MMCOMNET

Measuring and Modelling Complex Networks across Domains

Project of NEST Action in 6th EU Framework Programme

WORKSHOP BOOKLET

4th MMCOMNET WORKSHOP

FACULTY OF PHYSICS

WARSAW UNIVERSITY OF TECHNOLOGY, 14-17 APRIL 2007

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I. Project description

What is MMCOMNET?

The MMCOMNET project, that is part of the sixth EU Framework Programme, unites research teams from different countries and various scientific backgrounds in order to share their respective areas of expertise and to promote scientific collaborations through Europe.

The project has set out to measure and model complex networks from different domains, with the goal of understanding their structure, function and behaviour. The multidisciplinary consortium forms part of the NEST PATHFINDER initiative on ‘Tackling complexity in science’. This aims to encourage the study of complex systems and the transfer of knowledge between different disciplines.

The participating groups are:
• University of Oxford, **Coordinator**
• Germany: Technische Universität Dresden
• Poland: Warsaw University of Technology
• France: INSEAD Business School
• Switzerland: Swiss Federal Institute of Technolog, Zürich
• Sweden: Stockholm University

Project Abstract

The overall aim of this Specific Targeted Research Project is to develop a unified and cross-disciplinary understanding of the dynamic behaviour and functional properties of complex networks in different domains of application within the biological, social, and engineering sciences. Three domains have been selected on the basis of their abilities to be subject to the collection of systematic data that may be analyzed to reveal the structure, function and dynamics of the system: fungal growth, supermarket supply chains and the clustering of companies.

The three types of system consist of multiple interconnected layers, comprising autonomous agents which allocate resources within the network. Agents distribute resources on the basis of incomplete or noisy information. They typically act without a central control mechanism. The characteristic behaviour of networks emerges through the interactions of agents. Agents may be cells, people or companies in the case of biological, socio-economic and business networks, respectively.

The project exploits advances in complexity science to elucidate the individual and collective behaviour of agents. The participants are developing models which simulate the different combinations of agents and network dynamics that can account for desirable behaviour. Criteria for choosing between alternative combinations provide insights into how agents and networks adapt, and the trade-offs that occur between different network functions. In the case of the supply-chain model, for example, the conditions that enable networks to retain their integrity in the face of local disruptions are being investigated.

Project Objectives

The MMCOMNET project aims to develop unified tools for the empirical characterisation and modelling of complex network structures in different application domains and disciplines. The focus of the research is on the functional and dynamic properties of networks, and how they relate to the observed network structure and the characteristics of the agents which are linked in the network. The application domains under consideration span the biological, engineering and social sciences, and the particular systems that the research focuses on are fungal networks, supply networks, transport networks and innovation networks.

The four project objectives identified below should provide solutions to these research questions.

The first project objective for MMCOMNET is to develop novel statistical measures that can be deployed in different application domains, thus enabling a meaningful comparison of the functional and dynamic properties of biological, social and engineered networks. This project objective will develop a common language and a shared toolset for interdisciplinary research on complex and dynamic networks. The statistical measures developed will be tested on real data sets, in particular the Stockholm data with regard to social and socio-economic networks, and the laboratory data on growth for fungal mycelia, and can also guide the work on network models which is addressed in the second project objective. The key milestones for achieving the first objective are:

- Initial development of statistical measures and summary statistics, including trial software code (month 12, WP6).
- Testing statistical tools against Stockholm and fungal mycelia data (month 24, WP6).
- Statistics of public transport networks in Polish cities (month 24, WP5).
- Delivery of software package incorporating statistical tools (month 36, WP6).

