NETWORKS

NETWORKS is a project of University of Amsterdam, Eindhoven University of Technology, Leiden University and Center for Mathematics and Computer Science (CWI) and receives funding from OC&W through NWO

THENETWORKCENTER.NL

ANNUAL REPORT 2015

NETWORKS started in the summer of 2014. This is the programme's second yearly report, focusing on events organised and progress achieved in 2015. As introduction to the report, we highlight some of the most important achievements in the following.

In 2014, NETWORKS' first year, much effort was spent on setting up the programme's scientific and organisational structure. Research projects were outlined in detail and we worked hard on recruiting PhD students, postdocs and tenure-track employees. In the second year, attention shifted to the scientific content of the programme. The PhD projects started, typically co-supervised by researchers from different NETWORKS institutes with different scientific backgrounds. In addition, a Training Week was organised for the full NETWORKS team, so as to provide the necessary background knowledge in the two methodological domains of stochastics and algorithmics. Also NETWORKS' scientific advisory board was installed, with Jan van Leeuwen as chair.

At the organisational level, in 2015 the two remaining open tenure-track positions were filled: Jop Briët was appointed at CWI, and Jan-Pieter Dorsman at UvA. We have succeeded in recruiting an extremely gifted group of young researchers, as also witnessed by the NWO-Veni grants that were awarded to Jop Briët and Bart Jansen and the TKI *Wind op Zee* grant received by Stella Kapodistria. The second major hiring effort concerned recruiting temporary staff. As many as 11 PhD students and 3 postdocs were newly appointed in 2015, so that in total 20 PhD students and 6 postdocs have joined NETWORKS since the start of the project in June 2014.

The first results of the interaction between the various group members are emerging. Several multi-disciplinary research projects have been initiated and are gradually developing. Indeed, topics such as quantum random walks and robust optimization have one leg in stochastics and one leg in algorithmics; on both topics a successful workshop was held. Second-year PhD students are expected to do an internship at one of the other participating institutes, which also contributes to the enhancement of the ties between the teams.

Besides performing top-level research in stochastics and algorithmics, an important goal of NETWORKS is to educate talented young researchers and get them acquainted with the basic concepts and tools from both areas. To this end Training Weeks are organised; they are held off-campus, so that they also serve as community-building activities. The first Training Week was held in August 2015. 42 participants attended courses in Computational Geometry and Random Graphs. The interesting lectures, excellent location and social interactions made the week into a resounding success. Evaluations revealed that the week was highly appreciated by all participants.

4 INTRODUCTION

In December 2015 the NetworkPages were launched (www.NetworkPages.nl), presenting research on networks to a broad audience consisting of fellow-researchers, students, high-school pupils and laymen. In 2016, the main focus will be on generating content.

In 2015 the NETWORKS' management team, supported by an external advisor, further shaped the programme's outreach strategy. It was decided to focus on developing teaching material on complex networks for primary schools. In collaboration between *Vierkant voor Wiskunde* and NETWORKS a so-called *Wisschrift* will be set up. Throughout the year, various NETWORKS members gave presentations for general audiences, including the highly visible lectures by Harry Buhrman and Johan van Leeuwaarden for the Universiteit van Nederland. Michel Mandjes and Johan van Leeuwaarden were the guest editors of a special issue of *Nieuw Archief voor Wiskunde* on networks. Michel Mandjes gave a key-note lecture at the Dutch Mathematical Congress (NMC).

The interaction with partners from outside the consortium has been further intensified. A Memorandum of Understanding (MoU) was signed with NETWORKS' Australian counterpart, the ARC Center of Excellence for Mathematical and Statistical Frontiers (ACEMS). At the same time, NETWORKS is exploring the option to set up an MoU with the Statistical Applied Mathematics at Bath (SAMBa) programme of the University of Bath (UK) and the Indian Statistical Institute.

This annual report provides an overview of the NETWORKS activities in 2015. Additional information can be found on our website (www.theNETWORKcenter.nl) and on the NetworkPages. The NETWORKS team is eager to keep you informed about the programme's scientific progress.

Michel Mandjes (Project leader)
Marieke Kranenburg (Project coordinator)


PhD students networks

RESEARCH THEMES

NETWORKS consists of 7 research themes, each covering a number of key questions that zoom in on the challenging mathematical problems underlying complex large-scale networks. Within each of these themes several smaller research projects are distinguished, on which PhD students and postdocs have been appointed.
The themes are chosen in such a way that they focus on a specific aspect of networks, but they are evidently interrelated in many ways.
As mentioned, a priority in our research portfolio concerned the definition of PhD project. Therefore, we emphasize these projects in the research descriptions below.

THEME 1: APPROXIMATE AND EXACT NETWORK METHODS

INTRODUCTION

The design, optimisation, and control of networks leads to a large variety of challenging algorithmic problems. How can we compute a shortest tour that visits all nodes in the network? How can we find a minimum number of nodes in the network that together monitor all links? How can we decide whether two networks have the same structure? Unfortunately, many of these problems are NP-hard: there are no efficient algorithms that solve these problems optimally on all possible instances (unless P=NP). Nevertheless, NP-hard network problems need to be dealt with in practice. One approach is to develop approximation algorithms, which are guaranteed to compute solutions that are very close to an optimal solution. Another approach is to exploit that not all input instances are equally hard: some instances enjoy structural properties that make it possible to compute an optimal solution in an efficient manner; this idea underlies so-called FPT algorithms. In Theme 1 we explore these and other approaches to algorithmic network problems.

RESEARCH TOPICS

- Bart Jansen studied the problem of deciding whether a given host graph *G* contains a given pattern graph *H* as a subgraph. This fundamental problem generalizes many well-known algorithmic network problems. Some of these (finding perfect matchings, for example) are polynomial-time solvable, while others (finding large cliques or Hamiltonion cycles) are NP-hard. Together with Dániel Marx (Hungarian Academy of Sciences), Jansen characterised under which conditions it is possible to develop efficient algorithms for these types of problems.

- Lex Schrijver studied the problem of finding disjoint routes in a network between given source-terminal pairs, a problem arising in routing on VLSI chips and many other applications of multi-commodity flow routing. The general problem is NP-complete, but in certain networks the routes can be found efficiently if one fixes the number of sources and terminals. Schrijver studied a generalisation in which only certain pairs of source-terminal routes must be disjoint, but for other pairs there is no such condition. He proved that the problem can be solved efficiently for the important special case of planar directed networks.

- Viresh Patel started in May 2015 on a tenure-track position at UvA. Patel's research interests include extremal combinatorics, graph theory and algorithms, and probabilistic methods in combinatorics. Together with Ross Kang (RU Nijmegen), Eoin Long (Tel Aviv University) and Guus Regts (UvA), he proved a 30-year old

conjecture in Ramsey theory by Erdös and Pach: they showed that any graph with $C k \log k$ nodes, for a suitable constant C, either has a very dense subgraph of size k (namely where each node is connected to at least half the other nodes) or a very sparse subgraph of size k (where each node is connected to at most half the other nodes).

- Pieter Kleer started as a PhD student at CWI with Guido Schaefer to work on algorithms for toll systems to improve transportation in congested networks. The subject of study is the change in social welfare (e.g., average travel time) of equilibrium flows, in network routing games, as a result of (restricted) perturbed latencies. Players base their strategy (e.g., path through the network) on latencies that are different from the ones measured in the social welfare. The perturbations in the latencies can represent tolls/taxes, as well as risk-averse behaviour (where players take into account an uncertainty margin). Topics of interest are how a system designer should set the tolls in order to improve the social welfare, and how much the social welfare can deteriorate due to risk-aversion.

- Cristobal Guzman was appointed in September 2015 as a postdoc at CWI. One of his projects focuses on the complexity of stochastic optimisation problems in the statistical query (SQ) model. This work establishes optimal SQ algorithms for high-dimensional mean estimation in l_p norms and general convex bodies. These results are applied to improve algorithms in machine learning and differential privacy, among others. A second project is the computation of new upper bounds on the density of translative packings for convex bodies with tetrahedral symmetry. The aim is to improve various upper bounds, e.g. packing tetrahedra, and the methodology is based on sums of squares relaxations of the Cohn-Elkies bound.

