same way as other disciplines and should therefore not just be considered as a ‘tool box ‘.

3. Research Landscape in Europe for Complexity Science

3.1 SWOT analysis

A detailed list of strengths, weaknesses, opportunities and threats relating to complexity science, as generated by the workshop participants:

<table>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>

There is a strong diverse academic background on which to build complexity science
People are keen to collaborate on interdisciplinary research and research groups are networking to share and develop ideas
Excellent, creative, highly productive academics are getting involved in complexity science
The subject appeals to young people and therefore there is strong potential to grow the community
Complexity science really has the potential to impact on society, business and industry by providing new ways of looking at longstanding problems including real world challenges.
There is already active interest in complexity science from several sectors: for example, defence, IT and communications, environment and health. These should provide excellent success stories of where complexity science has made an impact
National funding agencies are trying to coordinate efforts across Europe

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Due to the interdisciplinary nature of complexity science, the community is quite loose and fragmented with often poor communication between the disciplines. This prevents a critical mass of activity being generated
In particular there are issues with social scientists and natural scientists not working together and sharing expertise. A specific example being that natural scientists do not always understand the nature of observation and measurement in social systems.
It is hard to provide a specific definition for complexity science and the concept of complexity is often misused
Academics are often tempted to stay within the comfort of their own discipline, rather than ‘stepping into the unknown’ to explore where other disciplines can add value. Discipline oriented funding systems exacerbate the problem, as do conservative peer review systems.
The national subdivision in Europe makes it difficult to initiate and develop new research areas
There is a lack of access to real data to work with
There is a lack of complexity science education and training programmes
There is a lack of public, political and industrial awareness of the benefits of complexity science
Communication technologies are not being used effectively
Women are poorly represented in complexity science

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Opportunities	**Threats**
• Promote complexity science by identifying case studies of where complexity science has been successful in making an impact • Increase cooperation between different disciplines, particularly between social and natural sciences, nationally and internationally • Better training in complexity science, including maths training for social scientists • Provide focus for research in complexity science by addressing real world challenges such as energy, traffic, finance, environment and stable critical infrastructure • Use ICT capabilities • Engage with industry and business more effectively • Attract the best researchers to work in complexity science • Use social sciences as a source of new and data rich problems	• Lack of sufficiently trained people (particularly in relation to maths training) and failure to attract good students and researchers • Lack of collaboration between social and natural scientists and a poorly networked Complexity science community will limit the impact that can be made • Lack of risk taking by funders and peer review and therefore no incentive to work in complexity science • Negative external perceptions of complexity science and a lack of recognition from industry, funders and the academic community • Complexity science being seen as a 'tool box' for other disciplines • A risk of wasting time on defining 'What is complexity science', overselling the concept and failing to deliver, resulting in enthusiasm for the subject disappearing • Failing to engage with industry, business, other disciplines and real world challenges • Over-generalising and making complexity science too narrow, lacking depth, or failing to engage with details and specifics

3.2 The challenges facing Complexity Science in Europe

The representatives for each country at the workshop were asked to select which of the challenges and issues relating to complexity science were of greatest interest to their country. The priorities are summarised as follows, with the number in parentheses relating to the number of votes received:

[1] Working together – across national borders, discipline borders, and the academic/user interface – towards delivery (30)

[2] Education and Training (25)

[3] Real world and Big Science problems – defining the problems where complexity science can play a role (24)

[4] Promotion and Recognition of Complexity Science- including external perceptions/ visibility/ enthusiasm (15)

[5] Focus – defining complexity science and what it can do (8)

[6] Funding councils, funding processes and incentives (5)

The priorities for each country were as follows:

Country	Priorities
Belgium	2, 3
Bulgaria	1, 2, 3
Denmark	2, 3, 4, 5
Estonia	1, 2
France	1, 2, 4
Greece	2, 3
Hungary	1, 3, 6
Ireland	1, 3, 5
Italy	1, 2, 3, 4
Netherlands	1, 3, 4
Portugal	1, 2, 3
Romania	2, 4
Spain	2, 3
UK	1, 2, 3
Europe (ESF)	1, 3

The highest priority is to increase the cooperation between disciplines. Many workshop attendees commented on the difficulty of bridging the gap between disciplines, especially between social and natural sciences, which arises, at least in part, from social scientists feeling their independence is threatened by the ‘mathematization’ of their subject. There is also often a lack of recognition for cross-disciplinary research from funding bodies, research institutions and academic peers. However, this academic fragmentation needs to be overcome, since it is felt that cross-disciplinary collaboration will provide the strongest opportunities for making an impact in complexity science. Furthermore, it will be important to encourage excellent, internationally leading scientists – including women – to become involved in complexity. France and the UK felt that it was important to look beyond Europe to India, China and the United States in order to ensure that the very best people were involved.