The second project objective seeks to advance both approaches to modelling in parallel with respect to the real-world network systems which serve as paradigms in the different application domains (i.e. fungal networks, supply networks, transport networks, innovation networks). The novel statistical measures developed as part of the first project objective can help establish goodness of fit between different models and empirical measurements. The key challenge of this objective is to explore and integrate the differences between the traditional top-down, partial differential equation (PDE) -based approach, and the bottom-up, agent-based approach, and to explore how hybrid models might be constructed and validated. Participating researchers from the collaborating organisations will contribute their existing expertise on the assessment of the complexity of the performance of individual nodes, the structure of the network and the global behaviour of the network. The key milestones for achieving this second objective are:

- Test agent-based models and PDE models against the experimental results for fungal mycelia (month 12, WP1).
- Develop PDE models of the supply network (month 12, WP3).
- Develop models of diffusion on innovation networks (month 18, WP4)
- Directly compare agent-based and PDE models of fungal mycelia to determine the feasibility of a hybrid model approach (month 24, WP1).
- Models of critical properties of networks (month 36, WP5).

The third project objective is the reverse problem: deducing agent properties and network dynamics from the global behaviour of network systems.

The development and empirical validation of novel statistical measures and summary statistics under the first project objective, and the development of PDE and agent-based models for specific systems under the second project objective, will provide a foundation for developing frameworks and techniques which allow potential models to be inferred systematically from empirical data sets, such as those obtained in the different MMCOMNET application domains (e.g. fungal networks, supply networks, transport networks, innovation networks). These models will be tested through simulation, although it must of course be recognised this is an under-constrained problem and that there are likely to be many possible candidate models for any empirically observed network system. Hence cross-disciplinary collaboration will be required to develop general methodologies and criteria for identifying plausible or mechanism-based explanations of observed behaviour, and new methods for choosing the most efficient models and descriptions. The measures of local, structural and global behaviour derived in the context of the first two project objectives will influence how this objective is pursued, and similarly the findings reached as part of the third project objective will redefine how the first two project objectives are approached.

The key milestones for achieving this third objective are:

- Models of the decision-making behaviour of agents in supply networks (month 18, WP2).
- Simulations of supply networks that display some aspects of observed behaviour, including software documentation. (month 36, WP2).
- Develop an experimentally supported multi-scale model of fungal growth and nutrient transport (month 36, WP1).
- Generative model for innovation networks in high-tech clusters (month 36, WP4).

The above project objectives enable the development of techniques which allow existing networks in different application domains to be characterised and modelled. As part of **the fourth project objective** this logic is now reversed, and in the forward problem we consider how strategies which allow specific networks in certain application domains to perform well against certain performance metrics (i.e. robustness, responsiveness, etc.) can be transferred to other contexts so that the desirable properties are preserved in the designed network. The successful identification of such design principles would make it possible to construct complex network systems which exhibit the desired characteristics of improved robustness, persistence, efficiency etc. Some potential application domains for this approach include engineered and IT networks, organisational networks, socio-economic networks such as high-tech innovation clusters, and socio-technical systems such as transport networks and supply chains. This approach, based on the transfer of specific functional network characteristics from one application domain to another, offers the prospect of designing networks with characteristics that cannot simply be reduced to a narrow conception of "optimality." By adjusting the local decision-making behaviour of agents or introducing new types of agents, for example, we may be able to achieve stability in supply networks, resistance to attack or node/link failure in computer networks, or more effective dissemination of innovation in business networks. The deliverables of this objective will be based on the simulation of networks with characteristics that are considered desirable, and the validation of these simulations against real world networks, with pilot application of these techniques to real world networks. Since this objective is contingent on success in all three previous project objectives, the corresponding deliverables at the end of the project lifetime will necessarily be more speculative and preliminary.

