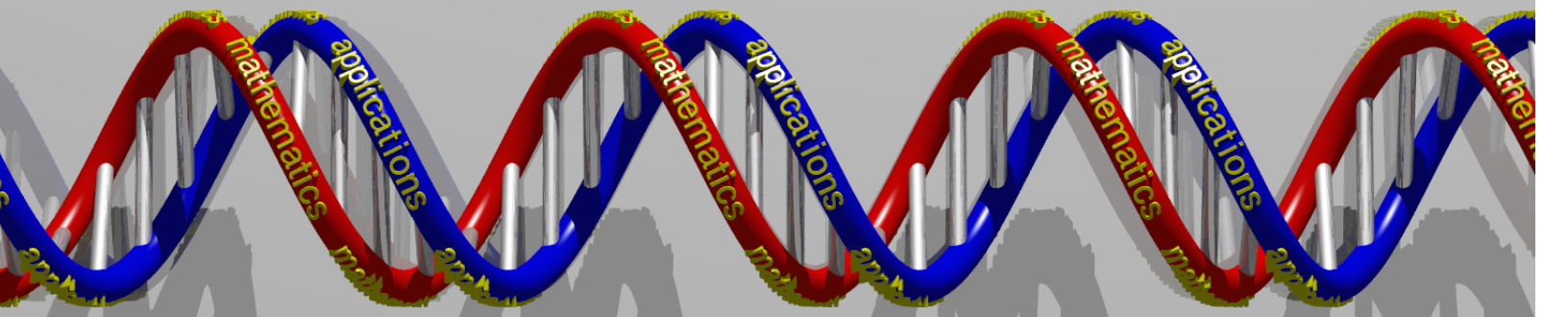
Research Evaluation Mathematics 2009-2014
Department of Applied Mathematics
University of Twente



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This scientific report has been written by the Discipline of Applied Mathematics of the Faculty of Electrical Engineering, Mathematics and Computer Science of the University of Twente for the periodic quality assessment of research under auspices of the VSNU/NVAO.

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List of abbreviations

Chairs in Applied Mathematics

AA	Applied Analysis
DMMP	Discrete Mathematics and Mathematical Programming
HS	Hybrid Systems
MACS	Mathematics of Computational Science
MMS	Multiscale Modeling and Simulation
SOR	Stochastic Operations Research

Research Institutes

CTIT	Centre for Telematics and Information Technology
MESA+	Institute for Nanotechnology
MIRA	Institute for Biomedical Technology and Technical Medicine

Graduate Schools & Networks

Beta	Research School for Operations Management and Logistics
DISC	Dutch national graduate school on Systems and Control
LNMB	Dutch Network on the Mathematics of Operations Research
TGS	Twente Graduate School

Faculties

BMS	Faculty of Behavioural and Management Science
ET	Faculty of Engineering Technology
EEMCS	Faculty of Electrical Engineering, Mathematics and Computer Science
TNW	Faculty of Science and Technology

Other Relevant Abbreviations

AMI	3TU Applied Mathematics Institute
CHOIR	Centre for Healthcare Operations Improvement and Research
CTS	Centre for Transport Studies (Faculty ET)
EWI	Dutch for EEMCS: Elektrotechniek, Wiskunde en Informatica
IEBIS	Chair Industrial Engineering and Business Information Systems (Faculty BMS)
IGS	Institute for Innovation and Governance Studies
TOM	"Twents Onderwijs Model" (Twente Teaching Concept)
T&SP	Training and Supervision Plan University of Twente
UT	University of Twente

Preface

In this report the research in the Discipline of Applied Mathematics at the University of Twente is presented. The report covers the period of 2009 to 2014, and has been prepared for the review committee assessing all research conducted in this time frame in Mathematics at all universities of the Netherlands. Such a research assessment is organized every 6–7 years, to evaluate the progress made over that period and to provide an outlook and an advice for the future. In preparing this report the joint Standard Evaluation Protocol (SEP) of the Dutch Research Organization NWO, the Association of Dutch Universities VSNU, and the Royal Academy of Sciences KNAW has been adopted.

At the University of Twente we take great pride in our Applied Mathematics research groups. These operate, on the one hand, in the disciplinary setting of their respective research fields, in which they strive for excellence among their (inter)national peers and provide a stimulating educational environment for the Bachelor and Master students, and, on the other hand, in a dynamic multidisciplinary setting to solve multifaceted problems and to create novel knowledge and technologies at the intersection of existing fields of expertise.

