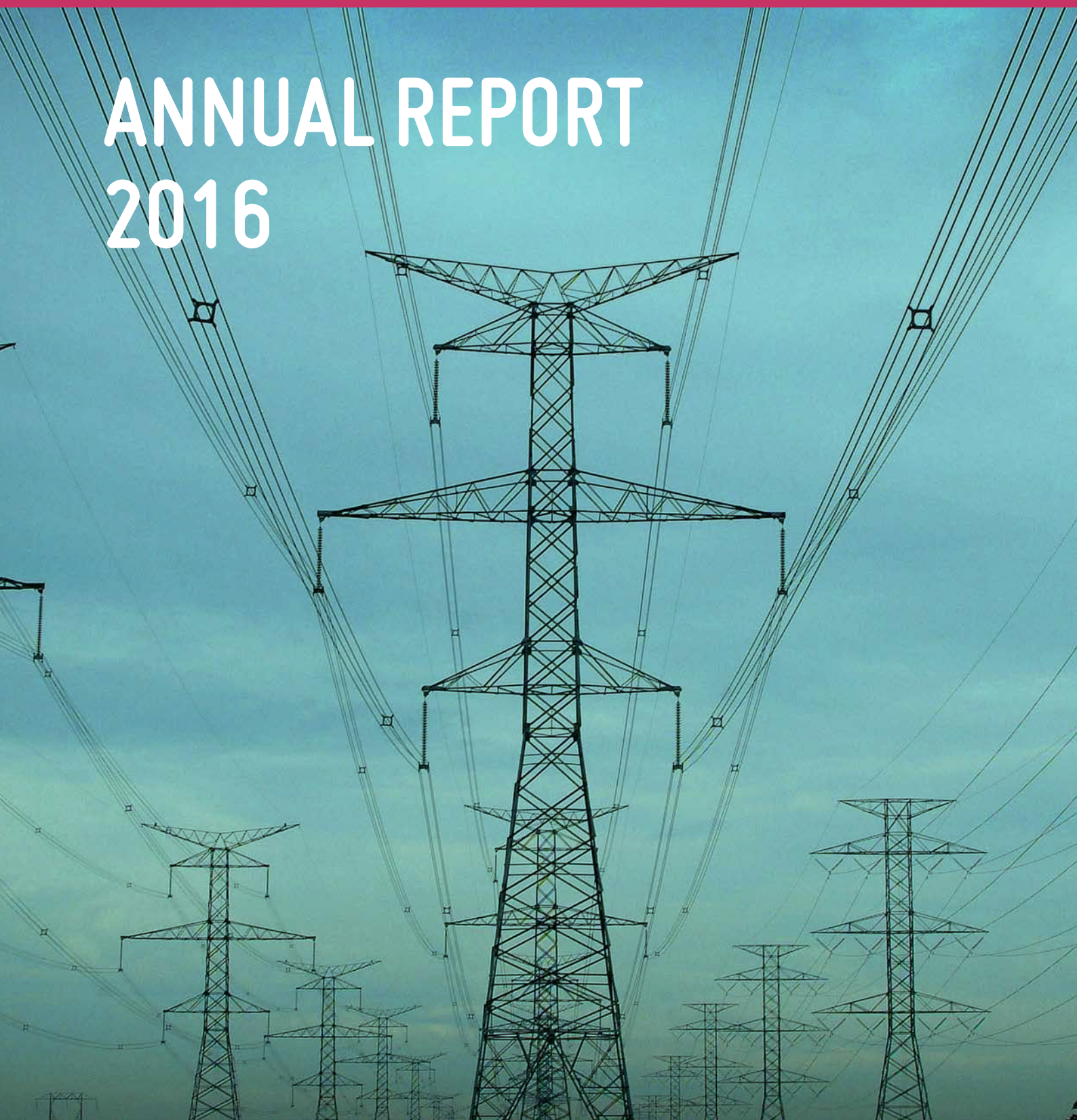
NET
WORKS

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 2016



In 2014, NETWORKS' first year, much effort was spent on setting up the programme's scientific and organisational structure, whereas in the second year, attention shifted to building up the scientific activities of the programme. By now, the programme is at full speed, with a solid organisation, and we are entering a new phase. Our scientific output becomes increasingly visible, with the first joint papers having been accepted for publication. Next to this, we have defined new focal points: the development of a broader outreach programme, keeping the Network Pages in full swing, and teaming up with new partners outside mathematics and computer science.

Scientifically, major progress has been made. Since its start, the programme has led to over 300 publications in leading journals and presentations at conferences on probability, combinatorics, operations research and algorithmics. The research interactions between the different research groups within NETWORKS are flourishing as well. In 2016, the programme's Scientific Advisory Board assessed the scientific progress for the first time. In their report, the Board states it was "impressed with what has been done already" and that the programme is "clearly on its way to becoming a world center for research in a domain that is generating some of the most interesting and important mathematical and algorithmic questions being generated today, and in the years to come".

A steady stream of articles stemming from the interaction between the various programme members is emerging. Even more multi-disciplinary research projects have been initiated and are gradually developing. Examples are newly set-up PhD projects on appointment scheduling (a joint effort of UvA and VU) and load balancing (at TU/e). Second-year PhD students at each institute do an internship at one of the other participating institutes, which also significantly strengthens the ties between the teams.

Launched in December 2015, the Network Pages (www.NetworkPages.nl) are now up and running. They present research on networks in a way that it appeals to a broad audience, ranging from fellow-researchers and students to high-school pupils and laymen. As of Fall 2016, an article is posted every two weeks and a blog every week.

In 2016, the programme's outreach strategy was further implemented. As was decided in 2015, a focus is on developing teaching materials about complex networks for primary and secondary schools. Various activities for secondary schools have been initiated, such as a 'NETWORKS challenge' and workshops on networks science. Throughout the year, various NETWORKS members gave presentations for general audiences.

The interaction with partners from outside the consortium has been further intensified. There was already a Memorandum of Understanding (MoU) with NETWORKS' Australian

counterpart, the ARC Center of Excellence for Mathematical and Statistical Frontiers (ACEMS), and in 2016 a similar agreement was signed with the Indian Statistical Institute (ISI). With both partners, joint activities are planned: joint doctorates with the Australian partners, and a workshop in Kolkata (early 2018) with ISI. In the area of road traffic research, the interaction with the transport modelling group at Delft University of Technology has been extended; in the area of optical networks, substantial progress was made, resulting in several papers with the electrical engineering group of TU/e.

The preparations for the midterm review of the programme in 2017 and the first international NETWORKS Conference have been started. The midterm review will take place in June 2017, after which the Dutch government will decide on the continuation of the programme for another 5 years. Also in June 2017, the first NETWORKS Conference will take place in Amsterdam, with an exciting scientific programme as well as a public event.

This annual report provides an overview of the NETWORKS activities in 2016. Additional information can be found on our website (www.theNETWORKcenter.nl) and on the Network Pages.

Michel Mandjes (Project Leader)
Marieke Kranenburg (Project Manager)

RESEARCH THEMES

Technological advancements have led to the creation of vast networks for the transport of people, goods, information, energy, and social contacts. The size of these networks and the unpredictable circumstances in which they have to function present grand challenges. It is the goal of NETWORKS to develop theory that helps to get a good grip on these challenges.