AGENDA
All lectures are held in Physics Building (Gmach Fizyki), Warsaw University of Technology (Politechnika Warszawska), address: ul. Koszykowa 75

Saturday 14th lecture hall 309
9:30 welcoming café
9:45 Opening by Janusz Hołyst and Felix Reed-Tsochas
Presentation of recent results by Project Partners, coffee break included
10:00 - 13:00 Oxford:
Mark Fricker, *Agent-based modeling of fungal network*
Serguei Saavedra Sanchez, *Consumer-resource interactions: From food webs to supply networks*
Gesine Reinert, *Progress report on Work Package 6*
Francois Collet, *Weighted graphs: tie formation, node growth and node exit.*
Sean Gourley,
13-14.30 lunch
Presentation of recent results by Project Partners, coffee break included
14:30 - 16:15 Zurich:
Markus Geipel, *Industry organization and efficiency*,
Stefano Batiston, *When are Networks too Dense? The Trade-off between Diversification and Contagion.*
Markus Geipel, *A tool for visualization of dynamic networks*
17:15 social event – Warsaw sightseeing by bus with a guide, dinner in Warsaw Old Town (Kompania Piwna, Podwale 25 str.) The bus will be waiting at the entrance to the building of Faculty of Physics.

Sunday 15th lecture hall 309
9:30- welcoming café
Presentation of recent results by Project Partners, coffee break included
10:00- 11:00 Dresden:
Dirk Helbing, *Self-Organized Network Flows*
11:00- 12:00 Warsaw:
Julian Sienkiewicz, *Log-periodic oscillations due to discrete effects in complex networks*
Janusz Holyst, *Predicting a winner in network-network competition*
12:00- 13:00 brainstorms on received results and project objectives, coffee break included
13-14.30 lunch
14:30 - 16:00 brainstorms on received results and project objectives, coffee break included
16:00 - 17:30 Meeting of the MMCOMNET Management Committee
19:00 social event – Ballet performance in Grand Theatre (Teatr Wielki, Plac Teatralny 1), dinner

Monday 16th lecture hall 111
9:30- welcoming café
10:00 - 13.00 Parallel meetings of various subgroups, part 1, coffee break included
13-14.30 lunch
14:30 - 16.00 Parallel meetings of various subgroups, part 2, coffee break included
16.15 - 17.30 Open MMCOMNET lecture
Felix Reed-Tsochas, *The Dynamics of Decline and Collapse in a Complex Network of Firms*

Tuesday 17th lecture hall 128
9:30- Meeting with Prof. Rajmund Bacewicz, Dean of Physics Department
10:00 - 12.30 Fixing project tasks for the next project period, coffee break included
12:30- 13:00 closing the workshop; **13:00-** ... departures

Workshop Participants

Felix Reed-Tsochas (MMCOMNET Coordinator) is Senior Research Fellow in Complex Systems, University of Oxford. His current research uses agent-based models as a tool which can provide a better understanding of how organisational behaviour in populations or networks can evolve. At present he is particularly interested in modelling some of the dynamic processes which drive changes in populations of organisational strategies.

François Collet is a final year doctoral student at the Said Business School, University of Oxford. His current research is on organizational status, inter-organizational alliances, the links between inter-personal networks and technology and statistical methods for the analysis of complex networks. Post-Doctoral Research Fellow Nuffield College University of Oxford

Serguei Saavedra Sanchez is a Doctoral Candidate, Department of Engineering Science, University of Oxford. He is focused on the study of supply chain models applying different techniques such as Information Theory, Network Analysis, Q-analysis and agent-oriented simulation in order to establish measures that guide us to understand the performance of different supply networks.

Mark Fricker is an University Lecturer in Plant Science Tutorial Fellow, Pembroke College, Oxford. His research area is imaging signalling and transport in intact plant and fungal systems operating in their correct tissue context.

Gesine Reinert is a Professor at the Department of Statistics, Oxford University and also a Fellow at Keble college, oxford. Her research interests include statistics on networks, approximations in Statistics, Stein's Method and Applications, and more generally Applied Probability and Computational Biology. She is focused on proving and improving on parametric inequalities.