Mathematics is important for all disciplines, both in research and education. After two serious reorganisations within the Faculty Electrical Engineering, Mathematics, and Computer Science the university decided to substantially increase the financial support of the Mathematics groups. This was done to maintain the high quality of the Mathematics groups and their contributions to the programs of the research institutes MESA+, MIRA, and CTIT of the University of Twente.

The Applied Mathematics groups join forces to address major scientific and engineering challenges in the main focus areas of the University of Twente: Nanotechnology, Biomedical and Health Technology, Information and Communication Technology. On the one hand, they contribute to these areas and, on the other hand, they get inspiration from these areas to further enhance their own discipline.

With this, the Applied Mathematics Discipline is getting prepared for the transition to a more challenge-driven science policy, which we are currently witnessing in the Netherlands. Industry and society are invited by the government to bring their science and engineering questions forward, based on which important funding streams will be flowing. The substantial additional financial support made the appointment of several tenure trackers possible. Therefore, I, together with the scientific directors of MESA+, MIRA, and CTIT, have confidence in a successful continuation of our Applied Mathematics programs in the years to come.

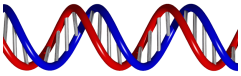
Prof. Peter M.G. Apers
Dean of the Faculty of Electrical Engineering, Mathematics, and Computer Science
Enschede, September 2015

1 Research Area and Objective

1.1 Research Area / Research lines

'DNA' of mathematics in Twente

Mathematics at the University of Twente has inspiration by application in its DNA. On the one hand mathematical insights help to advance adjacent fields. On the other hand, questions in these fields stimulate the development of mathematics.



The research is clustered into two research lines, namely *operations research* and *computational science*.

operations research

The research line operations research combines the chairs of Discrete Mathematics and Mathematical Programming (Uetz), and Stochastic Operations Research (Boucherie). Research topics include:

Mathematical optimisation: Aims at the development of new techniques that are relevant for the efficient solution of optimisation problems, ranging from combinatorial to nonlinear optimisation. This includes approximation algorithms, probabilistic and smoothed analysis of algorithms, as well as new methods for the design and analysis of mechanisms in distributed information settings. New models and techniques find their way into practice in optimising smart energy grids, health processes, and traffic models.

Stochastics & probability: Targets new methods for systems that are exposed to randomness. Our research advances theory and application of queueing systems, polling models, Petri nets, random graphs, Markov chains, rare event simulation as well as mathematical statistics. New stochastic and statistic methods are developed in modelling and optimising health processes, communication systems, large and complex networks, or in dynamic learning and pricing problems.

computational science

The research line computational science combines the chairs Applied Analysis (v Gils), Hybrid Systems (Zwart), Mathematics of Computational Science (vd Vegt) and Multiscale Modelling & Simulation (Geurts). Research topics include:

Numerical methods: Aims at the development and analysis of computational methods, tailored to the mathematical structure of the governing mechanisms found in key areas of science and engineering. Prominent examples are in (multiphase) fluid mechanics, nonlinear waves, neuroscience and electromagnetism.

Mathematical modelling: Powerful mathematical methods are developed for systematic modelling of problems in multidisciplinary applications. Expertise in variational analysis is adopted for medical imaging. Immersed boundary methods and interface reconstruction and tracking strategies are used in the analysis of aneurysms as well as boiling processes. Abstract delay equations and bifurcation methods are developed for neuroscience.

Systems and control: High tech systems are becoming increasingly complex, but also require tighter specifications. Simple classical linear controllers can often no longer provide this. This requires better models, often involving a spatial structure described by PDE's or decentralised models with interconnections modeled by graph theory. Estimation also needs to be improved to handle intrinsic nonlinearities as well as increasing in the number of sensors. Finally, control theory needs to be able to handle constraints and decentralised structures, while still meeting challenging specifications.

1.2 Vision, Mission and Objectives

Vision

Modern society is more than ever dominated by systems based on progress in mathematical sciences. Close interaction and collaboration between mathematics and its application domains in academia and society will enable progress both in mathematics and its application areas.

Mission

The mission of the Department of Applied Mathematics is to advance mathematical sciences through research and teaching, developing state-of-the-art research in computational science and operations research, and making progress in applications of societal and technological relevance.

Objectives

Our objective is training of high potentials in mathematical sciences as well as contributing to research in mathematics. In applications we focus on systems that are crucial to every-day life. We contribute to smart grids that make energy networks more efficient, mathematical models that assist medical doctors, schedules that make hospitals more efficient and numerical schemes to study multiscale fluid problems and wave progagation from nano to kilometer scales.