Another priority is to use complexity science to address, describe and solve ‘real world’ and ‘big science’ problems. Particular areas of interest include energy, traffic, finance, environment and stable critical infrastructure. To this end, the number of trained people needs to increase and complexity science must be promoted so that its importance is recognised by industry, funding bodies and other academics. Interaction with industry, business and the public sector needs to be raised to ensure students have greater opportunities, and good case studies of real world issues must be provided to attract high quality students and to convince government of the importance of complexity science. Furthermore, complexity scientists need to collaborate with policy makers, industrialists and other users, to gain better access to real data, which will strengthen their research and really prove how a complexity approach can be beneficial.

Keynote speakers at the workshop emphasised the necessity for complexity scientists to demonstrate and communicate the value of complexity science, in particular in regards to real world issues. Several countries feel it is important to publicise case studies to enable complexity's ability to address issues that cannot be addressed by other research disciplines to be recognised. Complexity science can deliver on a practical basis, and the benefits should be promoted to industry, thereby raising the visibility of complexity science. At the same time, it was pointed out that complexity science still needs to prove itself, and it shouldn't be over-hyped, without strong examples available to back up claims of making an impact. However, better promotion requires the complexity science community to first be strengthened by improving communication between scientists across borders and with industry through the formation of new networks and new educational frameworks.

The general consensus was that a lot of work has already been done on trying to define complexity science and that there would be little value in spending more time and effort developing a more precise definition than is already stated in section 2.1.

A major concern for many countries is the lack of risk taken by funding bodies and peer review when assessing proposals that do not sit squarely within a traditional research discipline. It was recognised that it was beyond the control of Complexity-NET to influence the way funding bodies worked, other than for the representatives of the funding bodies involved in the network to take back messages that less conservatism in awarding multidisciplinary research and high risk research grants should be encouraged. However, these concerns need to be thought about when developing any common activities, particularly when considering the peer review process.

3.2.1 Some specific 'real world' problems that complexity science could help to address

Complexity Science can potentially help with so many 'real world' problems that it will be necessary to focus efforts in a particular direction to ensure that a measurable impact is possible. There is a risk that by being too broad and all-encompassing in the complexity science research supported, the overall impact in any one area will be too small and complexity science will be seen as failing to deliver results.

An initial (but incomplete) set of suggestions for areas which could benefit from a complexity approach include:

- Water management. The transition of shallow lakes in The Netherlands from clear to turbid and the failure of water management policies to reverse this transition is a good example of the failure of policies due to not applying complexity theory
- Spread of infections. What are the appropriate strategies to limit them? This is not just limited to biological diseases, but could also include computer viruses and the spread of political/religious views
- "Imitation". Attitudes to smoking, obesity, littering, formation and spread of prejudices
- "Trust". Including financial credit and investment, trust in government, trust in peer to peer networks
- What is the impact of an extreme event (e.g. bird flu, forest fires, flooding, financial crashes) on critical infrastructures (power grid, transport network, health system, economy, IT and telecommunication networks)
- The role of regulation
- The impact of long lasting or permanently high oil prices

- The use of alternative energies to fossil fuels
- Complex social systems
- Complex economic systems
- Issues relating to the brain, mind and consciousness
- Organisms and ecosystems

4. Conclusions and next steps

4.1 Conclusions

The discussions and outputs of the Budapest meeting lead to the following major conclusions:

1. Complexity Science research is of high relevance for industry and society and also has an important role to play in policy making.
2. However, the impact complexity science currently has on society is limited and therefore must be substantially improved.
3. Improving impact requires more research and training across traditional scientific disciplines and more contact with industry and the public service sector is also needed.