- Astrid Pieterse started as PhD student at TU/e in September 2015. She works on the theory of pre-processing algorithms for computationally hard problems together with Bart Jansen and Mark de Berg. The project started by analysing constraint-satisfaction problems. In such a problem, the goal is to find a true/false assignment to a set of variables that satisfies a list of constraints. To speed up the search for a solution, it is useful to pre-process the problem to eliminate redundant constraints. Substantial progress has been made in understanding how such redundant constraints can be found and eliminated efficiently. Based on the types of constraints, which are allowed in a problem formulation, we can give guarantees for the number of constraints that remain after simplification. For several cases, we can also prove that no efficient pre-processing algorithm can exist which reduces the number of constraints even further. These fundamental results have many implications for problems about networks. For example, the 3-colouring problem for networks can be naturally formulated as a constraint satisfaction problem, and analysed using our results.

THEME 2: SPATIAL NETWORKS

INTRODUCTION

In many applications the networks under consideration are *geometric networks*, i.e., every node has a location in some geometric space and the edges are represented by connections between the nodes. An example is a railway network, where nodes correspond to stations and edges to railway

tracks. Another example is a large molecule, where nodes correspond to atoms and edges to chemical bonds. In many real-world networks the geometry is an important feature that is hard to treat mathematically. Typically, connections between nearby nodes are more abundant than connections between distant nodes, yet long-range connections play a crucial role in the *small-world behaviour* these networks exhibit, i.e., all vertices are connected via short connecting chains. In addition, a high variability in the degrees of the nodes is observed. A key spatial stochastic model is percolation, while a well-known algorithmic problem where geometry plays an important role is the Euclidean travelling salesman problem.

RESEARCH TOPICS

- Alexander Markovic, together with Mark de Berg and Gerhard Woeginger, is working on so-called conflict-free colourings, which can be used to model frequency assignments in wireless networks. The goal is to assign frequencies to antennas in such a way that wherever a user is located, she can always communicate without interference through at least one of the nearby antennas. Traditional methods compute such a conflict-free colouring in a static setting. Markovic considers a dynamic setting where antennas may be added to or removed from the environment.

- In September 2015, Sándor Kisfaludi-Bak joined the TU/e as a PhD student, supervised by Mark de Berg and Hans Bodlaender. He will be working on FPT algorithms for sensor networks. In such networks, the energy consumption of the nodes determines their transmission range and thus the connectivity of the network. The goal is to obtain good connectivity while minimizing the total energy consumption. Kisfaludi-Bak will investigate the parameterised complexity of the resulting optimisation problems.

- Lorenzo Federico, supervised by Remco van der Hofstad and Frank den Hollander, continued his investigation of the scaling behaviour of critical percolation on the Hamming graph. The Hamming graph is the Cartesian product of d complete graphs. Substantial progress was made towards the understanding of the cycle structure of the critical components, which is quite different from that in the Erdös-Rényi random graph, even though the component sizes appear to have the same scaling limit, at least when d is not too large. Federico also investigated the precise conditions for connectivity of the configuration model.

- Debankur Mukherjee (started August 2014) is finishing his paper on “Hard-core interaction models on dynamic graphs” in collaboration with Sem Borst and Johan van Leeuwaarden. This first paper investigates graph structures in continuums, in particular, networks that consist of repelling particles, which give rise to intricate time-varying behaviour in terms of network structure and network performance (mixing and hitting times). As a second line of research, Mukherjee started to work on routing and scheduling policies in large-scale systems. This has resulted in two papers, and promises to be an exciting new research line within NETWORKS that makes yet another valuable connection between stochastics and algorithmics.

- At UL, postdoc Siamak Taati works on the project “Dynamic behaviour of interacting-particle systems with hard-core interaction”. This project is supervised by Frank den Hollander (UL) and funded through his ERC Advanced Grant. At the same time there is close collaboration with Sem Borst and Francesca Nardi (TU/e), who act as co-supervisors. A random-access communication network is modelled as

a graph in which vertices correspond to servers and edges correspond to the possibility of interference. Each server has a queue of messages that need to be transmitted, but a server cannot transmit data while any of its neighbours is active. Therefore the set of active vertices at any moment in time has to be an independent set of the graph. Two papers are in preparation. One paper is on "Metastability of hard-core dynamics on bipartite graphs", and deals with the situation when there is a slight imbalance between the arrival rate of messages on the two subparts of the graph. This leads to metastable behaviour. The second paper deals with protocols for activation and deactivation of the servers that take into account the current load of the servers. It is studied how such a protocol may affect the metastable behaviour of the network.

THEME 3: QUANTUM NETWORKS

INTRODUCTION

Quantum computers hold great promise as the next generation of hardware. They are based on counterintuitive phenomena from quantum mechanics. The basic building block of a quantum computer is a quantum bit or qubit. Unlike a classical bit, which must take a value of either 0 or 1, a qubit can be in a quantum superposition – a simultaneous combination – of both 0 and 1. In the 1990s it was demonstrated that, for specific problems, quantum algorithms run on a quantum computer can massively outperform classical computers. Theme 3 investigates how networks and network algorithms are affected and influenced in a quantum world. Not only will quantum hardware have an impact on computing and algorithms, communication networks are also affected.

SPOTLIGHT ON NEW PERSONNEL

JOP BRIËT

TENURE-TRACK ASSISTANT PROFESSOR AT CWI

WHAT IS IT THAT MAKES NETWORKS ATTRACTIVE TO YOU?

NETWORKS brings together a very diverse group of interesting researchers. It provides a great setting in which to learn more about other research areas, in particular the types of questions that are asked and problem-solving techniques used to attack them, and to try to find common ground with my own research. One of the things I hope to learn more about is the community detection problem and its links to random matrix theory.

WHAT IS YOUR RESEARCH TOPIC WITHIN NETWORKS?

I am part of the quantum networks theme and am broadly interested in mathematics and theoretical computer science. My research includes the study of quantum entanglement, coding theory and approximation algorithms, and I often apply techniques from Banach spaces, combinatorics, harmonic analysis and probability.

HOW DID YOU EXPERIENCE YOUR FIRST MONTHS?

The most significant NETWORKS event in my first few months was the Training Week on optimisation, approximation and stochastic networks. It was a wonderful way to meet some of the other members and to hear about what they are working on.

HOW DO YOU EXPERIENCE WORKING IN THE NETHERLANDS?

The Netherlands is a great place to work. I am Dutch, however, so I may be slightly biased.

In 2015 Jop Briët started as a tenure tracker on this project. He currently holds an NWO-Veni grant on quantum and classical data protection, which seamlessly connects to this NETWORKS theme.

RESEARCH TOPICS

- In September 2015, Lars Jaffke was hired as a PhD within the theme of quantum networks. He is stationed at CWI in Amsterdam and supervised by Harry Buhrman (CWI/UvA) and Bart Jansen (TU/e). The goal of the project is to investigate the power of quantum computers for solving computational problems about networks. While quantum computers are known to be able to solve some computational problems (such as factoring large numbers into primes) much faster than classic computers, for other problems no quantum speedups are currently known. We are analysing whether several fundamental network optimization problems such as finding a large clique or finding a small dominating set, can be solved faster by quantum algorithms than by classical computers. Towards this end, we are considering new algorithmic approaches and new types of impossibility proofs. On the one hand, we search for new ways of exploiting quantum effects to speed up computation. On the other hand, we consider new ways of showing the limitations of quantum computers. These lower bounds are based on hypotheses about the time that is needed by a quantum computer to solve fundamental problems such as checking the satisfiability of a Boolean formula. An article describing initial results is in preparation.

- Also in September 2015, Tom Bannink started as a PhD student at CWI on a project concerning quantum walks in collaboration with Harry Buhrman (CWI/UvA) en Frank den Hollander (UL). Quan-

LAUNCH OF QUSOFT

On 3 December 2015 QuSoft was launched. QuSoft is the first research center dedicated to quantum software. It is a joint initiative of CWI, UvA and VU, and will be located at Amsterdam Science Park.

The mission of QuSoft is to develop new protocols, algorithms and applications that can be run on small and medium-sized prototypes of a quantum computer. The main focus is the development of quantum software, which requires fundamentally different techniques and approaches from those to develop conventional software because of the counter-intuitive quantum mechanical properties of the quantum computer such as superposition, interference and entanglement.

QuSoft builds on these excellent track record in quantum computing and quantum information of CWI, UvA and VU. The directorate of the center is in the hands of Harry Buhrman and Kareljan Schoutens, Professor of Theoretical Physics at UvA.