1.3 Strategy

General research strategy to meet the objectives

UT has a long tradition of co-operation between different disciplines, including the social sciences. It is the strategy of the Department of Applied Mathematics to actively engage in collaborative projects in three research institutes: CTIT for all ICT-oriented groups, MESA+ for nanotechnology, and MIRA for biomedical technology and technical medicine. Via the Institutes the Department participates in various multidisciplinary projects. This cooperation includes groups in both technical and non-technical faculties.

Research on the mathematical foundations of computational science and operations research helps groups to advance their core expertise. Multidisciplinary application-oriented research is equally important in view of the societal challenge and impact involved. This strategy is successful in applied mathematical sciences worldwide.

Adjustment in research focus during the review period

Following the recent retirement of all senior staff members of the Statistics group, the Department has re-focused its research in statistics. Statistics is a key area at a technical university, and is an integral part of the research environment at UT. This provided a strong motivation to rejuvenate the statistics group via the appointment of two researchers in Tenure Track positions in the areas "Statistical learning" (den Boer), and "Network Information Theory" (Goseling), and a part-time professor in "patial Statistics" (van Lieshout).

The retirement of prof. Bagchi initiated a re-orientation of our position in Control Theory. The research area financial engineering was discontinued. The two Control Theory groups merged into the new group Hybrid Systems, with a coherent focus on mathematical control. The application areas are selected to build bridges to operations research (via the appointment of dr. Frasca in a Tenure Track position), and to applications in mechanical engineering with emphasis on automotive and energy applications.

In the review period, the Department has established two multidisciplinary applied research areas: *health and energy*. In healthcare the Department has taken the lead in establishing the Center for Healthcare Operations Improvement and Research (CHOIR). This center is now one of the leading research centers on operations research for opti-

misation of healthcare logistics. It is a multidisciplinary collaboration of the UT research institutes IGS and CTIT.

Jointly with Computer Science, the Department has also taken the lead in establishing the research area on smart energy systems. This area is now well recognised for its decentralised energy management concept TRIANA. We also co-chair the SRO's on Energy and Health of the 3TU federation.

Within MESA+ a close collaboration was started in nanophotonics with the Complex Photonic Systems group on the development on novel techniques to increase the performance of solar cells. This research obtained substantial funding from the Computational Sciences in Energy Research program (Shell/FOM/NWO).

Strategic choices 2009–2014

Our Department invests in young mathematical talents by hiring about 40% new staff in tenure track positions. This impulse offers high-potential career opportunities for the new staff members. It also brings about unique new opportunities for the entire staff to intensify ongoing research and to establish cross-links between the Operations Research and Scientific Computing pillars, thereby contributing to the viability of applied mathematics at UT, see also 6.2.

1.4 Research environment and embedding

Faculty and Multidisciplinary Research Institutes

The Department of Applied Mathematics is one of the three Departments of the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS). The Dean of EEMCS and the department heads of Electrical Engineering, Mathematics and Computer Science form the management team of EEMCS. Within the Department 6 groups (vakgroepen) are active. The group leaders report to the Dean. Besides our research activities, we see education of highly qualified engineers as one of our core activities.

Co-operation between different disciplines is key at UT and was formalised about 20 years ago by organising research in multidisciplinary research institutes. The Department participates in three research institutes: CTIT, MESA+ and MIRA. CTIT is the largest academic research institute in the Netherlands – and one of the largest in Europe – in the field of ICT and ICT applications. With over 500 researchers, MESA+ is one of the world's leading nanotechnology research institutes. MIRA is the research centre for Biomedical Technology and Technical Medicine, an internationally leading institute in the field of Biomedical Engineering, with a closely integrated collaboration with the medical community.

National embedding

The Department participates in the NWO clusters DIAMANT (DMMP), NDNS+ (AA, MACS, MMS), and STAR (SOR), and in national research and graduate schools: Beta (DMMP, SOR), LNMB (DMMP, SOR), DISC (HS), and J.M. Burgers Center (MACS, MMS).

3TU.AMI

The Department participates actively in the 3TU.AMI institute, a joint venture of the three Dutch TU's in the Netherlands. Prof. Geurts was the founding chairman of this federation and we co-chair the SRO's on Energy and Health. See also Appendix A.7.

(Inter)national affiliations

Several members of scientific staff have shared affiliations with other Dutch institutes.