NETWORKS follows an integrated approach combining stochastic modeling (essential to capture the uncertainty and variability of networks) and algorithmics (needed to control and optimize networks). The overarching research objectives of the programme are to gain a better understanding of the relevant structural properties ("Network Structure") and to use these insights in the control and optimisation of complex networks ("Network Shaping"). To structure these objectives we defined seven research themes. These research themes are not independent: many of the running projects relate to multiple themes. The research themes act as different lenses through which we can view our networks of interest. They help us to distribute our research efforts in a balanced way over the various questions arising from these networks. Below, we give the highlights of each research theme.

THEME 1: APPROXIMATE AND EXACT NETWORK METHODS

Many important optimisation problems on networks are NP-hard, which means that most likely no fast (polynomial-time) algorithms exist that compute optimal solutions under all circumstances. A central question concerns the identification of the class of problems that allows fast computation of the optimal solutions. In addition, when optimal solutions are out of reach, we aim at developing fast algorithms that are guaranteed to compute near-optimal solutions. In Theme 1 we explore these and other approaches to algorithmic network problems.

HIGHLIGHTS

The Travelling Salesman Problem (TSP) is a one of the most widely studied NP-hard problems in computer science and combinatorial optimisation. In a TSP instance, one is given a set of locations and the travel distance between any pair of locations, and the goal is to compute a shortest tour that visits each of the given locations. The problem has many applications, not only in transport (for instance when a truck has to deliver goods at customers in different cities) but also in other scenarios (for instance when one needs to drill holes in specific locations in a printed circuit board). Thus, TSP is of great fundamental as well as practical relevance. NETWORKS researchers obtained new fundamental insights into this classic problem.

- Mark de Berg, Bart Jansen and Gerhard Woeginger, together with Kevin Buchin (TU/e), studied the famous k-OPT heuristic for TSP. The k-OPT heuristic is known to perform very well in practice, but it is rather slow (especially for large k) and its complexity was still poorly understood. Using the modern toolkit of fine-grained complexity, the researchers proved that for k=2 and k=3, the existing brute-force algorithms are most likely optimal. For k>3, however, they present a new algorithm, which is significantly faster than previous solutions. Moreover, they showed that for k=2,3, faster algorithms

are possible when the k-OPT heuristic has to be applied repeatedly. Besides the k-OPT heuristic, the researchers also studied the bitonic Euclidean TSP in the plane. Here they showed how to exploit the geometry of the Euclidean problem to speed up the traditional dynamic-programming algorithm by almost a linear factor.

- The results above concern the important case where the distances satisfy the triangle inequality. Viresh Patel, in collaboration with Gregory Gutin (University of London), studied the TSP problem for the case where the triangle inequality does not hold. For this general version, it is even NP-hard to approximate the optimal solution to within any constant factor. This led Vizing in 1973 to ask: is there a polynomial-time algorithm to find a tour whose length is at most the average length (instead of the minimum length) over all possible tours? As Vizing and several others have shown, the answer to this question is yes. However, not much else was known. Patel and Gutin took a significant step forward in understanding the complexity of TSP-without-triangle-inequality by giving an FPT algorithm for the following problem: given a graph G with integer weights and an integer k, is there a tour whose length is at most the average tour length minus k?

THEME 2: SPATIAL NETWORKS

In many applications, the networks under consideration are geometric, i.e., the nodes and the connections between them are embedded in a two- or higher-dimensional space. The goal is to assess, for various specific models, the impact of geometry on the network structure. In specific situations it is possible to exploit the geometry to obtain better solutions to network problems.

HIGHLIGHTS

- Mark de Berg, together with Mohammad Abam and Mohammad Javad Rezaei (Sharif University of Technology), studied a problem that arises in the design of spatial networks. Often, a desired property of a network is that it provides short paths between any pair of its nodes. One could put a direct connection between any pair of nodes, leading to a network having a quadratic number of edges, which is very costly. This raises the question whether it is possible to guarantee relatively short paths between any pair of nodes while using only a small number of edges. When the nodes are points in a Euclidean space and the edges are line segments connecting these points, the answer is known to be yes: using only a linear number of edges, one can ensure that for any two points there is a path that is only slightly longer than the Euclidean distance between the points. Abam, De Berg and Javad Rezaei extended this result to points in a mountainous terrain, where distances are no longer Euclidean. Their result constitutes the first network construction with constant spanning ratio in spaces that do not have a bounded doubling dimension.

- Together with Sandeep Juneja and Sarat Babu Moka (TIFR, Mumbai), Mandjes investigated a novel methodology for efficiently generating perfect samples from a so-called Gibbs distribution (which can be viewed as an invariant measure of a spatial birth-and-death point process). The approach is based on the classical idea of acceptance-rejection, but substantially enhanced by adding importance sampling to it. It provably outperforms alternative techniques, such as dominated coupling

from the past. The researchers succeeded in quantifying the performance gain of their simulation algorithm for the special case of hard-sphere models.

- Lorenzo Federico, Remco van der Hofstad, Frank den Hollander and Tim Hulshof studied bond percolation on the d-dimensional Hamming graph (the Cartesian product of d copies of the complete graph). They located the critical window in the situation that the size of the graph tends to infinity and showed that, inside this window, the successive largest clusters follow a scaling limit that is similar to the one known for the Erdös-Rényi random graph in terms of the cluster sizes, while the surplus edges that describe how different clusters are from trees behave rather differently. Their proof relies on a new way of exploring the clusters in the graph, which is needed because the geometry of the Hamming graph is highly non-trivial.

- Van der Hofstad continued his investigation on percolation on high-dimensional graphs. With Asaf Nachmias (Tel Aviv), his paper on the phase transition on the high-dimensional hypercube appeared in the *Journal of the European Mathematical Society*. In this 90-page paper, the researchers establish the last ingredient needed to identify the critical window of this graph, which turns out to be extremely small (exponentially small in the degree of the graph). Further, with Markus Heydenreich (LMU Munich), Van der Hofstad completed a first draft of a monograph on high-dimensional percolation based on his CRM-PIMS 2015 Summer School lectures in Montreal.

- Souvik Dhara, Johan van Leeuwaarden and Debankur Mukherjee studied packing problems on spatial networks, with the goal to obtain a solvable model for random sequential adsorption (RSA) of non-overlapping spheres in continuum spaces for 2 and more dimensions. In its simplest form, spheres arrive sequentially at uniformly chosen locations in space and are deposited when there is no overlap with a previously deposited sphere. Due to the spatial correlation, characterising the fraction of accepted spheres or the area covered by the deposited spheres, becomes intractable after a large number of deposition attempts. In a series of two papers the authors developed mathematical tools for characterising the coverage in mean-field regimes; first for packing problems on classical random graphs, and later for graphs with clustering. Their results advance the study of higher-dimensional disordered packings and have several potential applications, including the dipole-blockade of ultra-cold Rydberg gas molecules, studied for their potential impact on quantum computing.

THEME 3: QUANTUM NETWORKS

Quantum computers hold great promise as the next generation of hardware. The question addressed within NETWORKS is: How are networks and network algorithms affected by the quantum world? New steps have been made in understanding which problems allow for a substantial speed-up using quantum algorithms, and which remain hard.