QuSoft
Research Center for Quantum Software

tum walks are a set of tools in the field of Quantum Information Theory, providing a quantum counterpart to the well-known random walks in classical probability theory. These quantum walks yield rich behaviour that is very different from the classical behaviour, including shorter mixing and hitting times. Random walks play an important role in many classical randomised algorithms, and presently quantum walks are being investigated for their applications in quantum algorithms. Several algorithms have been studied, achieving quadratic speedups for different search problems, but many questions remain open. One particular topic of study is to lift the paradigm of a random walk in a random environment to the quantum setting. Several results and ideas are being investigated at the moment. A workshop was held on the same topic, at the Lorentz Centre in Leiden in December 2015. The successful meeting brought together top researchers from both the classical random-walk community and the quantum walk community. In addition, ideas to implement small quantum walks on few qubits are investigated.

- In December 2015, a centre for quantum software (QuSoft) was launched on the initiative of Harry Buhrman. This centre connects very naturally with the NETWORKS programme and the quantum networks theme in particular. Briët, Jaffke and Bannink are active collaborators in QuSoft.

THEME 4: DYNAMICS OF NETWORKS

INTRODUCTION

Virtually all sectors of society are faced with issues regarding the design, operation and control of highly complex networks. NETWORKS' theme 4 specifically focuses on networks that evolve over time in a way that is typically closely related to their functionality. Random graphs are essential tools to model real-life network structures as stochastic objects that grow in time according to certain local growth rules. By adapting these rules, different types of dynamic network behaviour can be captured and analysed.

RESEARCH TOPICS

- Souvik Dhara (started in August 2014) obtained first results for the critical behaviour of the configuration model, one of the most popular and most important mathematical models for network structures of large-scale complex systems such as social networks and the internet. In a sequence of three papers various aspects will be investigated, including connectivity properties and percolation on the critical network structure. The three papers are based on joint work of Dhara with Remco van der Hofstad, Johan van Leeuwaarden, Sanchayan Sen and Shankar Bhamidi (Chapel Hill). Sen (started in September 2014) continued to make progress on the "Universality for metric convergence of random graphs and minimal spanning trees", leading to two lengthy papers co-authored with Bhamidi, van der Hofstad, Nicolas Broutin (Inria) and Xuan Wang (Chapel Hill).

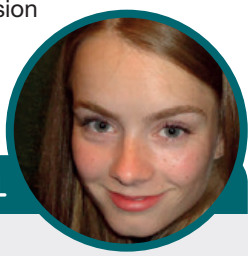
- In December 2014, Remco van der Hofstad and Johan van Leeuwaarden obtained an NWO-TOP grant for a topic related to the project "Information diffusion and epidemics on random graphs", but focusing more on networks with communities. Clara Stegehuis started in this project in February 2015 and made great progress, leading to three papers in 2015 on percolation on networks with community structure. Currently, she is exploring the critical behaviour of networks

with community structure, where she uses some of the techniques that were developed in the project of Dhara.

- Mariska Heemskerk started on the project "Correlated sources in networks", first as a Master's student, and in September 2015 as a PhD student. Together with Michel Mandjes and Johan van Leeuwaarden, she finished her first paper on infinite-server systems in random environments. Her research focuses on systems operating under overdispersion, experiencing higher intrinsic variability than in traditional Poissonian models. Heemskerk's first paper opens up a new way of modelling such overdispersion in critical (heavily loaded and large-scale) parallel server systems.

- Alessandro Garavaglia, appointed since January 2015, investigates citation networks. Garavaglia is supervised by Gerhard Woeginger and Remco van der Hofstad. The aim is to match a theoretical analysis of random graphs evolving in time with empirical data of citation networks. In terms of citation network data, Garavaglia has obtained access to the Web of Science data through contacts with Ludo Waltman from the CWTS of Leiden University. He has analysed several scientific subdomains, including probability and statistics, finding that the number of papers in these domains seems to grow exponentially with time. At the same time, several models of random graphs evolving in time on the basis of continuous-time branching processes that share this exponential growth have been formulated. The key point is to match model properties to the empirical properties observed in the data. We hope to achieve this by combining theoretical analyses to simulation studies.

- Paulo Serra (postdoc at UvA) works on a technique to estimate the dimension in random-connection models, having only access to binary



SPOTLIGHT ON NEW PERSONNEL

MARISKA HEEMSKERK
PhD student at UvA

WHAT IS IT THAT MAKES NETWORKS ATTRACTIVE TO YOU?
NETWORKS really is about bundling computational and analytical power to achieve a deep level of understanding regarding all kinds of networks. The project brings together algorithmics and stochastics, through theory as well as through people. For me, being part of the diverse network of inspiring NETWORKS people, and getting to work and hang out with them, makes life as a PhD truly worthwhile.

WHAT IS YOUR RESEARCH TOPIC WITHIN NETWORKS?
I focus on queueing systems with unusually spiky (non-Poissonian) arrivals, my goal being to model systems with such arrival processes and, for instance, match appropriate numbers of servers to them. I make use of the fact that system performance can be evaluated not only via simulation but also analytically, by considering asymptotics (i.e. scaling limits).

HOW DID YOU EXPERIENCE YOUR FIRST MONTHS?
If it goes on like this for some more years, I will be the last to complain. This position allows me to combine working on interesting topics, learning about state-of-the-art techniques, teaching to Bachelor students and meeting new people. I am especially enjoying the NETWORKS Training Weeks; they give me a lot of energy and inspiration.

HOW DO YOU EXPERIENCE WORKING IN THE NETHERLANDS?
If it was for gaining new international experiences, doing a PhD in the Netherlands would have been the worst choice, as I was born and raised in Amsterdam. Even more so, it has been a bliss to be around people from all around the world, located at universities all over the Netherlands. In this way my world has been expanding without me going anywhere (although I move around locally).

neighbouring information in terms of an adjacency matrix. Modelling the system as a random graph, a consistent estimation procedure was devised and extensively tested.

- Since April 2015 Hakan Guldas has been working on the PhD-project "Random processes on dynamic random graphs", which is based in Leiden and is supervised by Luca Avena, Remco van der Hofstad and Frank den Hollander. Research has so far focused on the mixing time of a random walk on a dynamic configuration model. A random graph of size n is generated according to the configuration model, and over time the edges are relocated at a constant rate. For degree distributions with a second moment that is bounded in n, it was shown that the mixing time is of order 1 and its distribution was estimated. The proof is based on a randomised stopping-time argument. For static random regular graphs it was known that the mixing time is of order $\log n$. Thus, the dynamics of the random graph speeds up the mixing time of the random walk. Although this result seems intuitively plausible, the proof is rather delicate.

THEME 5: DYNAMICS ON NETWORKS

INTRODUCTION

While random processes in static random structures are relatively well understood, their behaviour in dynamic random structures, such as dynamic random networks, poses major challenges. The presence of dynamics may be expected to alter the qualitative behaviour of the random process in significant ways. Classifying scenarios is one of the goals of this theme. In what way is the behaviour of a random process on a complex network controlled by the spatial organisation of the network and the interactions that take place along it?

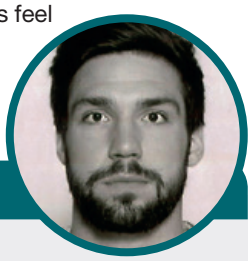
RESEARCH TOPICS

- Janusz Meylahn is working on the PhD-project "Spontaneous synchronization in complex networks", at UL in collaboration with Diego Garlaschelli, Frank den Hollander and Joke Meijer. The project is driven by the study of biological clocks in human brains. Synchronisation of neurons forming a network with a community structure is essential for the brain to be able to function optimally. We study the synchronisation of phase oscillators on the most basic network with a community structure, namely, the hierarchical lattice. Oscillators interact with each other at a strength that depends on their hierarchical distance, modulated by a sequence of interaction parameters. We look at block averages of the oscillators on successive hierarchical scales, which we think of as block communities. In the limit as the number of oscillators per community tends to infinity, referred to as the hierarchical mean-field limit, we find a separation of time scales, i.e., each block community can be thought of as a single renormalised phase oscillator evolving on its own time scale. We show that the evolution of the renormalised oscillators is given by a renormalised mean-field noisy Kuramoto equation, with an interaction strength that depends on the hierarchical scale of the block community. We identify four universality classes for the synchronisation level of the renormalised oscillators on successive hierarchical scales.

- On the PhD-project "Breaking of ensemble equivalence for complex networks" Andrea Roccaverde has been appointed at UL, under supervision of Diego Garlaschelli and Frank den Hollander.