- 3 professors have a secondment at a Dutch university or research center. (Geurts – TU/e, Zwart – TU/e, v Gils – UU),
- 2 assistant professors have a secondment at a Dutch university (den Boer – CWI, Goseling – TUD)
- 4 full professors of other Dutch universities or research institutes have a secondment in the Department (Kuerten – TU/e, Kuznetsov – UU, v Dijk – UvA, v Lieshout – CWI)
- 2 professor have a secondment at an international university (vd Vegt – University of Science and Technology of China, Hefei, China, Stoorvogel – Washington State University, Pullman, WA, U.S.A.)
- 3 staff members have appointments funded by industry (de Graaf, Kuczaj, Bocquel)

The most important international research partnerships are listed below.

institute/programme	**description**
TU Berlin and ZIB Berlin	Research collaboration with regular, mutual research visits with several groups in optimisation (prof. Skutella, prof. Megow, prof. Stiller, prof. Borndörfer), including invited research stays, joint publications, and exchange of students.
Northwestern Polytechnical University, Xi'an, China	Exchange of PhD students and joint organisation of Dutch-Chinese workshops funded by NWO and NSFC on game theory and its applications (in 2010 and 2013, the next one planned for 2016, prof. Sun, prof. Xu).
Zhejiang University, Hangzhou, China	Exchange of PhD students and invited research visits of both staff and PhD students on combinatorial optimisation and approximation algorithms (prof. Zhang).
University of Trier, Germany	Joint research, regular mutual research visits as well as joint supervision of PhD students (prof. Dür).
University of Durham, UK	Joint research with regular, mutual research visits and joint publications (dr. Paulusma).
Max-Planck Institute Saarbrücken and University of Saarland	Joint research with regular mutual research visits, joint research projects and joint supervision of PhD students (prof. Bläser).
University of Bonn	Mutual research projects with regular research visits and cooperation, collaboration on PhD projects, as well as joint organisation of international workshops (prof. Röglin).
University of Science and Technology of China (USTC)	Joint research on discontinuous Galerkin finite elements methods with joint PhD's, long term stays as visiting Professor and teaching of graduate courses.
TRAX	Initial Training Network. Partners: Germany (Fraunhofer, UBonn), Sweden (Linköping), UK (Sheffield)
ERCOFTAC	Twente provides the chair of the scientific program committee of ERCOFTAC, coordinating over 28 special interest groups and 14 national Pilot Centers.
Imperial College	Regularisation modelling of turbulent flow and multiscale modulation of flow structures.
University of Trieste	Environmental fluid mechanics. A number of joint workshops was organised as well as participation in the graduate school teaching and assessment program.
University of Chicago	Epilepsy modelling (prof. v Drongelen). Exchange of master students and regular mutual research visits.
University of Ghent	Joint research project MATCONT (prof. Govaerts)
Universität Wuppertal	Control of Partial Differential Equations: a Port-Hamiltonian Approach (NWO-DFG project). Joint research with mutual research visits.
INRIA MAESTRO Team	Joint research on web graphs and informations systems (dr Avrachenkov)

Our most important societal partnerships are listed below.

societal partner	description
DAT.mobility (Deventer)	Models for decision making in traffic; joint PhD projects and several MSc projects per year.
MARIN	Computation and modelling of nonlinear water waves; more than 20 PhD students over the past 20 years.
Shell	Computational Sciences for Energy Research (seismic waves, solar cells); 4 ongoing PhD projects .
UMCU	computational modeling of epilepsy; 1 ongoing PhD project and several MSc projects.
AMC	Computational modeling of Parkinson's disease; 1 PhD project.
Netherlands Cancer Institute, AMC, Haga, LUMC	Healthcare logisitcs. 1 Ongoing PhD project, funds for 2 PDEng students, and several MSc/BSc projects per year.
UMCU, Jeroen Bosch Ziekenhuis, Carint Reggeland, Sint Maartenskliniek	Healthcare logistics: 6 completed PhD projects, 8 ongoing PhD projects, several MSc projects per year, funds for 2 PDEng students.
ORTEC (Zoetermeer)	Healthcare Logistics (also with partners above), Scheduling & Optimization
Sanquin blood supply	2 Ongoing PhD projects.
KPN	Smart radio access. 1 Ongoing PhD project.
Netherlands Defense Academy (NDA)	Network intrusion detection & emergence systems. 2 Ongoing PhD projects.
Thales	Advanced signal analysis and filtering techniques; many PhD and master students over the past years.

2 Resources and Facilities

Personnel

The Department has developed a pro-active staff-replacement policy, which takes into account recent and future retirement of scientific staff. Under this policy, temporarily the volume of tenured plus non-tenured scientific staff exceeds the target volume of 24 fte scientific staff. The Department has been successful in appointing junior staff in Tenure Track positions. In the reviewing period, 6 young scientists (B. Manthey, P. Frasca, A. den Boer, C. Brune, P. Dickinson, J. Goseling) were appointed in Tenure Track positions. Recently, the Department opened 3 additional vacancies for Tenure Track positions.