HIGHLIGHTS

- Harry Buhrman, Matthias Christandl, David Perry and Jeroen Zuiddam (all CWI) studied the clean (quantum) communication complexity of the inner product function. They showed that, surprisingly, this function can be computed cleanly in n+3

qubits. They also showed that for random functions almost 2n bits are necessary in the classical case. The results were published in *Physical Review Letters* in December 2016.

- Harry Buhrman and Tom Bannink showed a new quantum analogue of a well-known connection between classical random walks and fractals. The probabilities of a standard random walk (or 'drunkard's walk') can be given in terms of the numbers in Pascal's triangle. When plotted modulo 3, Pascal's triangle becomes the fractal known as the Sierpinski triangle. Analogously, the researchers showed that the probability amplitudes associated with the Hadamard quantum walk give rise to the Sierpinski carpet when scaled and plotted modulo 3!

- Jop Briët and PhD student Shravas Rao (New York University) were awarded an NSF/NWO Grow fellowship to facilitate a three-month visit for Rao to CWI, resulting in the paper "Arithmetic expanders and deviation bounds for sums of random tensors" (submitted). Their work introduced new mathematical tools for the study of connectivity properties of random hypergraphs. In "Outlaw distributions and locally decodable codes", Briët with Zeev Dvir and Sivakanth Gopi (both at Princeton) revealed a close link between such hypergraphs and error correcting codes with ultra-fast decoders (presented at the conference Innovations in Theoretical Computer Science 2017).

NEW PERSONNEL

Mark van der Boor, MSc
TU/e, PhD student

dr. Jacobien Carstens
UvA, postdoc

dr. Jan-Pieter Dorsman
UL/UvA, TT

drs. Bart Groeneveld
UvA, Outreach coordinator

Madelon de Kemp, MSc
UvA, PhD student

dr. Sándor Kolumbán
TU/e, postdoc

Margriet Oomen, MSc
UL, PhD student

Matteo Sfragara, MSc
UL, PhD student

DEVELOPMENTS OUTSIDE NETWORKS

2016 was an eventful year for the research areas of quantum computing and quantum information theory. The research group at CWI grew over the course of 2016 and will continue to do so thanks to the launch of QuSoft, a brand-new research centre led by Buhrman and Kareljan Schoutens (UvA), whose mission is to develop new protocols, algorithms and applications that can be run on small and medium-sized prototypes of a quantum computer. In its first year after inception, QuSoft attracted external funds, media attention, new PhDs and tenure trackers, and hosted weekly seminar talks bringing together researchers from computer science, physics (both theoretical and experimental) and mathematics. On an international level, the European Commission launched an "ambitious, long-term and large-scale flagship initiative to unlock the full potential of quantum technologies and accelerate their development and take-up into commercial products in Europe."

THEME 4: DYNAMICS OF NETWORKS

In virtually all sectors of society we are faced with issues regarding the design, operation and control of highly complex networks. In this research theme we specifically focus on networks that evolve over time. The way in which this happens is often 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.

HIGHLIGHTS

- Souvik Dhara, supervised by Remco van der Hofstad and Johan van Leeuwaarden, worked on critical epidemics on the configuration model, one of the most popular and most important mathematical models for network structures of large-scale complex networks such as social networks and the internet. This is also joint work with Sanchayan Sen, who started in September 2014 as a postdoc on the related topic of "Universality for metric convergence of random graphs and minimal spanning trees." By now, Souvik completed two foundational works on the critical behaviour of the configuration model, and currently works on extending this foundation to metric spaces and scale-free conditions.

- Alessandro Garavaglia, Remco van der Hofstad and Gerhard Woeginger studied random-graph models that match their characteristics to those of citation networks. Such networks show power-law degree distributions with diminishing citations as time proceeds. This is modelled using preferential attachment models with aging and fitness. In a first paper, the conditions for power-law degrees were obtained when the aging is integrable. Interestingly, this happens precisely when the fitness distribution has exponential tails, a result that is novel and quite intriguing. The next step is to extend this result to the graph setting, as well as to match the model to data in a quantitative manner.

- The research of Hakan Guldas, supervised by Luca Avena, Remco van der Hofstad and Frank den Hollander, 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, the team showed that the mixing time is of order 1 and computed its distribution. 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.

- Mariska Heemskerk, Michel Mandjes and Johan van Leeuwaarden completed two technically advanced papers on novel scaling limits for stochastic systems facing arrivals that are dictated by some random environment. This environment creates correlation and fascinating limit theorems related to system occupancy and large deviation events.

- Paolo Serra and Michel Mandjes developed a procedure to estimate the intrinsic dimension of a dataset. The estimator is based on just the underlying adjacency matrix, i.e., without explicit distance information. The underlying graph is modelled according to a subset of a specific random-connection model. As it turns out, the estimator scales like n log n; its asymptotic distribution is explicitly identified, as well as the corresponding rate of convergence.

- Remco van der Hofstad and Johan van Leeuwaarden, together with PhD student Clara Stegehuis (funded by an NWO TOP grant) pursued the study of epidemics on networks with communities. In a series of four papers they introduced and studied new classes of random-graph models that allow for hierarchy and clustering. A next project concerns the rigorous underpinning of the occurrence of motifs (such as triangles) in network infrastructures.

THEME 5: DYNAMICS ON NETWORKS

Network functionality can often be described in terms of stochastic processes living on, possibly random, networks. This theme studies such processes, with, in 2016, a specific focus on: metastability for spin-flip dynamics on random graphs, scaling limits of random walks, synchronisation of oscillators with a hierarchical interaction, breaking of ensemble equivalence for random graphs with a community structure, statistical inverse problems for network dynamics, and algorithms for detecting the stability of stochastic networks (such as multi-class queueing systems).

HIGHLIGHTS

- The work of Diego Garlaschelli (UL), Frank den Hollander and Andrea Roccaverde, lead to a full classification of the breaking of ensemble equivalence for models of sparse random graphs with constraints on the degree distribution. Fixing the degrees or fixing the average degrees leads to models with different global behaviour, even when the graph becomes large and has a modular structure. Currently, den Hollander, Roccaverde, Michel Mandjes and Nicos Starreveld are joining forces to see what happens in the dense random-graph regime.

- Another highlight has been the work of Sander Dommers, Frank den Hollander, Oliver Jovanovski and Francesca Nardi on metastability for spin-flip dynamics on the configuration model. Spins sit at vertices and interact with each other along edges. They can flip up and down according to a Metropolis dynamics associated with the energy functional on configuration space induced by the interaction Hamilton. The set of critical configurations for the transition between the all-minus and the all-

plus configuration turns out to be a large collection of saddle points for the energy functional. For large graphs, the size and the shape of this set were identified, which leads to sharp control on the transition time.

- Haralambie Leahu and Michel Mandjes worked on automated and simulation-based stability detection for a general class of stochastic networks. This class covers nearly all relevant queueing network structures, including for instance re-entrant lines (which are notoriously hard to analyse and for which no explicit stability criterion is known). Together with e.g. Brendan Patch, Mandjes worked on a related problem, relying on a simulated annealing approach. Under mild conditions on the structure of the underlying Markov chain, the algorithm provably returns the correct stability region (up to a controllable statistical error).