Sean Gourley is a researcher from Oxford University, Department of Physics. Recently he has been focused on flaws in the survey of Iraqi deaths published in the *Lancet.*

Dirk Helbing is a Professor at the Technische Universität Dresden, Institute for Transport and Economics. Research Interests involve Analysis, Modelling, Simulation, and Optimization of Active Multi-Component Systems. He focuses on the traffic flows and phenomena occurring in them.

Stefano Battiston is a Professor at the Eidgenössische Technische Hochschule Zürich, Department Management, Technology and Economics. He has a Physics background (Laurea Thesis in SISSA Trieste, Italy, and a PhD in Physics from Paris VII). He joined the scientific community of Complex Networks in 2001. This recent and innovative community has applied a number of methods inspired from Statistical Physics and Dynamical Systems to the characterization of real world complex networks. He has focused on the structure and dynamics of networks in socio-economic systems.

Markus Geipel is a PhD student at Eidgenössische Technische Hochschule Zürich, Department Management, Technology and Economics. His research interests are focused on Multiagent Systems, Production Networks and Artificial Intelligence.

Janusz Hołyst is a Professor at Warsaw University of Technology, Faculty of Physics. His research field includes various issues of complex systems such as statistical physics of evolving networks, econophysics and sociophysics. He works also on deterministic chaos, time series analysis and noise level estimation.

Julian Sienkiewicz is a PhD student at Warsaw University of Technology, Faculty of Physics. His research includes investigation of complex network topology. He performed investigation of path lengths in urban transport networks and its dependence on node (stop) parameters.

Krzysztof Suchecki is a PhD student at Warsaw University of Technology, Faculty of Physics. His research interests are focused on Ising model in complex networks and voter model dynamics. His expertise is in Monte Carlo simulations.

Anna Chmiel is a PhD student at Warsaw University of Technology, Faculty of Physics. Her scientific interest is focused on economic complex networks, specially on networks of branches and companies in Poland.

Sebastian Komosa is a MSc student at Warsaw University of Technology, Faculty of Physics. His research contains investigation of Ising model dynamics in hierarchical networks.

Paweł Sieczka is a PhD student at Warsaw University of Technology, Faculty of Physics. He investigates stock market time series in search for time correlations and their patterns.

Krzysztof Urbanowicz is a post-doc researcher at Warsaw University of Technology, Faculty of Physics. His research focuses on the investigation of noise in stock market time series and in portfolio optimalisation.

Ken Bedding holds the position of the Project Administrator. Ken’s last post was on the project management team of the National College for School Leadership (NCSL) Fast Track Teaching programme. Ken’s experience also includes providing project support for the Enterprise and Knowledge Transfer Partnership (KTP) activity of the University of the West of England (UWE Bristol).

Workshop Abstracts

Mark Fricker, *Agent-based modeling of fungal network*

Progress on agent-based modelling of fungal development has led to the development of a Functional Dynamic Network Framework and a Network Automata

In brief, there have been many models of out of equilibrium dynamic networks and their evolution. Often, networks perform a function other than merely sustaining their own topology such as propagation of information or resource. We outline a generic framework that encompasses this property into the evolution of a network. This framework utilises concepts from the well-studied fields of dynamic networks and multi-agent systems. We develop the framework through two pedagogical cases and then demonstrate its versatility through its application to a more interesting biologically inspired system.

Progress on understanding the network properties of the fungal mycelium has focused on (i) exploration of more recent metrics used for planar networks and (ii) the development of appropriate null models to test the behaviour of the network. This has led to a refinement of the conclusions on the network efficiency and robustness, and this work has now been submitted. A review chapter is also in press that covers a discussion of the application of network analysis to fungal mycelia.