The tenure track system at UT is a five-year temporary appointment, starting at the assistant professor level. After five years either tenure is awarded, consequently leading to promotion to the associate level, or the track is terminated. The aim of the Tenure Track is the appointment of excellently performing academics who have the potential to develop into the position of full professor. The UT Tenure Track is successfully completed when the Tenure Tracker is promoted from Adjunct Professor (Adj- HGL, i.e. associate professor with the right to promote) to Professor-2 (HGL-2).

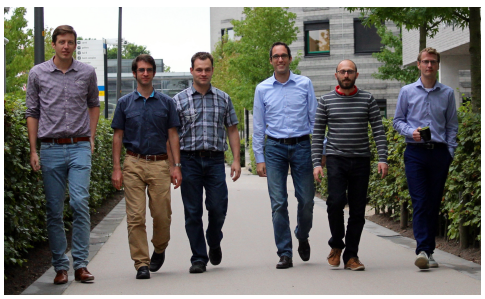


Figure 1: The tenure trackers appointed during the review period.

Funding targets

The Department has a funding target that is expressed in both teaching and research

Total	2009		2010		2011		2012		2013		2014	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff	35	11,30	32	11,19	30	11,25	29	10,45	28	9,81	31	10,45
Researchers (incl.postdoc)	9	4,66	11	4,97	10	3,96	9	4,27	8	2,63	7	4,28
PhD candidates (employed)	31	17,49	28	15,43	28	16,19	33	17,30	32	18,04	27	15,78
PhD candidates (other)			21		25		21		19		21	
Visiting fellows (> 3 months)												
Total res. Staff	75	33,44	92	31,59	93	31,40	92	32,02	87	30,48	86	30,51
Computational Science	2009		2010		2011		2012		2013		2014	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff	21	6,84	19	6,54	17	6,44	17	5,84	16	5,20	16	5,49
Researchers (incl.postdoc)	8	4,09	10	4,20	9	3,06	6	3,17	4	1,45	3	2,05
PhD candidates (employed)	21	13,87	20	12,36	17	11,21	18	9,78	15	8,41	13	7,77
PhD candidates (other)			5		7		6		8		12	
Visiting fellows (> 3 months)												
Total res. Staff	50	24,80	54	23,10	50	20,71	47	18,79	43	15,05	44	15,31
Operations Research	2009		2010		2011		2012		2013		2014	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff	14	4,46	13	4,65	13	4,81	12	4,61	12	4,61	15	4,96
Researchers (incl.postdoc)	1	0,57	1	0,76	1	0,90	3	1,10	4	1,19	4	2,23
PhD candidates (employed)	10	3,61	8	3,07	11	4,98	15	7,52	17	9,63	14	8,01
PhD candidates (other)			16		18		15		11		9	
Visiting fellows (> 3 months)					0							
Total res. Staff	25	8,64	38	8,49	43	10,69	45	13,23	44	15,43	42	15,20

Table 1: Research staff and research-fte.

volume. The total research volume of scientific staff amounts to 12 fte (=50% of the total volume of scientific staff). Our target is a total volume of about 40 PhD students financed through external funding. Currently this number is 39.

Research facilities

The research facilities are, in part, embedded in the scientific research institutes CTIT, MESA+, and MIRA. The Department further has a computation cluster with 128 cores. The chair Applied Analysis participates in MIRA's neuroscience lab. The latter is a unique situation that has stimulated successful Parkinson research during the review period.

Researchers

Table 1 shows the numbers for various categories of staff members in the period 2009–2014. Note that "PhD's (not employed)" are PhD students who are employed at another institution, for example at the Foundation for Fundamental Physics (FOM) or at a a hospital, but who work (partly) at the UT and have a UT promotor.

Research funds

Table 2 gives the research funds in the period 2009-2014.

3 Research Quality

3.1 Research highlights

In Section 1.1 we have given an overview of the main research topics of the two research lines in the Department. Here, we present four research highlights ranging from

Funding	2009		2010		2011		2012		2013		2014		Average 2009-2014	
	k€	%	k€	%	k€	%	k€	%	k€	%	k€	%	k€	%
Direct Funding	6316	86%	6455	83%	6142	85%	5044	78%	5047	79%	6367	80%	5895	82%
Research grants nat.	620	8%	707	9%	556	8%	811	12%	776	12%	810	10%	715	10%
Research grants inter.	105	1%	36	1%	58	1%	88	1%	96	1%	222	3%	101	1%
Contract Research	338	5%	571	7%	484	7%	555	9%	484	8%	541	7%	496	7%
Other	0		0		0		0		0		0		0	
Total Funding	7379	100%	7769	100%	7240	101%	6498	100%	6403	100%	7940	100%	7207	100%
Expenditure	k€	%	k€	%	k€	%	k€	%	k€	%	k€	%	k€	%
Personal Costs	5299	70%	5001	70%	5321	70%	4596	66%	4629	66%	5080	69%	4988	68
Other Costs	2314	30%	2186	30%	2241	30%	2330	34%	2419	34%	2302	31%	2293	32
Total Exepnditure	7613	100%	7187	100%	7562	100%	6926	100%	7048	100%	7382	100%	7281	100&