THEME 6: TRANSPORTATION AND TRAFFIC NETWORKS

Virtually all sectors of society are facing issues regarding the design, operation and control of highly complex networks. In research theme 6, the focus is on a key application area that is of primal societal interest, namely, transportation and traffic networks. 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 focus lies on the effect of the randomness involved in user behaviour, while in others the main objective concerns 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).

HIGHLIGHTS

- In a joint effort of the UvA and TU/e teams, problems were considered that are related to smooth merging of traffic streams; involved were Abhishek (PhD student), Sindo Nunez-Queija and Michel Mandjes at UvA, and Marko Boon and Onno Boxma at TU/e. In a first project, the focus was on unsignalised intersections. Two new features were studied in depth. First, the impact of human behaviour was studied, so as to quantify how various types of driver impatience may affect the capacity. Second, the effect of vehicles arriving in platoons was quantified. Various case studies reveal surprising effects that have remained unobserved in the existing literature so far. Currently, attention is shifting towards new analysis techniques, which make it possible to obtain a wider variety of relevant performance measures, such as queue lengths and waiting times.

- In September 2016, in the VU matching compartment of NETWORKS, Jaap Storm started his PhD project, working under the supervision of Sandjai Bhulai, Wouter Kager and Michel Mandjes. Storm studies the effect of traffic control measures, relying on a broad array of techniques, ranging from simulation and Markov decision processes to cellular automata. In a first project, the random dynamics of traffic on a roundabout are studied. The remarkable feature is that, despite its general nature, closed-form expressions for various relevant quantities can be derived. In addition, non-trivial stability issues have been identified.

- Pieter Kleer and Guido Schäfer studied the change in social welfare (average travel time) in network routing games, as a result of perturbed latency functions on the arcs of the network. Network routing games model situations in which flow in the network is controlled by players, who aim at minimising their individual latency through the network. Here one might think of a road or communication network without centralised control. A (tight) theoretical analysis is given of the effect of bounded perturbations on the latency functions in networks with a very high number of players. In other words, this provides a worst-case analysis of what might happen to the average travel time if the information on which players base their routing decisions contains bounded errors. This modelling technique also generalises recent game-theoretical models for studying the effect of risk-averse behaviour, in which case the players take into account safety margins in order to deal with uncertainty in the network.

THEME 7: COMMUNICATION AND ENERGY NETWORKS

Communication and energy networks are both prominent instances of highly complex large-scale networked systems. As both are of critical importance to society, these systems need to be designed in such a way that they achieve consistently high levels of performance and reliability, and yet are 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.

HIGHLIGHTS

- Murtuza Ali Abidini, Jan-Pieter Dorsman and Jacques Resing proved a heavy-traffic limit theorem for the joint queue length distribution in a polling system with retrial and reservation periods. Such a polling system may be used to study the performance of certain switches in optical communication networks.

- Bart Post completed a paper on optimal cell-assignment algorithms for wireless pico-cell networks, which he presented at the MASCOTS conference in London held in September. Smart cell-assignment algorithms play a critical role in leveraging the full resources of emerging ultra-dense networks and meeting the ever-growing demand for wireless capacity and connectivity. The results were shared with Hans van den Berg (TNO), triggering discussions on the possible use for learning, self-configuring and self-healing mechanisms. Such capabilities are of vital importance in pico-cell network deployments, and of key interest to wireless network operators and TNO.

- Fiona Sloothaak completed a paper on robustness of power-law behaviour in cascading failure processes, in which she characterised scenarios where the total number of failures exhibits power-law behaviour. The results provide fundamental insight into reliability issues and blackout occurrences in electrical power grids. Understanding and quantifying the potential for major outages is of critical importance as power grids are subject to increasing levels of uncertainty and variation due to the rising deployment of renewable resources such as wind farms and solar panels. Sloothaak gave a pitch talk at the Stochastic Networks 2016 Conference in San Diego and participated in the programme on Algorithms and Uncertainty at the Simons Institute in

Berkeley. She also visited the University of Augsburg where she initiated a collaboration with Vitali Wachtel on the use of random-walk methods to extend the analysis of cascading failure processes.

- A topic that gained strong momentum in 2016 revolves around performance evaluation and algorithm design for data-centre networks and cloud systems. Murtuza Ali Abidini, together with Nicola Calabretta and Ton Koonen, initiated a performance study of optical data-centre communications.

- Mark van der Boor and Debankur Mukherjee actively pursued the analysis and design of load-balancing algorithms. Van der Boor wrote a paper on load balancing in large-scale service systems with multiple dispatchers, which he will present at the upcoming Infocom 2017 conference in Atlanta. He introduced and analysed two novel mechanisms that provide asymptotically optimal performance in a many-server regime, even when the incoming workloads a the various dispatchers are skewed. Mukherjee wrote a series of papers in which he addressed the fundamental trade-off between performance and communication complexity. He identified universality and asymptotic optimality properties for a wide range of randomised and threshold-based load-balancing policies, which provide crucial guidance for algorithm design.

GRANTS AND AWARDS

GRANTS

NWO-TOP grant
Viresh Patel – "Hamilton cycles in sparse graphs"

NSF visitor grant
Jop Briët

AWARDS

Best-paper award
Bart Jansen and Astrid Pieterse – 41st International Symposium on Mathematical Foundations of Computer Science, title paper "Optimal sparsification for some binary CSPs using low-degree polynomials".

ASML Graduation Prize for Mathematics
Madelon de Kemp

Royal distinction of Knight in the Order of the Dutch Lion
Frank den Hollander

↑ Frank den Hollander was appointed Knight in the Order of the Dutch Lion. The adornments were pinned on Den Hollander by Mayor Emile Jaensch of Oegstgeest.
Photo: Rien Meulman

PORTFOLIOS

EDUCATION

Two main components of the NETWORKS educational programme are the Training Weeks and the internships.