The goal of the project is to investigate the equivalence or non-equivalence of certain basic probability distributions ("ensembles") that come from statistical physics. We look at the set of all possible graphs on n vertices, and at probability distributions on this set that are obtained by restricting the degrees of the vertices, either via a hard constraint in which the degrees must be matched perfectly ("micro-canonical ensemble") or a soft constraint in which the degrees must be matched only on average ("canonical ensemble"). We computed the relative entropy per vertex of these two ensembles in the limit as n tends to infinity, and found that this is strictly positive. Thus, breaking of ensemble equivalence occurs when the degrees are constrained. The results have been extended to random graphs with a community structure, revealing an interesting dependence of the relative entropy on the community structure itself. Jointly with Michel Mandjes we are currently investigating what happens when constraints are put on higher-order quantities, such as the numbers of triangles at the vertices.

- Oliver Jovanovski (UL) is working on the PD-project "Metastable behaviour of random graphs", supervised by Frank den Hollander and Francesca Nardi. The goal of the project is to study stochastic dynamics on random graphs in metastable situations, where the stochastic dynamics has to overcome a "high energetic hill" to tunnel from one quasi-equilibrium to another. Research has so far focused on Glauber spin-flip dynamics on the configuration model in the sparse regime. Sander Dommers (Bochum) has joined the project. A paper has been submitted in which the tunnelling time from the "all minus" state to the "all plus" state is computed when the spins feel a positive magnetic field and feel a ferromagnetic interaction with



SPOTLIGHT ON NEW PERSONNEL

JANUSZ MEYLAHN
PhD student at UL

WHAT IS IT THAT MAKES NETWORKS ATTRACTIVE TO YOU?
Through the NETWORKS programme I am exposed to a variety of research areas that I would otherwise hear nothing about. It puts me into contact with people with whom I could collaborate in the future and challenges me to make my research accessible to people that do not have the same expertise as I have. This prepares me well for a future in interdisciplinary research.

WHAT IS YOUR RESEARCH TOPIC WITHIN NETWORKS?
We are studying the way phase oscillators synchronise on a network with a strong community structure. We want to understand how the choice of interaction strength between oscillators (which should depend on which communities the two oscillators are in) affects the behaviour of the entire system.

HOW DID YOU EXPERIENCE YOUR FIRST MONTHS?
I'm from South Africa and it took me a while to settle in and adjust to the Dutch lifestyle and the European temperatures. But even in this time I have learnt a lot and feel well equipped for tackling my research. I am surprised at the progress we have made with the research project already and am excited to see what other interesting discoveries lie ahead.

HOW DO YOU EXPERIENCE WORKING IN THE NETHERLANDS?
A major upside of working in the Netherlands is the large size of the research group I am in. With such a big group, I have the opportunity to interact with many PhD students working on similar topics as mine and so I can always share my frustrations or ask for help.

neighbouring spins. The "critical droplet" for the crossover turns out to have a size that is of the order of the graph, which is very different from what happens on regular lattices. The paper exploits potential-theoretic arguments, in combination with combinatorial estimates about optimal trajectories. Jovanovski wrote a separate paper about Glauber spin-flip dynamics on the hypercube, where computations can be carried through explicitly.

- At UvA, PhD student Nicos Starreveld continued working on the project "Interpretation of measurements for distributed control", together with Rene Bekker (VU) and Michel Mandjes. He has focused on analysing a transient metric, the occupation time in a Lévy-driven system, which has led to a paper that has been submitted ("Occupation times of alternating renewal processes with Lévy applications"). The ultimate objective is to analyse how the results can be used to interpret network measurements. It is anticipated that an important role will be played by novel techniques developed by Den Boer, Mandjes and Núñez-Queija (in the paper "Convergence rates of Laplace-transform based estimators").

- David Koops, PhD student at UvA, supervised by Michel Mandjes and Onno Boxma, has performed a heavy-traffic analysis of a tandem Lévy network. Under a specific scaling, non-standard asymptotic results have been derived. Numerical experiments show that the resulting approximation outperforms the classical heavy-traffic approximation substantially. A second project, initiated recently, studies limiting behaviour of a general network of queues with compound Poisson input with service rates that depend linearly on the current buffer content.

- Haralambie Leahu, postdoc at UvA, has developed a framework for the automated, simulation-based stability detection of a general class of queueing networks. This class covers nearly all relevant queueing network structures, including for instance re-entrant lines (for which no explicit stability criterion is known). Together with Neil Walton and Brendan Patch, Michel Mandjes has worked on a similar problem, relying on a simulated annealing approach. Under mild conditions on the structure of the underlying Markov chain, it was proven that the algorithm returns (up to controllable statistical error) the correct stability region.

- Birgit Sollie (PhD student at VU, supervised by Bartek Knapik, Mathisca de Gunst and Michel Mandjes) develops techniques to estimate a network's system parameters, based on observations of the dynamics of the populations of particles present at the individual nodes. Casting it in the framework of a hidden Markov model, she has set up a procedure to estimate the parameters of the (Markov-modulated) input process.

THEME 6: TRANSPORTATION AND TRAFFIC NETWORKS

INTRODUCTION

Virtually all sectors of society are faced with issues regarding the design, operation and control of highly complex networks. Research theme 6 specifically focuses on a key application area that is of primal societal interest, namely, transportation and traffic networks.

In this theme several network-related problems are studied, shedding light on different

aspects of the design and operation of transportation and traffic networks. In some of these the network structure is fixed and the focus lies on the effect of the randomness involved in user behaviour, while in others the main objective is the shaping of the network structure. The emphasis is both on structure-related issues (planning and dimensioning of transportation and traffic networks) and the operations on existing networks (routing and scheduling and other traffic management mechanisms that relate to shorter time scales).

RESEARCH TOPICS

- In a first project, the focus has been on problems related to enabling smooth merging of traffic streams on highways. Abhishek (PhD student), Sindo Nũnez-Queija and Michel Mandjes at UvA, and Marko Boon and Onno Boxma at TU/e are actively involved in defining and solving problems revolving around this theme. Queueing theoretic models are being developed to study the dynamics of the waiting time process at the ramp; a similar modelling framework can be used to describe the evolution of traffic at intersections. Interestingly, non-trivial stability conditions are identified: the criterion that decides whether the queues involved are stable depends on the full distribution of the random variables involved, rather than just the mean. Follow-up projects have been initiated, in which the impact of irregular dynamics on the highway is assessed; remarkably, in specific situations such irregularity has a benign impact on the queue at the ramp.

- In the VU matching compartment of NETWORKS a project has been defined in which the effect of traffic control measures will be quantified, relying on a broad array of techniques, ranging from simulation and Markov decision processes to cellular automata. A first project led to a tractable model for the random dynamics on a roundabout. The remarkable feature is that despite its general nature, closed-form expressions for all relevant quantities can be derived. There is a vacancy for a PhD student on this topic, to be supervised by Sandjai Bhulai, Wouter Kager and Michel Mandjes.

- Cristobal Guzman (CWI) works on the design of efficient algorithms for tolls on congested networks, where links are owned by strategic players. The objective is to compute tolls such that, firstly, they induce the optimal flow and, secondly, when given as upper bounds for the strategic players, it is an equilibrium for them to charge the upper bound. It was shown that marginal tolls satisfy these conditions. Guzman also developed improvement algorithms that preserve these properties, while lowering driver payments.

- In line with the plans outlined in the NETWORKS project plan, satellite projects were set up in which the results from NETWORKS are translated to more applied settings. One such project is DYNAFLOAT, funded by the Top consortiums for Knowledge and Innovation (TKIs) and NWO; the academic partners involved are CWI, TU/e and UT. In addition, a promising interaction with Delft University of Technology (TUD; Bart van Arem and Serge Hoogendoorn, Department of Transport & Planning) has been initiated, which led to two mini-workshops in which ongoing work and research ideas from the NETWORKS team as well as TUD were presented. In addition, a collaboration with TNO (Maaike Snelder) on this topic was set up, which led to a joint proposal in the NWO call “Complexity in Transport and Logistics”.

THEME 7: COMMUNICATION AND ENERGY NETWORKS

INTRODUCTION

Communication and energy networks are both prominent instances of highly complex large-scale networked systems, which are of critical importance to society. Because of their vital interest, these systems need to be designed to achieve consistently high levels of performance and reliability, and yet be cost-effective to operate. This involves huge challenges, especially since both communication and energy networks are subject to inherent uncertainty and random variation in demand as well as supply.