4.2 Next Steps

There are two basic directions suggested:

1. “The challenge driven approach”: This approach is about improving the impact of complexity through the formation of stronger networks involving complexity scientists from a variety of discipline backgrounds and representatives from industry, business, the public service sector and other users of complexity science. A two way flow of communication is needed so that users can articulate “real world” problems and complexity scientists can demonstrate how they can help solve them.
2. “The investigator driven approach”: This approach is about providing a strong complexity science research base across Europe by encouraging scientists from different disciplines to work together and to teach complexity science to the next generation of researchers. Mechanisms are required to facilitate interdisciplinary working, to enable (a) fundamental scientific questions across traditional scientific disciplines to be addressed and (b) complexity science methods with potential relevance for society to be taught and developed. Whilst the approach is about strengthening the core research base, there should still be an emphasis on supporting research and training that tackles issues that have a societal or economic impact, to show the added value of using complexity science.

Both approaches will be necessary and there should be a reciprocal relationship between them, such that the problem driven approach should inspire advances in fundamental complexity science research and the investigator driven approach should generate research which is of use to industry and policy makers. The question is in what order the approaches should be implemented. This may depend on the country, but many countries involved in the workshop suggested that the “investigator driven” scenario is unlikely to be funded without the “challenge driven” scenario - simply because the funding partly has to come from industry.

Therefore the major strategic conclusion seems to be to first develop the “challenge driven” approach, to help the complexity science community to become sufficiently networked and shaped to then successfully implement the “investigator driven” approach.

The “challenge driven” scenario can be implemented by funding networking activities involving complexity scientists across all disciplines, industry, business and the public service sector. This will encourage complexity researchers to cross barriers towards industrial collaborations. It is important not to immediately expect research projects to come out of the networking activities, but rather allow time to enable the partners to get to know and understand each other.

Complexity-NET should really be able to make an impact in Europe using this approach.

Networking activities will be crucial and can take many forms, for example: workshops (specifically those involving researchers across many disciplines and also users of complexity research including industry and business), brokering, “science dating”, career visits, summer schools, news letters, project offices etc., all helping in building real collaborations and strengthen links.

It will be important that the networks are as inclusive as possible, attracting academics from **all** relevant disciplines and users from **all** relevant industry sectors, both private and public. New complexity networks should be encouraged to make the most of the many initiatives already implemented by Complexity-NET as well as by others. Although the envisaged network activities do not include research projects or a full Ph.D. education, effective networks still require substantial funding.

Complexity-NET could add significant value to the current European complexity research landscape by facilitating the collaboration between existing networks and centres for complexity. This may be a very cost effective approach in that establishing new networks will require a large amount of funding, whereas establishing a formal way for these centres and networks to communicate together will require less funding but will have greater impact.

In terms of instruments, the “investigator driven” scenario would provide initial funding for research projects and Ph.D. schools that are interdisciplinary and address problems of relevance for society. In order for these mechanisms to be successful, some preliminary work needs to be done on agreeing what the focus of the training and research should be, as this is still unclear. Complexity-NET can help by holding workshops to ascertain what the focus should be, followed by calls for funding.

It was noted that Complexity Science proposals tend to get lost in calls for cross-disciplinary research or complexity-related research. Therefore in order to make an impact, funding must be solely for complexity research, so that it is recognised. To reflect this, the calls must be themed to be multidisciplinary and to cover specific research challenges. The emphasis should be on supporting projects which enable the translation of techniques and abilities across different disciplines.

In short, the proposed action for Complexity-NET is:
(1) Support multi-disciplinary workshops and/or networks with users as a preparatory basis for further activity, to gather different disciplines together with user input and to understand real world challenges.
(2) Encourage better organisation between existing complexity institutes and networks, strengthening what is already being done in complexity across Europe.
(3) Add value by having calls specifically in complexity science rather than relying on complexity science being supported by existing calls with non-complexity titles. The calls should be themed, relating to real world challenges and/or investigator driven activities

In addition to the above approaches, it is important that the examples where complexity science has already made an impact should be made generally available to highlight the importance of the subject. Complexity-NET can play an important role in disseminating such complexity science success stories.