TRAINING WEEKS

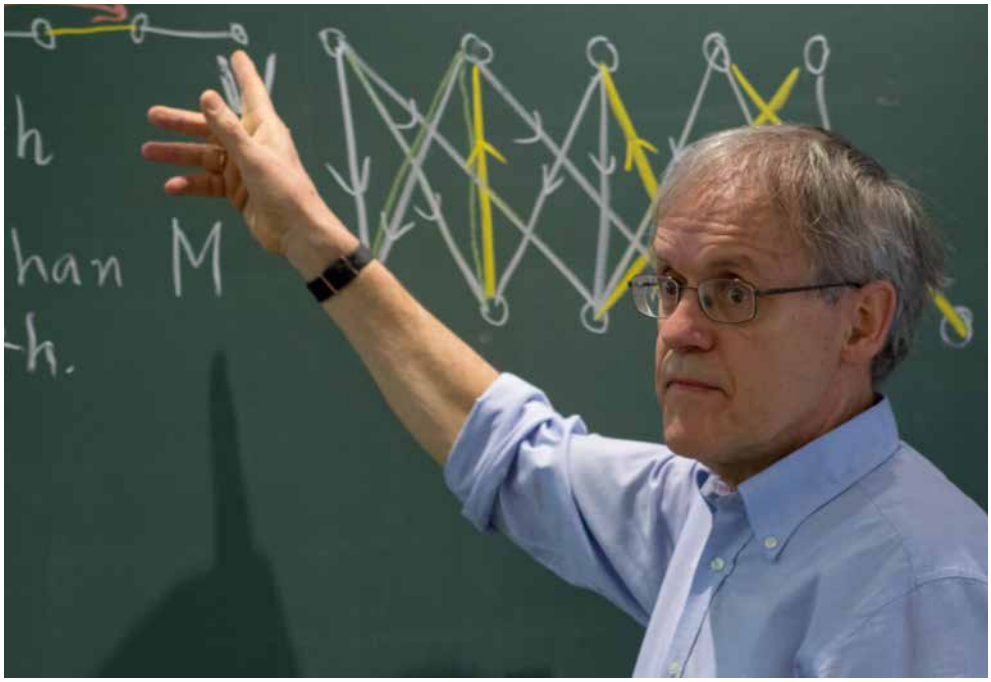
In the Training Weeks, researchers from NETWORKS gather to learn more about the research areas studied within the project. Each Training Week focuses on two topics, one from stochastics and one from algorithmics. In this way, the Training Weeks provide a broad view on the various stochastic and algorithmic aspects of network problems. The Training Weeks not only play an important role in the education of PhD students, but also help to connect (the researchers from) stochastics and algorithms. In 2016, we organised two Training Weeks.

In the week of 15 to 19 February, a Training Week was held in *Kaap Doorn*. It consisted of two mini-courses: one on approximation and optimisation, given by Lex Schrijver and Gerhard Woeginger, and one on stochastic networks, given by Sem Borst and Johan van Leeuwaarden.

The second Training Week was organised from 30 May to 3 June, this time in conference centre *De Werelt*. Frank den Hollander and Michel Mandjes gave lectures on large deviations, and Harry Buhrman lectured on quantum computing.

Both weeks were a big success. Almost all PhD students and postdocs attended and most tenure trackers and PIs were present as well, resulting in 41 participants for the first week and 45 participants for the second week. The interesting lectures, nice locations and excellent atmosphere made for two very stimulating weeks.

The next Training Week, in January 2017, will offer two shorter mini-courses and schedule time for presentations by the junior staff on running projects. This will also serve as a ‘marketplace’ to further enhance cross collaboration.



INTERNSHIPS

The Networks internships are brief (2-3 months) research projects. Typically, PhD students do their internship with another research group within NETWORKS. Thus, the internships not only broaden the view and knowledge of the students, but also provide an excellent mechanism to foster interaction and collaboration within the NETWORKS research groups and to create synergy between stochastics and algorithms. In 2016, the first internships started, and some are already leading to interesting new results on the interface of algorithmics and stochastics.

INTERNATIONALISATION

Around the theme of internationalisation, focus has been on setting up collaboration with the Indian Statistical Institute (ISI) and on strengthening ties with the Australian counterpart of NETWORKS, the ARC Centre of Excellence for Mathematical and Statistical Frontiers (ACEMS).

ISI

The ISI serves as the anchor point in India for top-level education and research in applied mathematics. NETWORKS signed a Memorandum of Understanding (MoU) with the director of ISI. Exchange of staff and students is planned, as well as co-organisation of workshops.

Two PI's from NETWORKS gave invited lecture series at three locations of ISI: Bangalore, Delhi, Kolkata. On 23 June 2017, three staff members from ISI will make a return visit and speak at a mini-workshop in Leiden. NETWORKS will participate in the upcoming programme on "Large Deviations and Statistical Physics", hosted by the International Centre for Theoretical Science in Bangalore, in the Summer of 2017. Complex programme. From 29 January to 2 February 2018, a joint workshop of NETWORKS and ISI will take place in Kolkata.

ACEMS

The collaboration with ACEMS has been intensified. Last year, a Memorandum of Understanding (MoU) was signed. In the framework of this partnership, two PhD students are shared between UvA and the University of Queensland (UQ), both under the supervision of Michel Mandjes (UvA) and Thomas Taimre (UQ): Julia Kuhn has been working on various decision problems for stochastic networks, including bandit and detection problems, whereas Brendan Patch

INTERNSHIP HIGHLIGHT

RECONFIGURATION THRESHOLDS FOR INDEPENDENT SETS

Consider a network whose nodes try to become active (transmit information) at some rate, independently of each other. In this process, a node can only become active if none of its neighbouring nodes are active, as otherwise the transmissions would interfere. Active nodes also deactivate at some rate. At any point in time, the active nodes form an independent set in the network. An important question (for example in statistical physics, where the above process is known as Glauber dynamics with hard-core interaction) is how long the process takes to go from an initial maximum independent set to a target one. It has been shown in the stochastics literature that this process is quite slow if one needs to go through independent sets that are much smaller than maximum. This raises the question: how does the size of the intermediate independent sets depend on the structure of the underlying network? Debankur Mukherjee, a PhD student in stochastics, became interested in this question. However, answering it requires tools from structural graph theory. Therefore, Debankur decided to do his internship in the Algorithms Group. Together with Mark de Berg and Bart Jansen he managed to characterise which network structures cause the process to be slow.

focuses on automated simulation-based procedures to detect the stability region of general stochastic networks. In addition, Mandjes has joined the Scientific Advisory Board of ACEMS.

NETWORK PAGES

A new design of the layout of the Network Pages was finalised due to hard work of the Network Pages team consisting of Mark de Berg, Robert Fitzner, Remco van der Hofstad, Tim Hulshof and Bart Post. The layout has been significantly streamlined. Also, the decision was made to post all material in English, except that aimed at teachers and pupils, which will be in Dutch.

In more detail, we have written basic notions to explain some of the key concepts that recur frequently on the pages, and have finalised the editorial guidelines. A plan has been made to guarantee regular appearance of articles (2 per month) as well as blogs (1 per week) in the coming year. Robert Fitzner has designed many demos that can be included in future articles and series.

Such demos make the content substantially more lively. We see that many participants in the NETWORKS project are considering a contribution to the Network Pages. This makes us confident that we can keep the momentum that was achieved in 2016 in the years to come. One of the main tasks for 2017 is to expand the editorial board and to activate them to generate content for the Network Pages.

OUTREACH

As of February 2016, Bart Groeneveld has been appointed as NETWORKS' outreach coordinator, primarily focusing on supporting the programme's visibility. Groeneveld, who has an extensive track record in various outreach activities, will adopt a policy that is in line with the advice Franka Buurmeijer gave to the Management Team (see the annual report of 2015), i.e., organising outreach activities through short, focused projects.