Table 2: Research funds.

established to very young staff members. For a broader selection of fifteen research highlights, see also Appendix A.2.

Discontinuous Galerkin Methods

The research on the development, analysis and application of discontinuous Galerkin (DG) finite element methods in the Mathematics of Computational Science (MaCS) Group, lead by van der Vegt, has received significant international recognition. Highlights are space-time DG methods for compressible, incompressible and two-phase flows, Hamiltonian structure preserving DG algorithms for free surface flows, DG discretisations for non-conservative hyperbolic partial differential equations, and novel multigrid algorithms for high-order accurate DG discretisations. Many of these techniques have been incorporated in the public domain hpGEM software under development in the MaCS group.

Numerical continuation

Numerical continuation quantifies the effect of varying parameters on the qualitative dynamics by bifurcation diagrams. Meijer and Kuznetsov have developed new methods that cover all known codim 1 and 2 bifurcations of steady states and cycles. Continuation requires good initial data. Based on homotopy and asymptotics, we have invented new algorithms for the initialisation of global bifurcation analysis. The software has been downloaded about 25000 times, and has been used in more than 400 research papers. In addition, various groups use the software in graduate courses. The current status has been presented at an invited mini-symposium at the SIAM Annual Meeting 2014 in Chicago, organised by the SIAM Activity group on Dynamical Systems.

Algorithm Analysis

Led by tenure tracker Manthey, the Department develops new methods for the analysis and design of algorithms, such as probabilistic and smoothed analysis. The goal is to reconcile theory and practice for the case that classical methods fail to explain the performance of algorithms. This research received funding from the German DFG and NWO (Open Competition, TOP2), and a recently organised Dagstuhl workshop on the "Analysis of Algorithms beyond the Worst Case" (2014), co-organised with T. Roughgarden (Stanford), M. Balcan (Georgia Tech) and H. Röglin (Bonn), testifies the relevance and timeliness of this research. The high quality of this research is also confirmed by publications in top journals such as Journal of the ACM (2011).

Discrete Choice and Learning Problems

Tenure tracker Den Boer works on multi-armed bandit problems with discrete-choice models: How do people choose and how to optimally respond to these choices? This connects two research areas: choice modelling and online learning. It establishes a deeper understanding of statistical estimators widely used in practice, and also addresses problems in adaptive design of experiments. This work is relevant to a variety of applications in business, psychometrics, and healthcare economics. Den Boer's research appears in

Academic publications	2009	2010	2011	2012	2013	2014	Total
a. Refereed articles	75	67	57	84	82	84	449
b. Non-refereed articles	3	2	2	1	4	0	12
c. Books	0	0	0	2	0	0	2
d.1. Refereed book chapters	4	3	1	9	1	0	18
d.2. Non-refereed book chapters	0	1	1	0	0	0	2
e. PhD theses	6	7	4	11	16	8	52
f. Conference papers	48	62	56	56	59	46	327
Total academic publications	136	142	121	163	162	138	862
Number of PhD theses per staff member with ius promovendi	**0,55**	**0,64**	**0,36**	**1,10**	**1,60**	**0,89**	5,13

Table 3: Research output.

journals such as Mathematics of Operations Research (2014), is in teaching programs of international Business schools (Stanford, Columbia, Chicago), and has been recognised by an NWO VENI grant and the Gijs de Leve PhD Award.