RESEARCH TOPICS

- Murtuza Ali Abidini has focused in his PhD project on three threads. Firstly, he has written a joint paper with Onno Boxma and Jacques Resing on the analysis and optimisation of vacation and polling models with retrials, which serve to represent the operation of router nodes in optical networks. Whenever there is a need to buffer photons, they are made to move locally in fibre loops; this is modelled via retrial queues. In a second study, together with Bara Kim (Korea University) and Jeongsim Kim (Chungbuk National University) as well as with Onno Boxma and Jacques Resing, Abidini has relaxed certain modelling assumptions of the first study, paying more attention to the numerical analysis of key performance measures, and to so-called pseudo conservation laws. In a third paper, Abidini has studied revenue maximization for optical routing nodes. Together with Boxma, Koonen and Resing he has tackled the problem of assigning visit periods (service windows) to the different ports of a node such that the mean profit per cycle (frame) is maximised. Under mild assumptions, the optimisation may be formulated as a separable concave resource allocation problem, which can be elegantly solved.

- Bart Post has further pursued his PhD project “Dynamic Resource Allocation and User Association in Wireless Radio-Fiber Pico-Cell Networks”, under the supervision of Sem Borst, Ton Koonen and Gerhard Woeginger (all TU/e), with a joint appointment in the Departments of Electrical Engineering and Mathematics & Computer Science. Three distributed algorithms have been devised to optimise user association in a simplified model of a wireless pico-cell network. The algorithms have been analysed by means of simulations, and for one of them it could be established that convergence occurs towards a balanced allocation of load among the various pico cells. Regular meetings have taken place with Hans van den Berg (TNO).

- In April 2015, Fiona Sloothaak started her PhD project “Dynamic Interaction and Volatility in Future Energy Networks”, in collaboration with Sem Borst (TU/e) and Bert Zwart (CWI, TU/e). The project involves a probabilistic approach to examine how a single line failure can cascade through an energy network and possibly lead to large blackouts. Sloothaak has studied a stylised dynamic model and established asymptotic properties for the blackout size and the robustness of the observed power-law behaviour. Proposals have been submitted for two satellite projects, a national one with STW focusing on infrastructure reliability issues from a probability perspective, and a European one for an ETN pursuing computational techniques and capacity planning methods for emerging networks with renewable energy sources.

Using a combination of statistical process control and stochastic processes, Stella Kapodistria (tenure tracker at TU/e) and collaborators developed a theoretical framework for prognostics and health management solutions for the critical components of wind turbines based on available environmental data, condition data, vibration readings and maintenance and event logs. Empirical tests of the prediction algorithms on the OLAZ 1 wind turbine revealed that imminent failures of the critical components can be accurately predicted. In addition, a global health index has been developed for prediction of imminent failures and power output forecasting based on deviations of the power output.

Masha Remerova (postdoc at UvA) and Michel Mandjes have worked on fluid limits for a special class of networks, inspired by the dynamics of the bitcoin protocol. The analysis shows rich mathematical structures: a highly non-standard random fluid limit has been established.

GRANTS AND AWARDS

GRANTS

NWO VENI Grant

Jop Briët

Quantum and classical data transmission

Structural funding for QuSoft

QuSoft receives structural funding through UvA's research priority area Quantum Matter and Quantum Information (QM&QI).

AWARD

Lex Schrijver has been awarded the EURO Gold Medal 2015 at the EURO 2015 Conference on Operational Research in Glasgow (Scotland,12–15 July 2015) for "his outstanding contribution to Operational Research".

PORTFOLIOS

WORKSHOPS AND CONFERENCES

NETWORKS pushes an active workshop agenda. Funding applications from outside are solicited, provided that the topics are closely linked to the main themes of the NETWORKS programme. Typical funding is in the range of 5-15 kEuro. In 2015, NETWORKS supported 6 workshops, on a range of topics linked to complex networks. PI's from NETWORKS were involved in the organisation of each of these workshops, together with organisers from outside NETWORKS.

The members of the project team are often invited as keynote speakers. Michel Mandjes has given a key-note lecture at the Dutch Mathematics Congress (NMC) in Leiden. Frank den Hollander gave public lectures at Institut Henri Poincaré in Paris. Remco van der Hofstad gave a series of lectures at CRM-PIMS in summer 2015 and at ISI Kolkata, New Delhi and Bangalore, in November 2015. Lex Schrijver was keynote speaker at the "Panorama of Mathematics" at the Hausdorff Institute for Mathematics in Bonn.

There have been discussions within the Project Team on the possible theme and format of a larger NETWORKS conference. Finding a suitable topic that is attractive for a broad audience is not easy, especially because NETWORKS consists of researchers from two research areas, stochastics and algorithmics. The current plan is to organize a 3-day meeting at CWI in June 2017, for 150 participants, focussing on 4 themes: (1) Communication Networks, (2) Logistics, (3) Scheduling and Robust Optimisation, and (4) Mathematical Physical Aspects of Complex Networks. One of the three days will be a public day, with laymen lectures by top international researchers, followed by presentations by speakers from Dutch politics and research management, possibly including the Minister of Education, Culture and Science and the chairman of NWO. The day will be concluded with a plenary discussion about the role of complex networks within the Dutch National Research Agenda (*Nationale Wetenschapsagenda*).

WORKSHOPS

In 2015 NETWORKS supported and co-organised the following conferences and workshops:

- TACO day "Treewidth and Combinatorial Optimization", 16 March 2015, Eurandom, Eindhoven
- SAM 2015: "Random Walk in Random Environment", 23 March- 24 April 2015, Eurandom, Eindhoven
- "Scheduling under Uncertainty", 1-5 June, Eurandom, Eindhoven
- Computational Geometry Week, 22-25 June, TU Eindhoven
- "Robust optimization & Applied probability", 8-10 November 2015, Eurandom, Eindhoven
- YEQT-IX "Scaling limits of queueing networks", 11-13 November 2015, Eurandom, Eindhoven
- "Quantum Random Walks & Quantum Algorithms", 7-11 December 2015, Lorentz Centre, Leiden
- Workshop on Algorithms and Models for Web graphs 2015, 10-11 December 2015, Eurandom, Eindhoven

INTERNATIONALISATION

Around the theme of internationalisation NETWORKS has taken the following initiatives in 2015:

- A meeting took place in the summer of 2015 in Amsterdam with representatives of the EPSRC Centre for Doctoral Training "Statistical Applied Mathematics at Bath" (SAMBa). It was agreed that members of NETWORKS can participate in the "Integrative Think Tank" meetings organised in Bath (1-2 times a year), and that members of SAMBa can participate in the "Training Weeks" organised by NETWORKS (2-3 times a year). The option of a joint application for RISE-funds (Research and Innovation Staff Exchange) of the EU was discussed, with possible partners Brazil and Chile. However, the required intensity of exchange is very high and the financial support is limited. It was felt that not enough capacity was available from the side of SAMBa and NETWORKS. An alternative RISE-application with partners British Telecom and TNO is being considered.

- Colleagues from Berlin, Munich and Münster have submitted an application with the DFG for a Collaborative Research Center (SFB/Transregio) called "Networks and Stochastics: Growth and Dynamics". There has been intensive collaboration and exchange between Dutch and German probabilists in the past, via joint programmes. In case the German application is successful, exchange and joint workshops are planned.

- Two PI's from NETWORKS made visits to three locations of the Indian Statistical Institute (ISI): Bangalore, Delhi and Kolkata. The ISI is gradually opening up new locations, and serves as the anchor point in India for top education and top research in applied mathematics. NETWORKS is preparing a Memorandum of Understanding with the director of ISI. Exchange of staff and students, and co-organisation of workshops are planned as well. Several mutual visits are scheduled for 2016 and 2017. NETWORKS will also participate in the upcoming programme on "Large Deviations and Statistical Physics" hosted by the International Center for Theoretical Science in Bangalore, in the fall of 2017. Complex Networks will be one of the themes in this programme.

OUTREACH

In 2015 various outreach activities have taken place.

- NETWORKS hired Franka Buurmeijer to give advice to its Management Team on the optimal infrastructure for the outreach programme and on what activities NETWORKS should focus on. Buurmeijer explored several possibilities by interviewing various Dutch outreach experts. She presented her results in September 2015. The main recommendation is to organise larger outreach activities on a project-by-project basis in close collaboration with the various partners already working in this field (*Platform Bèta Techniek, Vierkant voor Wiskunde, Wetenschapsknooppunten*). Especially in primary schools there is a demand for mathematics teaching materials.

- Budget has been allocated to *Vierkant voor Wiskunde* (vierkantvoorwiskunde.nl), an organisation of mathematicians that fosters mathematics activities for children, and publishes supplementary educational materials for gifted pupils. For NETWORKS, *Vierkant voor Wiskunde* is involved in developing a so-called *Wisschrift*, which is done in close collaboration with the NETWORKS members Onno Boxma and Lex Schrijver.