Last year's budget has been allocated to *Vierkant voor Wiskunde* (see the website vierkantvoorwiskunde.nl), an organisation

INTERNSHIPS

PHD STUDENT	INTERNSHIP AT	SUPERVISOR	TITLE INTERNSHIP
Souvik Dhara (TU/e)	UvA	Michel Mandjes	Efficient simulation of the scaling limits for critical random graphs
Alessandro Garavaglia (TU/e)	CWTS	Vincent Traag (CWTS)	Temporal dynamics in citation networks
Hakan Guldas (UL)	TU/e	Mark de Berg	The conflict-free coloring problem of unit disk regions
Sándor Kisfaludi-Bak (TU/e)	CWI	Jop Briët	Representing quantum algorithms with low degree polynomials
Janusz Meylahn (UL)	CWI	Harry Buhrman	Quantum Boltzmann machines
Andrea Roccaverde (UL)	UvA	Michel Mandjes	Ensemble Equivalence for Dense Graphs
Nicos Starreveld (UvA)	UL	Frank den Hollander	Equivalence of random graph models

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 a teaching material that allows pupils to individually experience and practice a specific topic in mathematics. The development of this Wisschrift is done in close collaboration with the NETWORKS members Onno Boxma and Lex Schrijver. The results are expected to appear in Spring 2017.

A second activity was the development of a NETWORKS challenge for secondary schools, with the key question "What would you like to know about Networks?". The challenge is part of the NETWORKS 2017 Conference and a follow-up will be realised by organising masterclasses for high-school students interested in writing their essay (in Dutch: *Profielwerkstuk*) on this topic.

Next to this, many NETWORKS members are involved in several outreach activities. Van Leeuwaarden is strongly involved in outreach in his role as a member of De Jonge Akademie, which is the junior section of The Royal Netherlands Academy for Arts and Sciences (KNAW). Public lectures were given by Briet, Buhrman, Van der Hofstad, Den Hollander and Mandjes.

VALORISATION

The research activities in NETWORKS are not only driven by intriguing scientific quests, but also strongly inspired by urgent challenges involving complex dynamic networks that industry and society are increasingly being confronted with. A significant number of projects within NETWORKS has a strong practical inspiration; we in particular mention two joint PhD projects with TU/e's electrical engineering group on optical and wireless networks, a PhD project on cloud computing, three PhD projects on road traffic, and a PhD project on energy networks.

Several paths are being pursued to accomplish the transfer of novel insights and results and translate fundamental concepts into actual implementations. Specifically, the main vehicles for knowledge transfer and utilisation are:

- a long-term flux of young talented professionals trained in the various groups in NETWORKS and entering the job market;
- active engagement of the various groups in NETWORKS in several broader efforts to promote the application of advanced knowledge in mathematics and computer science to solve problems of industrial and societal relevance;
- close ties maintained by many of the principal investigators in NETWORKS with various companies and societal organisations, and involvement in application-oriented multi-disciplinary projects;
- open and high-visibility channels towards companies and societal organisations that face challenges relating to complex dynamic networks and seek innovative solution approaches.

It is NETWORKS' policy to realise technology transfer primarily in projects (possibly with industry) 'around' NETWORKS. Several of the PIs are directly engaged in such application-driven projects, providing a natural and effective channel for fundamental research results obtained in NETWORKS to find their way into actual system implementation and innovation. Such 'satellite projects' around NETWORKS exist in various forms: projects directly with industry, with non-academic knowledge institutes, and with more application-oriented branches within academia. A few partnerships are particularly worth mentioning. TU/e has a long-standing interaction with Philips (e.g. Data Science and

Lighting Flagship programmes), and both TU/e and UvA with SURFnet (the organisation that provides ICT infrastructure to Dutch academic institutions). A partnership with the transport modelling group of TU Delft (Van Arem, Hoogendoorn) is currently being set up. QuSoft offers a natural channel to disseminate knowledge on quantum software.

There is a fruitful interaction with TNO, which is a semi-public organisation in technology research with an active interest in the various application areas pursued by NETWORKS, in particular societal infrastructure networks. In the past, there has been a steady flow of joint PhD students of TNO and the UvA team. In 2016, various actions have been undertaken to extend the collaboration between NETWORKS and TNO. Michel Mandjes and Sem Borst have had contacts with Prof. Hans van den Berg (TNO), discussing common research interests. This has led to the plan for NETWORKS researchers to give seminars at TNO and for TNO scientists to give presentations at NETWORKS events; Mandjes has already given a talk on the NETWORKS programme in a TNO lecture series. The general objective is to stimulate the interaction with TNO, leading to new joint research efforts.

We developed a plan to invite colleagues as well as professionals from industry and societal research organisations, in particular alumni who have been trained in the various NETWORKS groups, to give presentations at the regular plenary meetings of the NETWORKS members. Prof. Leo Kroon (Erasmus University Rotterdam) gave such a lecture at the NETWORKS Day on 13 April, on mathematical models for optimisation of timetables, train vehicle planning and personnel schedules at NS (the Dutch Railways). NETWORKS has taken on an active role in the organisation of the annual “Study Group Mathematics with Industry” event at CWI and UvA, held in January 2017, and will have the lead in organising the next edition at TU/e in January 2018. This study group is a combined industrial-academic workshop where mathematics is used to tackle problems supplied by companies and other organisations outside academia.

PhD students NETWORKS

WORKSHOPS AND CONFERENCES

In 2016, NETWORKS supported 6 workshops, on a range of topics linked to complex networks. Members of NETWORKS were involved in the organisation of these workshops, together with organisers from outside. NETWORKS pushes an active workshop agenda. Funding applications from outside are solicited, but topics must be closely linked to the main themes of the programme. Typical funding is in the range of 5-15 kEuro per workshop.

On 7-9 June 2017, the first NETWORKS conference will be held at CWI Amsterdam. There will be a public day, with non-expert lectures by top international researchers, a prize competition for high-school students, followed by presentations of speakers from Dutch politics and research management, including the Minister of Education, Culture and Science, the vice-president of KNAW and the chairman of NWO.
The day will be concluded with a plenary discussion about the role of complex networks within the *Nationale Wetenschapsagenda*, the Dutch national research agenda. The other two days will consist of parallel sessions for experts, focussing on 4 themes: (1) Communication Networks; (2) Planning and Logistics; (3) Scheduling and Robust Optimisation; and (4) Mathematical Physical Aspects of Complex Networks.

WORKSHOPS

WORKSHOP	PERIOD	LOCATION	INVOLVED FROM NETWORKS
Stochastic Activity Month (SAM) 2016: Probability and Analysis	March 2016	Eurandom, Eindhoven	Frank den Hollander Michel Mandjes
Nederlands Mathematisch Congres	March 22-23, 2016	UvA-FNWI Amsterdam	Frank den Hollander
Fixed-Parameter Computational Geometry	April 4-8, 2016	Lorentz Center, Leiden	Mark de Berg Hans Bodlaender
Metastability in statistical mechanics and stochastic processes	April 18-22, 2016	Eurandom, Eindhoven	Roberto Fernandez Francesca Nardi
8th Workshop on Flexible Network Design	July 4-8, 2016	VU Amsterdam	Viresh Patel Leen Stougie
2016 International Workshop on Structure in Graphs and Matroids	July 25-29, 2016	Eurandom, Eindhoven	Gerhard Woeginger Rudi Pendavingh
11th International Workshop on Retrial Queues and Related Topics (WRQ11)	August 31- September 2, 2016	Tinbergen Instituut, Amsterdam	Sindo Núñez-Queija Michel Mandjes
Data Driven Operations Management	October 24-27, 2016	Eurandom, Eindhoven	Stella Kapodistria
Young European Queueing Theorists (YEQT) X - Queueing Theory in Operations Research	November 7-9, 2016	Eurandom, Eindhoven	Jan Pieter Dorsman
A guided tour through random media	December 12-16, 2016	Eurandom, Eindhoven	Remco van der Hofstad