The basic description of the oscillatory phase domains is now in press

Serguei Saavedra Sanchez, *Consumer-resource interactions: From food webs to supply networks*

Contemporary research on ecological networks1-3 provides us with an increasingly detailed picture of how the interactions between different species in an ecosystem are structured, and demonstrates that purely local interactions can generate macroscopic patterns of resource (e.g. biomass and energy) flows that are clearly not random. Recent ecological models4-6 have been remarkably successful in reproducing some of the most important properties of real food webs. These models share two ingredients which appear to be central to their success6: (1) an ordered set of species' niche values; (2) an exponentially decaying probability of preying on species with lower niche values. If we now shift our focus to the population dynamics of firms and other organizations, we find that biological models of population ecology have played a key role in defining the field of organizational ecology in the social sciences7. Organizational ecology is concerned with the dynamic evolution of populations of organizations, characterized by macroscopic variables such as population density, where it is assumed that the organizations in a population compete with each other for resources. However, the entirely macroscopic perspective of organizational ecology does not allow the network structure which underlies inter-firm interactions to be taken into account. Here we propose a simple resource-allocation model for firms driven by biological consumption patterns in order to understand the emerging interactions in a distributed supply network. We use simulations based on our stochastic model which we then compare directly with the dynamic buyer-seller network of the renowned New York garment industry, and find that the model is remarkably successful in replicating important global and modular properties of the empirical network over a total period of 19 years (Fig. 1). We found that three conditions account for the model's ability to reproduce the empirically observed behavior: (1) buyers are assigned a maximum number of sellers to deal with which form a totally ordered set; (2) buyers have an exponentially decaying probability of actually dealing with their maximum number of sellers; (3) buyers have an approximately exponential probability of finding different sellers from an unranked set of firms. In addition, we found further evidence that the emergence of third-party collaborative structures for joint production in the network is in fact a consequence of the special constraints under which the network evolve8. We believe that the unexpected correspondence between organizational and biological consumption patterns may open new directions to explore better resource allocation and adaptive mechanisms in supply and ecological networks.

Gesine Reinert, *Statistical Network Metrics: Progress Report*

We address the key questions of how to compare networks, using network metrics. Both a social network data set from Stockholm and a data set on protein interaction networks are studied.
Exploratory data analysis leads to some implicit network metrics. While different research questions will require different metrics, these metrics still have a fairly general range of applicability.
We also give a brief overview on progress concerning theoretical results for network statistics.

Francois Collet, *Weighted graphs: tie formation, node growth and node exit*

We consider a directed graph. In this graph the weight of an arc joining two nodes is inversely proportional to the amount of information circulating between these nodes. We calculate the shortest path between two nodes on and use this measure as a predictor for the formation of new ties controlling for many other factors. Second we use this weighted graph to examine the growth and exit of nodes. These tools are applied to research on social networks and labor markets and entrepreneurship.

Markus Geipel, *Industry organization and efficiency*

We investigate the effects of industrial organization for industry efficiency. The latter aspect is measured by a variety of welfare-related indicators including average and top product quality as well as product differentiation. The model takes the complexity and modularity of the production process as the independent variable. By comparing the performance of integrated versus integrated modes of industry organization, it sheds light on the conditions under which (dis)integration pays. In line with conventional wisdom, (nearly) modular production processes befit disintegrated organizational forms while very interdependent ones call for greater integration. However, disintegration in itself is not guaranteed to lead to greater product differentiation unless competition and selection are introduced. A brief case study supporting the findings of the model is also provided.

Stefano Batiston, *When are Networks too Dense? The Trade-off between Diversification and Contagion*

We investigate the role of links density in a network of firms tied by supply-customer relationships. Firm-firm links are seen in the literature primarily as a means to diversify risk. While links are channels for financial contagion they also dilute the financial damage, thus improving the stability of the economy. What has not been emphasized so far, is that synchronization may have devastating effects: if many firms get simultaneously close to their default threshold, the default of one single firm can trigger a major avalanche of defaults. Therefore, we introduce a model in which both the risk diversification and the synchronizing effect of links are taken into account. Under these assumptions, firms are always better off by increasing their number of links, but the economy as a whole gain in stability only if the network is not too dense. In fact, at high density the network tends to synchronize and large avalanches may occur. Therefore, at the global level, we find a trade-off between benefit and cost of connectivity.