3.2 Demonstrable Products – Research products for peers in science

Journal and conference publications

Table 3 shows the quantitative research output of the Department. It is worth mentioning that – in line with our research strategy – our publications appear in journals within the core discipline, such as Mathematics of Operations Research, Journal of the ACM, Journal of Mathematical Biology, Journal of Computational Science and IEEE Journal on Automatic Control, but also in journals of adjacent disciplines, such as Econometrica, PNAS, Journal of Computational Physics, European Journal of Neuroscience, Journal of Fluid Mechanics.

books

During the review period two books were published:

Jacob, B. and Zwart, H.J. (2012) Linear Port-Hamiltonian Systems on Infinite-dimensional Spaces. Operator Theory: Advances and Applications 223. Springer Verlag, Basel. ISBN 978-3-0348-0398-4

Saberi, A. and Stoorvogel, A.A. and Sannuti, P. (2012) Internal and external stabilisation of linear systems with constraints. Systems & Control: Foundations & Applications. Birkhäuser, New York. ISBN 978-0-8176-4786-5

Dissertations

During the review period the number of dissertations per year has increased, see Figure 2. In the first three years the total number is 16, while it is 33 during the last three years. We anticipate that the average number of dissertations per year will stabilise at 10 per year. This requires approximately 44 PhD students, given the drop out rate of 10% percent. Some of our PhD and MSc students have also received awards such as:

- N. Kortbeek: ORTEC excellence in Advanced Planning Award 2010, Beta PhD Award 2013.
- P.T. Vanberkel: ORTEC Excellence in Advanced Planning Award 2012, Canadian Operations Research Society's Practice Prize 2012.
- M. Mitici: Best Presentation Award at WIC/IEEE SP 2014.
- J. Mikhal: Philips Mathematics Price for PhDs, 2011.

- A. Ohazulike: TRAIL rookie of the year award, 2010.
- S. Rhebergen: Rubicon fellowship from NWO, 2010.
- M. v.d. Vrugt: KIVI NIRIA/UT Internship award 2010.
- A. Rouwette: KIVI NIRIA Cuperus award 2010.
- A. Braaksma: Menzis UT MSc award 2011.

Moreover, several of our PhDs succeeded in getting attractive academic positions worldwide, for example at the MIT, RWTH Aachen, Zhejiang University, Oxford University (UK) and University of Waterloo (Canada).

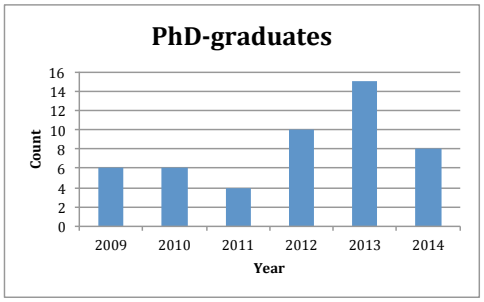
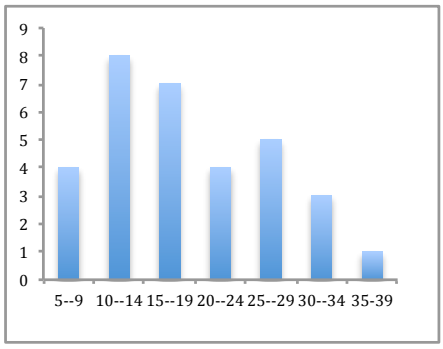
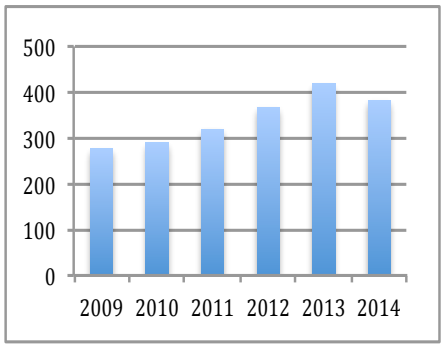


Figure 2: Number of PhD's per year.



(a) Distribution of H-indices.



(b) Citations per research-fte and per year.

Figure 3: Citation scores.

Citations and H-indices

Figure 3a gives an overview of the distribution of H-indices of our scientific staff (tenure-track and tenured staff as well as part-time professors) based on Google Scholar. Eight staff members have an index of 20 or higher. The peak is at 10–14, containing several of the young and promising staff members. For a detailed overview see A.6. Figure 3b gives the citations per research-fte for the review period, based on Google scholar. It shows a tendency to increase.

Table 4 gives the number of short-term and long-term visitors .

	2009		2010		2011		2012		2013		2014	
Group	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long
Computational Science	3	9	16	5	7	3	7	3	7	2	8	2
Operations Research	11	2	7	1	11	2	16	5	24	11	7	4

Table 4: Short-term and long-term visitors.

Software Tools

The software that we list below have been (co)developed by researchers of the Department. They are used in practice or serve as tools for peers inside and outside academia.