ORGANISATIONAL ASPECTS

NETWORKS installed its Scientific Advisory Board in 2015. This board, consisting of the PIs' (international) peers, monitors the scientific progress of the programme. Its members are David Gamarnik (MIT), Dorothea Wagner (Karlsruhe Institute of Technology), Jan van Leeuwen (emeritus Utrecht University, chair), Joel Spencer (New York University), Kurt Mehlhorn (Max Planck Institute and Saarland University) and Peter Glynn (Stanford University). In December 2016, the Scientific Advisory Board delivered its first report on the scientific progress and quality. It stated that the Board was "impressed with what has been done already" and that the programme is "clearly on its way to becoming a world center for research in a domain that is generating some of the most interesting and important mathematical and algorithmic questions being generated today, and in the years to come".
The Board's recommendations include to further explore the programme's relation with networks-oriented data science and statistics and to strike a proper balance between prescriptive and descriptive methodologies. In addition, advise was provided on the technology transfer portfolio (primarily realised by satellite projects around NETWORKS).

In 2016, 4 PhD students, 2 postdocs, 1 tenure trackers and a outreach coordinator have been appointed. By the end of 2016, NETWORKS counted 51 members and 23 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 two or 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, and new hires have the opportunity to introduce themselves.

In 2016, two such meetings were organised:

- **13 April 2016.** Meeting of the project team; main topics were the organisation of the NETWORKS conference 2017, and outreach. The meeting was followed by two lectures on applications of network science and introductory talks of the new hires. Location: Winkel van Sinkel, Utrecht.
- **28 October 2016.** Scientific presentations by (affiliated) staff members and introduction of new PhD students. Location: Van Nelle Fabriek, Rotterdam.

As of 2017, the NETWORKS days will be more focused on current research within the programme. Now that the organisation of NETWORKS has been stably set up, the focus is on the scientific programme, so as to inform the community about the current research lines.

In 2017, the midterm review of NETWORKS will take place. The first preparations to this midterm review were done in 2016. With the project team and a delegation of the temporary staff members, a discussion session was held, to systematically record the programme's strengths, potential adjustments, and points of concern. The outcome of the discussion will be an input to the self-evaluation report that will be submitted to a committee of Critical Friends, who will assess the programme early 2017.

NETWORKS MEMBERS

AFFILIATION	NAME	FUNCTION
UvA	Abhishek, MSc	PhD student
TU/e	Murtaza Ali Abidini, MSc	PhD student
UL	dr. Luca Avena	TT
CWI	Tom Bannink, MSc	PhD student
TU/e	prof.dr. Nikhil Bansal	PI
TU/e	prof.dr. Mark de Berg	PI
UU + TU/e	prof.dr. Hans Bodlaender*	Staff
TU/e	Mark van der Boor, MSc	PhD student
TU/e	prof.dr.ir. Sem Borst	PI
TU/e	prof.dr.ir. Onno Boxma	PI
CWI	dr. Jop Briët	TT
CWI + UvA	prof.dr. Harry Buhrman	PI
UvA	dr. Jacobien Carstens	PD
TU/e	Souvik Dhara, MSc	PhD student
UL + UvA	dr. Jan-Pieter Dorsman	TT
TU/e	Lorenzo Federico, MSc	PhD student
TU/e	dr. Robert Fitzner	Scientific programmer
TU/e	Alessandro Garavaglia, MSc*	PhD student
UvA	Bart Groeneveld	Support Staff
UL	Hakan Guldas, MSc	PhD student
CWI	dr. Cristobal Guzman	PD
UvA	Mariska Heemskerk, MSc	PhD student
TU/e	prof.dr. Remco van der Hofstad	PI
UL	prof.dr. Frank den Hollander	PI
TU/e	dr. Tim Hulshof	TT
CWI	Lars Jaffke, MSc*	PhD student
TU/e	dr. Bart Jansen	TT
UL	dr. Oliver Jovanovski	PD
TU/e	dr. Stella Kapodistria	TT
UvA	Madelon de Kemp, MSc*	PhD student
TU/e	Sándor Kisfaludi-Bak, MSc*	PhD student

AFFILIATION	NAME	FUNCTION
CWI	Pieter Kleer, MSc	PhD student
TU/e	dr. Sudeshna Kolay	PD
TU/e	dr. Sándor Kolumbán	PD
TU/e	prof.ir. Ton Koonen	PI
UvA	David Koops, MSc	PhD student
TU/e	Patty Koorn	Support staff
UvA	dr.ing. Marieke Kranenburg	Support staff
UvA	dr. Haralambie Leahu	PD
TU/e	prof.dr. Johan van Leeuwaarden	PI
UvA	prof.dr. Michel Mandjes	PI
TU/e	Aleksandar Markovic, MSc	PhD student
UL	Janusz Meylahn, MSc*	PhD student
UvA	prof.dr. Sindo Nunez Queija*	Staff
UvA	Monique Onderwater	Support staff
UL	Margriet Oomen, MSc*	PhD student
UvA	Brendan Patch, MSc*	PhD student
UvA	dr. Viresh Patel	TT
TU/e	Astrid Pieterse, MSc	PhD student
TU/e	Bart Post, MSc*	PhD student
UvA	dr. Maria Remerova	PD
UL	Andrea Roccaverde, MSc*	PhD student
TU/e	Petra Rozema	Support staff
CWI + UvA	prof.dr. Lex Schrijver	PI
TU/e	dr. Sanchayan Sen	PD
UvA	dr. Paulo Serra*	PD
UL	Matteo Sfragara, MSc	PhD student
TU/e	Fiona Sloothaak, MSc	PhD student
VU	Birgit Sollie, MSc*	PhD student
UvA	Nicos Starreveld, MSc	PhD student
VU	Jaap Storm, MSc*	PhD student
UL + TU/e	Marjolein de Vries, BSc	PhD student
TU/e	prof.dr.ing. Gerhard Woeginger	PI

See www.thenetworkcenter.nl/people/people-overview for extended profiles

* Funded from partners matching resources

AFFILIATED MEMBERS

AFFILIATION	NAME	FUNCTION
TU/e	prof.dr.ir. Ivo Adan	Staff
VU	dr. Rene Bekker	Staff
VU	prof.dr. Sandjai Bhulai	Staff
UvA	dr. Arnoud den Boer	TT
TU/e	dr.ir. Marko Boon	Staff
CWI	dr. Daniel Dadush	TT
UU	prof.dr. Roberto Fernandez	Staff
UL	dr. Diego Garlaschelli	Staff
VU	prof.dr. Mathisca de Gunst	Staff
CWI	dr. Stacey Jeffery	TT
VU	dr. Wouter Kager	Staff
VU	dr. Bartek Knapik	Staff
TU/e	dr. Sándor Kolumbán	PD
TU/e	dr. Julia Komjathy	TT
CWI	prof.dr. Monique Laurent	Staff
UT	dr. Nelly Litvak	Staff
TU/e	Debankur Mukherjee, MSc	PhD student
TU/e	dr. Jan Nagel	PD