Markus Geipel, *A tool for visualization of dynamic networks*

Networks and their structure have become a major field of research: The interest in networks spans disciplines such diverse as sociology, physics, mathematics, economics and biology. Along with this interest goes the need to visualize these networks. One major class of layouters is formed by variations of the spring layout presented by Eades in 1984. Despite its obvious success, it has shortcomings when it comes to visualizing highly heterogeneous networks or visualizing dynamically changing networks. Still, this class of layouters remains very promising as their design space is as yet vastly unexplored. More radical variation or the original theme should be considered. We address this challenge by formalizing the spring layout in its most general from, thus opening up the design space. Drawing from the knowledge of systems design, we then derive a new layout algorithm from these equations. An algorithm, that relies on the balancing of two antagonistic forces. An algorithm, as we claim, particularly suited for dynamic network layout and complex systems research. We back this claim with several application examples from on going complex systems research.

Dirk Helbing, *Self-Organized Network Flows*

A model for traffic flow in street networks or material flows in supply networks is presented, that takes into account the conservation of cars or materials and other significant features of traffic flows such as jam formation, spillovers, and load-dependent transportation times. Furthermore, conflicts or coordination problems of intersecting or merging flows are considered as well. Making assumptions regarding the permeability of the intersection as a function of the conflicting flows and the queue lengths, we find self-organized oscillations in the flows similar to the operation of traffic lights.

Julian Sienkiewicz, ***Log-periodic oscillations due to discrete effects in complex networks***

We show how discretization of distances affects two major characteristics in complex networks: internode distances (measured as the shortest number of edges between network sites) and average path length. Direct effects of such discretization are log-periodic oscillations of above quantities. The effect occurs both in numerical network models as well as in such real systems as co-authorship, language, food and public transport networks. Analytical description of these oscillations based on the properties of the hidden variables in complex networks fits well numerical simulations. We consider a simple case of network optimization problem, arguing that discrete effects lead to a nontrivial solution that can be important for real-world systems.

Janusz Hołyst, ***Predicting a winner in network-network competition***

A model of two competing social groups will be presented. The system will be simulated by a pair of weakly coupled Barabasi-Albert networks with Ising-like interactions describing opinion dynamics and its dynamics will be illustrated by on-line computer simulations. If at the beginning both group are isolated and their members possess opposite opinions then due to internetwork interactions a sudden change of opinions in the weaker group can be observed. The winning group can be larger, can possess a denser/stronger structure of intragroup relations or can be supported by external factors holding up the winning opinion and affecting a few most connected nodes. The winner can be predicted by observing fluctuation amplitudes of average opinions in both networks.

Felix Reed-Tsochas, ***The Dynamics of Decline and Collapse in a Complex Network of Firms***

The by now very substantial body of literature across disciplines on the dynamics of complex networks has to date restricted itself almost entirely to models of network growth. Growing networks such as the internet clearly play an important role in modern life, but the opposite process of network contraction should not be ignored since it is relevant to many social, economic, and ecological networks. In this talk I will focus on a specific empirical example, the network of firms in the New York Garment Industry over a period of almost 20 years. The New York Garment Industry declined from a vibrant economy with over 3000 production and design firms in the mid 1980s to about 200 firms in 2003. Over this period a dataset of 700,000 transactions allows us to track how the network of relationships between firms evolved as the firm population decreased by an order of magnitude. I will discuss our empirical findings, with a particular focus on the surprising topological robustness that this network exhibits while declining. This robustness depends on a combination of specific deletion and growth mechanisms that we have identified for the network's nodes and links. These mechanisms are incorporated in a general model of network contraction, which is able to replicate our empirical results. The model also provides us with new insights about mechanisms that can promote robustness in declining networks.