- Johan van Leeuwaarden and Michel Mandjes and have been involved in compiling, jointly with Jan van Neerven, a special issue of *Nieuw Archief voor Wiskunde* on the mathematics and computer science of networks. This special issue features contributions by NETWORKS members as well as colleagues from other mathematical teams in the Netherlands, presenting an overview of both theoretical and application-oriented developments.

- Mandjes has organised (with Gregor Brandt of ORTEC) LNMB's annual "Back-to-School-day" in Lunteren, which is part of the annual Dutch operations research conference. The programme consisted of seven talks on developments and applications of Operations Research in the area of networks, with expert speakers from academia as well as industry (KLM, TNO, SURFnet, CQM).

- Van Leeuwaarden has been elected member of *De Jonge Akademie* of KNAW, in the context of which he has done several outreach activities. Most notably, he presented a series of on-line courses for laymen, in the framework of the *Universiteit van Nederland*. Harry Buhrman also gave a series of lectures for the *Universiteit van Nederland* on quantum computing and cryptography. With the launching of the QuSoft initiative, a lot of attention was paid to his research in the national media and scientific platforms (Kennislink, New Scientist).

- From February 2016, Bart Groeneveld will be appointed as NETWORKS' outreach coordinator. He is tasked to help the programme to become more visible. Groeneveld has an extensive track record in various outreach activities.

SPOTLIGHT ON NEW PERSONNEL

ROBERT FITZNER

scientific programmer NetworkPages at TU/e

WHAT IS IT THAT MAKES NETWORKS ATTRACTIVE TO YOU?

The research on networks is an emerging field with many hard theoretical open questions as well as many applications. As I have a strong background in statistical physics as well as computer science I see many interesting opportunities.

WHAT IS YOUR RESEARCH TOPIC WITHIN NETWORKS?

In the recent years I have worked mostly in statistical physics (percolation). Only recently I have begun a project studying the properties of a particular type of random graph. I hope to start more network projects in the future.

HOW DID YOU EXPERIENCE YOUR FIRST MONTHS?

The first months were very welcoming and I had the time to settle with my family. Having moved between different countries before, I knew what to expect. I would like to thank the TU/e support staff for making this relatively easy, in comparison to other countries.

HOW DO YOU EXPERIENCE WORKING IN THE NETHERLANDS?

The atmosphere at the TU/e is productive, helpful and professional. For foreigners it can be very difficult to get a social environment inside as well as outside of university. One has to work hard to get a healthy private life.

NETWORKPAGES: AN INTERACTIVE NETWORKS WEBSITE

In 2015, the NetworkPages were launched during the 2015 Workshop on Algorithms and Models for the Web Graph (WAW), held on December 10-11 at Eurandom. The NetworkPages are aimed at fellow researchers with a multidisciplinary background and a shared fascination for networks, but also at high-school students, teachers and laymen. Anyone in the NETWORKS programme is encouraged to contribute to the website, either through popular articles about their own work, or through articles explaining the basics of their area of expertise to a broad audience.

The NetworkPages team is formed by Mark de Berg, Remco van der Hofstad, Tim Hulshof, Robert Fitzner and Bart Post. This team has worked feverishly towards this launch. Particularly the technical aspects of the launch required substantial attention. Choosing an internet hosting company as well as defining the technical requirements of the website and preparing material to be put online constituted the main focus for 2015.

Robert Fitzner started in September 2015 as the technical and demo specialist of the NetworkPages. Fitzner has already designed several beautiful demos for the site, for example on traffic simulation, the Erdös-Rényi random graph as well as various other random graph models. In the coming year, we aim to also create demos for algorithmic problems, with the help of Fitzner and specialists within NETWORKS' algorithmic community.

In 2016, the main goal will be to achieve regular input for the site. We aim to recruit an editorial board, create the necessary guidelines for contributing authors, and guarantee a steady flow of articles, demos and blogs for the site. We are currently preparing basic notions that can be used as background material in our articles.

See www.networkpages.nl for more details.

EDUCATION

One of the exciting aspects of NETWORKS is that it covers both stochastic and algorithmic aspects of networks. Besides performing top-level research in these areas, an important goal of NETWORKS is to educate PhD students and get them acquainted with the basic concepts and tools from both areas. To this end NETWORKS organises so-called Training Weeks. Each Training Week combines two topics, one from stochastics and one from algorithmics. The Training Weeks are held off-campus, so that they also serve as community-building activities.

FIRST TRAINING WEEK

In August 2015, NETWORKS organized the first Training Week in Woudschoten, with parallel mini-courses on computational geometry and on random graphs. Computational geometry is the field within algorithms research dealing with the design and analysis of algorithms and data structures for spatial data. Random graphs are models for complex networks where the connections are formed through some random process. As many networks are inherently spatial and many networks evolve in a non-deterministic manner, both topics are highly relevant when studying networks. In total 41 PhD students, postdocs and faculty members participated in the Training Week. The lectures were given by Mark de Berg and Remco van der Hofstad.

The Training Week started Monday afternoon with brief reviews of algorithms and probability theory basics, followed by overview lectures of computational geometry and random graphs. In the remaining four days, the morning sessions were devoted to computational geometry and the afternoon sessions to random graphs. Each session consisted of a lecture, an exercise session, and another lecture. De Berg and Van der Hofstad explained a number of important concepts and techniques from their fields, giving the audience a good feeling for the type of results that have been obtained in

Training Week 'Bamboestieken'

these areas. On Friday, several research topics currently being addressed within the NETWORKS project were discussed. The interesting lectures, excellent location and social interaction made the week a big success.

INTERNSHIPS

Internships are another way to broaden the education of the PhD students. Each PhD student is expected to do an internship of a few months, either in one of the other research groups within NETWORKS or in an institution outside NETWORKS. By doing an internship in a group from a different research area, the synergy and collaboration between the different research fields within NETWORKS are increased. In the fall of 2015 the PhD students started discussing internship topics with their supervisors and with potential hosts, and early 2016 the first internships will start.

VALORISATION

The research activities in NETWORKS are not only driven by intriguing scientific quests, but are also strongly inspired by urgent challenges involving complex dynamic networks that industry and society are increasingly being confronted with. Several paths are pursued to accomplish the transfer of novel insights and results to society, and to translate fundamental concepts into actual implementations. Specifically, the main vehicles for knowledge transfer and utilisation are:

(i) Long-term flux of young talented professionals trained in NETWORKS' groups.
We have developed a plan to invite professionals from industry and societal organisations, in particular alumni who have been trained in the various NETWORKS groups, to give presentations at the NETWORKS days on their job activities in industrial or societal research.

(ii) Close ties between NETWORKS' principal investigators and various companies and societal organisations, and involvement in application-oriented multi-disciplinary projects.
Michel Mandjes and Sem Borst have discussed common research interests and joint research efforts with Hans van den Berg (TNO). In addition, first steps have been taken towards officially launching a possible broader NETWORKS-wide strategic alliance with TNO under the umbrella of a formal Memorandum of Understanding, which could provide a prototype for alliances with other strategic partners. We plan to play an active role in the organisation of the annual *Studiegroep Wiskunde met de Industrie* event at CWI and the University of Amsterdam, to be held in January 2017, and take the lead in organising the next edition at Eindhoven University of Technology in January 2018.

(iii) Active engagement of the NETWORKS' groups in broader efforts to promote the application of advanced knowledge in mathematics and computer science to solve problems of industrial and societal relevance.
These application-oriented projects are typically carried out in the framework of the Topsector priority areas of the Dutch government, special industrial partnerships or various local initiatives. We have systematically queried the eleven principal investigators in NETWORKS to compile an overview of all these `satellite' projects, and aim to provide a pipeline of fundamental results fuelling them and driving long-term innovation.

SELECTION OF RECENT PUBLICATIONS

Below a selection of recent publications is given. For the complete list, see http://www.thenetworkcenter.nl/output

K. Kosinski and **M. Mandjes**
Logarithmic asymptotics for multidimensional extremes under non-linear scalings.
Journal of Applied Probability, 52: 68-81 (2015).

T. Squartini, J. de Mol, **F. den Hollander, D. Garlaschelli,**
Breaking of ensemble equivalence in networks.
Physical Review Letters 115: 268701 (2015)

N. Bouman, **S.C. Borst, J.S.H. vanLeeuwaarden**
Stability of random admissible-set scheduling in spatially continuous wireless systems.
Markov Processes and Related Fields 21(1): 85-108 (2015).