Appendix 1: Budapest workshop

Participants

Pierre Gaspard, Belgium		Luca Pitolli, Italy	
Gregoire Nicolis, Belgium		Lex Zandee, Netherlands	
Nikolay Vitanov, Bulgaria		Marieke van Duin, Netherlands	
Preben Alstrøm, Denmark		Arjen Doelman, Netherlands	
Jens Juul Rasmussen, Denmark		Devaraj van der Meer, Netherlands	
Erik Mosekilde, Denmark		Anders Malthe-Sørensen, Norway	
Juri Engelbrecht, Estonia		Jens Feder, Norway	
Leo Mõtus, Estonia		Margarida Telo da Gama, Portugal	
Paul Bourgine, France		Rui Dilão, Portugal	
Jürgen Kurths, Germany		Jorge Louçã, Portugal	
Tassos Bountis, Greece		Ioan Dumitrache, Romania	
Nikos Sidiropoulos, Greece		Carmen Costea, Romania	
Astero Provata, Greece		Miguel Rubi, Spain	
George Vlahos, Greece		Raúl Toral, Spain	
Imre Kondor, Hungary		Annette Bramley, UK	
Tamás Vicsek, Hungary		Robin Ball, UK	
Zénó Farkas, Hungary		Caroline Batchelor, UK	
Éva Gönczi, Hungary		Katharine Bowes, UK	
Dávid Pap, Hungary		Barbara Richardson, UK	
Heather Ruskin, Ireland		Steve Lansing, Santa Fe Institute, US	
John Denari, Ireland		Jeff Johnson, ECCS/ONCE-CS	ONCE-CS
Antonio Politi, Italy		Diana Mangalagiu, GIACS	
Giulia Loguercio, Italy		Eva Hoogland, ESF	

A1.1 Presentations: Keynote speakers

This section provides links to presentations on some of the important issues and intriguing results from complexity research by the following 12 keynote speakers at the Budapest workshop:

Tamás Vicsek, Eötvös Loránd University (ELTE), Hungary: *'From "snapshots" to evolution'*; link *to presentation*

Steve Lansing, Santa Fe Institute, USA: *'Water Networks in Bali'*. link to webpage

Peter Grindrod, University of Reading, UK:*'The Impact of Complexity Analysis'* (video presentation); *link to presentation and link to manuscript*

Tassos Bountis, University of Patras, Greece: *'Complexity - a new science or a new direction in science?'*; link *to presentation*

Gregoire Nicolis, Université Libre de Bruxelles, Belgium: *'Complex Systems Research'*; link *to presentation*

Erik Mosekilde, Technical University of Denmark, Denmark: *'Complex Phenomena in Biomedical Systems'*; link *to presentation*

Miguel Rubi, University of Barcelona, Spain: *'Complexity in Marine Ecosystems'*; link *to presentation*

Jürgen Kurths, University of Potsdam, Germany: *'Sychronization in Complex Systems'*; link to presentation

Paul Bourgine, École Polytechnique, France: *'Towards a Complex Systems Science'*; link to presentation

Antonio Politi, CNR-Istituto Dei Sistemi Complessi, Italy: *'Complex Systems'*; link to presentation

Devaraj van der Meer, University of Twente, Netherlands: *'The effect of air on fine granular matter'*; link to presentation

Anders Malthe-Sørensen, University of Oslo, Norway: *'How are complex patterns of the Earth formed?'*; link to presentation

A1.2 Presentations: Coordinated activities

This section provides links to presentations on coordinated activities relevant for complexity science, by the following 5 speakers at the Budapest workshop:

Jeff Johnson, ECCS/ONCE-CS: *'Shaping the Community for Complex Systems Science and Policy'*; link to presentation

Diana Mangalagiu, GIACS: *'General Integration of the Applications of Complexity in Science - NEST coordination action'*; link to presentation

Eva Hoogland, ESF: *'European Science Foundation – 30 years experience in trans-national collaboration'*; link to presentation

Caroline Batchelor, UK: *'The Complexity-NET ERA-NET'*; link to presentation

Nikos Sidiropoulos, Greece: *'The SEE-ERA-NET'*; link to presentation