AFFILIATION	NAME	FUNCTION
TU/e	dr. Francesca Nardi	Staff
VU + CWI	dr. Neil Olver	Staff
UvA	dr. Guus Regts	TT
TU/e	dr. Jacques Resing	Staff
CWI	prof.dr. Guido Schäfer	Staff
UL	prof.dr.ir. Ionica Smeets	Staff
TU/e	prof.dr. Bettina Speckmann	Staff
UL	dr. Floske Spieksma	Staff
TU/e	Clara Stegehuis, MSc	PhD student
VU	prof.dr. Leen Stougie	Staff
UL	dr. Siamak Taati	PD
TU/e	Viktória Vadon, MSc	PhD student
UL	prof.dr. Evgeni Verbitskiy	Staff
TU/e	dr. Maria Vlasiou	Staff
UU	Tom van der Zanden, MSc	PhD student
UL	Qi Zhang, MSc	PhD student
CWI+ TU/e	prof.dr. Bert Zwart	Staff

PHD PROJECTS

PROJECT TITLE	SUPERVISORS	LOCATION	PHD STUDENT	STARTING DATE
Optimisation of polling networks with limited service disciplines	Sindo Núñez-Queija Marko Boon	UvA	Abhishek	1-Oct-2014
Optical Networks	Onno Boxma Ton Koonen Jacques Resing	TU/e	Murtaza Ali Abidini	1-Oct-2014
Quantum Walks and Quantum Algorithms	Harry Buhrman Frank den Hollander	CWI	Tom Bannink	1-Sep-2015
Load Balancing Algorithms in Networked Systems	Sem Borst Johan van Leeuwaarden	TU/e	Mark van der Boor	1-Nov-2016
Information diffusion and epidemics on random graphs	Remco van der Hofstad Johan van Leeuwaarden	TU/e	Souvik Dhara	1-Aug-2014
Invasion percolation and minimal spanning trees on spatial graphs	Remco van der Hofstad Frank den Hollander	TU/e	Lorenzo Federico	1-Nov-2014
Citation networks and performance measures	Remco van der Hofstad Gerhard Woeginger	TU/e	Alessandro Garavaglia	1-Jan-2015
Random processes on dynamic random graphs	Frank den Hollander Remco van der Hofstad	UL	Hakan Guldas	1-Apr-2015
Correlated sources in networks	Michel Mandjes Johan van Leeuwaarden	UvA	Mariska Heemskerk	1-Sep-2015
Optimized Appointment Scheduling	Michel Mandjes Neil Olver	UvA	Madelon de Kemp	1-Sep-2016
FPT algorithms for geometric network problems	Mark de Berg Hans Bodlaender	TU/e	Sándor Kisfaludi-Bak	15-Sep-2015
Refined Models and Coordination Mechanisms for Network Games	Guido Schäfer Lex Schrijver	CWI	Pieter Kleer	1-Sep-2015
Scaling limits of random walks	Michel Mandjes Onno Boxma	UvA	David Koops	1-Jan-2015
Algorithms for Range- and Frequency-Assignment Problems in Wireless Networks	Gerhard Woeginger Mark de Berg	TU/e	Aleksandar Markovic	1-Sep-2014
Spontanenous synchronization in complex networks	Frank den Hollander Diego Garlaschelli Joke Meijer	UL	Janusz Meylahn	1-Sep-2015
Spatial populations with seed-bank	Frank den Hollander Andreas Greven (Erlangen)	UL	Margriet Oomen	1-Oct-2016
Stability and control of transportation and communication networks	Michel Mandjes Thomas Taimre	UvA	Brendan Patch	1-Nov-2015
Parameterized Preprocessing for Network Analysis Problems	Bart Jansen Mark de Berg	TU/e	Astrid Pieterse	1-Sep-2015

More PhD projects on the next page »

PHD PROJECTS (CONTINUATION)

PROJECT TITLE	SUPERVISORS	LOCATION	PHD STUDENT	STARTING DATE
Dynamic resource allocation and user association in pico-cell networks	Sem Borst Ton Koonen Gerhard Woeginger	TU/e	Bart Post	1-Nov-2014
Breaking of ensemble equivalence for complex networks	Diego Garlaschelli Frank den Hollander	UL	Andrea Roccaverde	1-Nov-2014
Dynamic behavior of interacting-particle systems with hard-core interaction	Frank den Hollander Sem Borst Francesca Nardi	UL	Matteo Sfragara	12-Sep-2016
Dynamic interaction and volatility in future energy networks	Sem Borst Bert Zwart	TU/e	Fiona Sloothaak	1-Apr-2015
Statistical inverse problems for network dynamics	Michel Mandjes Mathisca de Gunst Bartek Knapik	VU	Birgit Sollie	1-Sep-2015
Interpretation of measurements for distributed control	Michel Mandjes Rene Bekker	UvA	Nicos Starreveld	1-Sep-2014
Stochastic models for road traffic	Michel Mandjes Sandjai Bhulai Wouter Kager	VU	Jaap Storm	1-Nov-2016

JOINT PUBLICATIONS

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

- M.A. Abidini, O.J. Boxma, A.M.J. Koonen and J.A.C. Resing
  Revenue maximization in an optical router node: allocation of service windows
  20th International Conference on Optical Network Design and Modeling, Cartagena, Spain, 2016, pp 1-6 Piscataway: IEEE.

- Abhishek, M.R.H. Mandjes, M. Boon and R. Núñez-Queija
  Congestion analysis of unsignalized intersections
  8th International onference on Communication Systems and Networks, 2016 , Piscataway, NJ : IEEE

- E. Aïdékon, R.W. van der Hofstad, S. Kliem and J.SH. van Leeuwaarden
  Large deviations for power-law thinned Lévy processes
  J. Stochastic Processes and Applications 126(5), 2016, pp 1353-1384

- M. de Berg, K. Buchin, B.M.P. Jansen, and G. Woeginger
  Fine-grained complexity analysis of two classic TSP variants
  Proc. 43rd Int. Coll. on Automata, Languages and Programming (ICALP), 2016, pp 5:1—5:14

- M. de Berg, B.M.P. Jansen, and D. Mukherjee
  Independent set reconfiguration thresholds of hereditary graph classes
  Proc. 36th IARCS Ann. Conf. on Foundations of Software Technology and Theoretical Computer Science (FSTTCS), 2016, pp 34:1—34:15

- O.J. Boxma, M.R.H. Mandjes and J. Reed
  On a class of reflected AR(1) processes
  Journal of Applied Probability 53(3), 2016, pp 818-832

- D.T. Koops, O.J. Boxma and M.R.H. Mandjes
  A tandem fluid network with Levy input in heavy traffic
  Queueing Systems 84, 2016, pp 355-379

- N.J. Starreveld, R. Bekker and M.R.H. Mandjes
  Transient analysis of one-sided Lévy-driven queues
  Stochastic Models 32(3), 2016, pp 481-512

- C. Stegehuis, R.W. van der Hofstad and J.S.H. van Leeuwaarden
  Epidemic spreading on complex networks with community structures
  Scientific Reports 6, 2016, 29748

- C. Stegehuis, R.W. van der Hofstad and J.S.H. van Leeuwaarden
  Power-law relations in random networks with communities
  Physical Review E 94(1), 2016, 012302

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