J.P. Dorsman, S.C. Borst, **O.J. Boxma,** M. Vlasiou
Markovian polling systems with an application to wireless random-access networks.
Performance Evaluation 85-86: 33-51 (2015)

S. Bhamidi, J. Goodman, **R. van der Hofstad,** J. Komjáthy.
Degree distribution of shortest path trees and bias of network sampling algorithms.
Annals of Applied Probability 25(4): 1780-1826, (2015).

J. Briët, O. Regev, and R. Saket
Tight Hardness of the Non-Commutative Grothendieck Problem.
Foundations of Computer Science (FOCS), IEEE 56th Annual Symposium, 1108-1122, 17-20 Oct. 2015

Z. Cao, N.M. Tessema, S. Latkowski, Z. Zhao, H. Chen, V. Moskalenko, K.A. Williams, H.P.A. van den Boom, E. Tangdiongga, **A.M.J. Koonen**
Integrated remotely tunable optical delay line for millimeter-wave beam steering fabricated in an InP generic foundry.
Optics Letters 40(17): 3930-3933 (2015)

T.M.M. Meyfroyt, **S.C. Borst, O.J. Boxma,** T.J.J. Denteneer
On the scalability and message count of Trickle-based broadcasting schemes.
Queueing Systems 81 (2-3): 203-230 (2015)

R.J. Kang, J. Pach, **V.S. Patel,** G. Regts
A precise threshold for quasi-Ramsey numbers.
SIAM Journal on Discrete Mathematics 29 (2015), no. 3, 1670–1682.

R. van Bevern, R. Bredereck, J. Chen, V. Froese, R. Niedermeier, **G.J. Woeginger**
Network-based vertex dissolution.
SIAM Journal on Discrete Mathematics 29: 888-914 (2015)

B.M.P. Jansen, D. Marx
Characterizing the easy-to-find subgraphs from the viewpoint of polynomial-time algorithms, kernels and Turing kernels.
Proc. 26th ACM-SIAM Symposium on Discrete Algorithms (SODA): 616-629 (2015)

SCIENTIFIC HIGHLIGHTS

T. Squartini, J. de Mol, **F. den Hollander, D. Garlaschelli,**

BREAKING OF ENSEMBLE EQUIVALENCE IN NETWORKS

PHYSICAL REVIEW LETTERS 115: 268701 (2015)

It matters which "statistical ensemble" one chooses when analysing a large physical, chemical, biological or social system that has a networked structure.

In large systems – like fluids, social structures, wildlife interactions or the global economy – the interacting units are so many that they can only be described in terms of probability distributions, called "statistical ensembles". The details of the system remain unspecified, and it is assumed that the system is in any of the equally likely microscopic configurations compatible with a number of macroscopic constraints – like the energy, the degree of friendship, or the amount of trade. There are two trains of thought for doing this. Either the constraints are 'hard', which means that they must be matched perfectly, or they are 'soft', which means that they need only be matched on average. The two resulting ensembles are called micro-canonical and canonical.

For over a century it was taken for granted that, for systems with short-range interactions, the two approaches lead to the same global behaviour, the idea being that in large systems relevant quantities fluctuate only little around their average value. However, this is not true for networks with topological constraints that are 'extensive' in the size of the network (i.e., in number proportional to the number of nodes). When constraints are put on the degrees of each node, it turns out that the relative entropy per node between the two ensembles is non-zero. This means that it actually matters which ensemble is chosen to analyse the network.

R.J. Kang, J. Pach, **V.S. Patel,** G. Regts

A PRECISE THRESHOLD FOR QUASI-RAMSEY NUMBERS

SIAM JOURNAL ON DISCRETE MATHEMATICS 29 (2015), NO. 3, 1670–1682

Ramsey theory seeks to understand how disordered a graph or network can be. It turns out that in any sufficiently large network, one can always either find k nodes that are all adjacent to each other or k nodes that are all non-adjacent to each other. But how large is sufficiently large? That is a question first posed about 80 years ago which continues to stimulate research today.

Suppose r is a number between 0 and 1. A collection S of nodes in the network is called r-dense (resp. r-sparse) if every node in S is adjacent (resp. non-adjacent) to at least a proportion r of all other nodes in S. How large does a network have to be to guarantee the existence of collection of k nodes that is either r-dense or r-sparse? Clearly this depends on r (and k). It turns out that there is a sharp change in behaviour as r increases from 0 to 1 and we determine precisely where this threshold is.

SCIENTIFIC HIGHLIGHTS

B.M.P. Jansen, D. Marx

CHARACTERIZING THE EASY-TO-FIND SUBGRAPHS FROM THE VIEWPOINT OF POLYNOMIAL-TIME ALGORITHMS, KERNELS AND TURING KERNELS

PROC. 26TH ACM-SIAM SYMPOSIUM ON DISCRETE ALGORITHMS (SODA): 616-629 (2015)

When analyzing the structure of a network, a question that often needs to be answered is whether the network contains a particular pattern as a subnetwork. Answering such questions generally requires a lot of computing time. To speed up the search, it would be useful to have a preprocessing step that removes parts of the network in which the subnetwork surely does not occur. The smaller the preprocessed network is, the quicker one can search through it. We show that whether or not such a preprocessing step can be effective strongly depends on the type of subnetwork being sought. We give efficient preprocessing algorithms that can be used when searching for star-like subnetworks, consisting of a few servers connected to many clients. For the types of subnetworks to which our algorithms do not apply, we prove that no effective preprocessing algorithms can exist.

J. Briët, O. Regev, and R. Saket

TIGHT HARDNESS OF THE NON-COMMUTATIVE GROTHENDIECK PROBLEM

FOUNDATIONS OF COMPUTER SCIENCE (FOCS), IEEE 56TH ANNUAL SYMPOSIUM, 1108-1122, 17-20 OCT. 2015

Grothendieck's inequality is a celebrated result from pure mathematics that allows for a large number of reformulations in a wide variety of contexts. Alon and Naor showed that the inequality gives efficient approximation algorithms for computational problems arising in the study of interacting particles (spin glasses) and graph partitioning, both Networks-related topics. Such problems are unlikely to be solvable exactly in any reasonable amount of time (that is, in polynomial time). Recently, Naor, Regev, and Vidick showed that a "non-commutative" variant of Grothendieck's inequality implies efficient approximation algorithms for problems arising for instance in the study of quantum entanglement, an important part of the quantum theme within Networks, and data and image analysis. Our contribution to this line of work shows that the latter algorithm and a special case of the former are in fact optimal provided the complexity classes P and NP are distinct, making it unlikely that better approximation algorithms exist.

ORGANISATIONAL ASPECTS

In 2015 the organisational aspects of NETWORKS were developed further.

The Consortium Agreement was finalised early 2015, addressing all legal issues associated with the NETWORKS programme.

On 1 May 2015, the first meeting of the Supervisory Board took place. The Supervisory Board is formed by the Deans of all the participating Faculties plus the Director of the CWI centre: Prof.dr. Karen Maex (UvA), Prof. dr. Emile Aarts (TU/e), Prof.dr. Geert de Snoo (UL), Prof.dr. Jos Baeten (CWI, chair). Aarts was succeeded by Prof.dr. Jacob de Vlieg in September 2015. The Supervisory Board discussed the progress of the programme as a whole, the financial result and the remaining budget.

NETWORKS installed its Scientific Advisory Board. This Board pays attention to the scientific progress of the programme and is formed by (international) peers. The members are David Gamarnik (MIT), Dorothea Wagner (Karlsruhe Institute of Technology), Jan van Leeuwen (emeritus Utrecht University, *chair*), Joel Spencer (NYU), Kurt Mehlhorn (Max Planck Institute and Saarland University), and Peter Glynn (Stanford). The Scientific Advisory Board will have online meetings; the chair of the Board will be present at the NETWORKS-day (see below).

Recruiting new personnel received much attention in 2015. 11 PhD students, 3 postdocs and 2 tenure trackers have been appointed in 2015. By the end of 2015, NETWORKS counted 52 members and 26 affiliated members (while affiliated members are not paid by the grant, they are strongly connected to the NETWORKS programme).

NETWORKS members and affiliated members convene three times a year during the so-called “NETWORKS-days”. These days typically start with a presentation of the programme leader, highlighting the general progress of the programme. Next, scientific presentations are given by NETWORKS members; in particular, the new hires get the chance to introduce themselves. The day ends with a social event in order to build up and strengthen the NETWORKS community.

In 2015 three such meetings were organised:

- 30 January 2015.
  Introduction of new staff and discussion regarding the setup of the educational programme. Location: Boerhaave Museum, Leiden.
- 15 June 2015.
  Meeting of the project team; main topics were the organisation of workshops and conferences, and valorisation. The meeting was followed by the introduction of new staff and a tour through the museum. Location: Philips Museum, Eindhoven.
- 30 October 2015.
  Scientific presentations by (affiliated) staff members and introduction of new PhD students. Location: Natuurhistorisch Museum, Rotterdam.

In collaboration with De Zagerij (graphic design) and Greenlights Solutions (web development) NETWORKS’ new website was launched early 2015. During the summer of 2015 an ‘internal’ website for NETWORKS members was implemented.

NETWORKS MEMBERS

NAME	AFFILIATION	FUNCTION
Murtaza Ali Abidini MSc	TU/e	PhD
dr. Luca Avena	UL	TT
Tom Bannink MSc	CWI	PhD
prof.dr. Nikhil Bansal*	TU/e	Staff
Abhishek MSc	UvA	PhD
prof.dr. Mark de Berg	TU/e	Staff
prof.dr. Hans Bodlaender*	TU/e, UU	Staff
prof.dr.ir. Sem Borst	TU/e	Staff
prof.dr.ir. Onno Boxma	TU/e	Staff
dr. Jop Briet	CWI	TT
prof.dr. Harry Buhrman	CWI / UvA	Staff
Souvik Dhara MSc	TU/e	PhD
Lorenzo Federico MSc	TU/e	PhD
dr. Robert Fitzner	TU/e	Scientific prog.
Alessandro Garavaglia MSc*	TU/e	PhD
Hakan Guldas MSc	UL	PhD
dr. Cristobal Guzman	CWI	postdoc
Mariska Heemskerk MSc	UvA	PhD
prof.dr. Remco van der Hofstad	TU/e	Staff
prof.dr. Frank den Hollander	UL	Staff
dr. Tim Hulshof	TU/e	TT
Lars Jaffke MSc	CWI	PhD
dr. Bart Jansen	TU/e	TT
dr. Oliver Jovanovski	UL	postdoc
dr. Stella Kapodistria	TU/e	TT
Sandor Kisfaludi-Bak MSc*	TU/e	PhD

NAME	AFFILIATION	FUNCTION
Pieter Kleer MSc*	CWI	Phd
prof.ir. Ton Koonen	TU/e	Staff
David Koops MSc	UvA	PhD
Patty Koorn	TU/e	Support staff
dr.ing. Marieke Kranenburg	UvA	Support staff
dr. Haralambie Leahu	UvA	postdoc
prof.dr. Johan van Leeuwaarden	TU/e	Staff
prof.dr. Michel Mandjes	UvA	Staff
Aleksandar Markovic MSc	TU/e	PhD
Janusz Meylahn MSc*	UL	PhD
prof.dr. Sindo Nunez Queija*	UvA	Staff
Monique Onderwater	UvA	Support staff
dr. Viresh Patel	UvA	TT
Astrid Pieterse MSc	TU/e	PhD
Bart Post MSc*	TU/e	PhD
dr. Maria Remerova	UvA	postdoc
Andrea Roccaverde MSc*	UL	PhD
Petra Rozema	TU/e	Support staff
prof.dr. Lex Schrijver	CWI / UvA	Staff
dr. Sanchayan Sen	TU/e	postdoc
dr. Paulo Serra*	UvA	postdoc
Fiona Sloothaak MSc	TU/e	PhD
Birgit Sollie MSc*	VU	PhD
Nicos Starreveld MSc	UvA	PhD
prof.dr.ing Gerhard Woeginger	TU/e	Staff

* Funded from partners matching resources

AFFILIATED MEMBERS

NAME	AFFILIATION	FUNCTION	NAME	AFFILIATION	FUNCTION
prof.dr. Ivo Adan	TU/e	Staff	prof. Monique Laurent	CWI	Staff
dr. Rene Bekker	VU	Staff	Debankur Mukherjee MSc	TU/e	PhD – student
dr. Sandjai Bhulai	VU	Staff	dr. Francesca Nardi	TU/e	Staff
dr.ir. Marko Boon	TU/e	Staff	dr. Jacques Resing	TU/e	Staff
dr. Daniel Dadush	CWI	Staff	prof.dr. Guido Schaefer	CWI	Staff
prof.dr. Roberto Fernandez	UU	Staff	prof.dr. Bettina Speckmann	TU/e	Staff
dr. Diego Garlaschelli	UL	Staff	dr. Floske Spieksma	UL	Staff
dr. Dion Gijswijt	CWI	Staff	dr. Siamak Taati	UL	postdoc
prof.dr. Mathisca de Gunst	VU	Staff	prof.dr. Evgeni Verbitskiy	UL	Staff
dr. Markus Heydenreich	UL / CWI	Staff	dr. Maria Vlasiou	TU/e	Staff
dr. Wouter Kager	VU	Staff	dr. Neil Walton	UvA	Staff
dr. Bartek Knapik	VU	Staff	Tom van der Zanden MSc	UU	PhD – student
dr. Julia Komjathy	TU/e	Staff	dr. Bert Zwart	CWI	Staff

PHD PROJECTS

PROJECT TITLE	SUPERVISORS	LOCATION	PHD STUDENT
Quantum Random Walks	Harry Buhrman Frank den Hollander	CWI	Tom Bannink
Refined Models and Coordination Mechanisms for Network Games	Guido Schaeffer Lex Schrijver	CWI	Pieter Kleer
Multi-model parameterized complexity analysis of network problems	Harry Buhrman Gerhard Woeginger	CWI	Lars Jaffke
Invasion percolation and minimal spanning trees on spatial graphs	Remco van der Hofstad Frank den Hollander	TU/e	Lorenzo Federico
Information diffusion and epidemics on random graphs	Remco van der Hofstad Johan van Leeuwaarden	TU/e	Souvik Dhara
FPT Algorithms for Geometric Networks	Mark de Berg Hans Bodlaender	TU/e	Sandor Kisfaludi-Bak
Algorithms for Range- and Frequency-Assignment Problems in Wireless Networks	Mark de Berg Gerhard Woeginger	TU/e	Alekasander Markovic
Citation networks and performance measures	Gerhard Woeginger Remco van der Hofstad	TU/e	Alessandro Garavaglia
Dynamic interaction and volatility in future energy networks	Sem Borst Sindo Nunez Queija Bert Zwart (CWI)	TU/e	Fiona Sloothaak

PHD PROJECTS (CONTINUATION)

PROJECT TITLE	SUPERVISORS	LOCATION	PHD STUDENT
Optical Networks	Ton Koonen Onno Boxma Jacques Resing	TU/e	Murtuza Ali Abidini
Dynamic resource allocation and user association in pico-cell networks	Ton Koonen Sem Borst Gerhard Woeginger	TU/e	Bart Post
Parameterized Preprocessing for Network Analysis Problems	Bart Jansen Mark de Berg	TU/e	Astrid Pieterse
Random processes on dynamic random graphs	Frank den Hollander Remco van der Hofstad	UL	Hakan Guldas
Breaking of ensemble equivalence for complex networks	Frank den Hollander Diego Garlaschelli	UL	Andrea Roccaverde
Spontanenous synchronization in complex networks	Joke Meijer Frank den Hollander Diego Garlaschelli	UL	Janusz Meyhlan
Scaling limits of random walks	Onno Boxma Michel Mandjes	UvA	David Koops
Optimisation of polling networks with limited service disciplines	Sindo Nunez Queija Marko Boon	UvA	Abhishek
Correlated sources in networks	Michel Mandjes Johan van Leeuwaarden	UvA	Mariska Heemskerk
Interpretation of measurements for distributed control	Michel Mandjes Rene Bekker	UvA	Nikos Starreveld

NETWORKS

by address: University of Amsterdam
Faculty of Science Korteweg-de Vries Institute
PO Box 94248
1090 GE Amsterdam
the Netherlands
+31 (0)20 525 6499
info@thenetworkcenter.nl
www.thenetworkcenter.nl

NETWORKS is a project of University of Amsterdam, Eindhoven University of Technology, Leiden University and Center for Mathematics and Computer Science (CWI) and receives funding from OC&W through NWO

Universiteit van Amsterdam

TU/e Technische Universiteit Eindhoven University of Technology

Universiteit Leiden

CWI Centrum Wiskunde & Informatica

NET WORKS

THENETWORKCENTER.NL