- MatCont, Matlab public domain software for numerical continuation and bifurcation studies of continuous and discrete parameterised dynamical systems. By W. Govaerts (Gent, B), A. Kuznetsov (UU and UT) and H. Meijer (UT).
- hpGEM, public domain software to support the development and application of discontinuous Galerkin finite element methods. By the MACS group, in collaboration with the Multi-Scale Mechanics (MSM) group in the Mechanical Engineering Department.
- TRIANA, control software for smart grid energy systems. By the DMMP group in collaboration with the Computer Architecture for Embedded Systems (CAES) group in the Computer Science Department. This software is being developed in collaboration with RWE Germany and currently field tested in a kindergarten in Haren (D), as well as in 25 private houses in Wertachau (D).
- Aerosim, a module for the multiscale analysis and simulation of aerosol formation and transport. This software is being developed in collaboration with industry and is being used for advanced design of aerosol generators. It is embedded in the community code OpenFOAM to stimulate its global use in other disciplines.
- Hawassi: software for the simulation of a wave tank, coastal and oceanic water waves for research on modelling of coastal engineering applications and for simulations of practical problems in hydrodynamic laboratories, coastal and ocean engineering, and the maritime industry.
- XHSTT is a schol timetabling platform that has been developed and is being maintained at the department (DMMP). In 2011 an International Timetabling Competition has been organised. By now there are almost 50 instances available, and they are used extensively in scientific research on the development of algorithms for timetabling worldwide.

3.3 Demonstrable marks of recognition – Marks of recognition from peers

Personal grants, awards, prizes, memberships

The previous Assessment Committee observed that the Department lacked junior staff that had the potential to score in personal grant competitions. We have since attracted six young tenure trackers in core research areas, namely B. Manthey (Algorithms), P. Frasca (Hybrid Systems), Chr. Brune (Image Processing), P. Dickinson (Optimisation), A. den Boer (Stochastics & Statistics) and J. Goseling (Random Processes).

Research grants to tenure trackers

The first signs of success of this rejuvenation strategy are the NWO OC and TOP2 grants for B. Manthey (2011 and 2014) 435k€, the two NWO tenure track grants for Chr. Brune and P. Dickinson, 360k€ (2014), the NWO VENI grant for A. den Boer, 250k€ (2014), and a MIRA research voucher for Chr. Brune, 50k€ (2014).

Recognition for senior staff

Senior staff of the Department received substantial external funding for PhD students from STW, NWO and hospitals: Boucherie obtained funds for 10 PhD positions in health care logistics during the review period, Geurts and van der Vegt obtained funds for 19 PhD positions in computational science, and Hurink obtained funding for 7 PhD en 2 PostDoc positions for optimisation for energy systems in cooperation with Prof

G.J.M. Smit from the chair CAES of the Computer Science Department.

Scientific leadership

We pursue a role as leader in scientific programs. Van der Vegt served as the chairman of the Scientific Computing Community in the Netherlands and Belgium from 2011–2014. Geurts is Chairman of the Scientific Program Committee of ERCOFTAC (European Research Community On Flow, Turbulence And Combustion), and was founding chairman of 3TU.AMI. Mandal and Bagchi are project leaders of two Marie-Curie training networks: Tracking in Complex Sensor Systems (2013–2017) and Monte Carlo based Innovative Management and Processing for an Unrivalled Leap in Sensor Exploitation (2009–2013). Uetz is member of the steering committee of MAPSP (Models and Algorithms for Planning and Scheduling Problems).

Awards

- N. Litvak: Professor De Winterprijs (2011)
- N. Litvak: Google Faculty Research Award (2012)
- A. den Boer: Gijs de Leve PhD award (2014)
- P. Frasca: Best Paper Award SIAM (2013)

Editorships, editorial boards, relevant committees

The Department fulfils duties in various scientific committees and editorial boards. For instance Uetz is Area Editor for Operations Research Letters, Litvak is Managing Editor for Internet Mathematics and Boucherie is Editor in Chief of "Nieuw Archief voor de Wiskunde".

We serve in the editorial boards of more than twenty international journals, including Computers and Fluids, Operations Research Letters, J. Scheduling, Queuing Systems, J. Mathematical Neuroscience, Int. J. Robust and Nonlinear Control, and J. Scientific Computing.

We also serve in program committees or as cluster chairs for international conferences with refereed proceedings. Examples include the European Symposium for Algorithms (ESA), the Workshop on Graph-Theoretic Concepts in Computer Science (WG), the Annual Int. Computing and Combinatorics Conference (COCOON), the Workshop on Approximation and Online Algorithms (WAOA), the Int. Workshop on Algorithms and Models for the Web-Graph (WAW), the Int. Conf. on Wired / Wireless Communications (WWIC), Operations Research (OR), and the INFORMS Applied Probability Society Conference (APS).

Selection of Invited lectures

Researchers of the Department are internationally recognised experts in their respective fields, and regularly invited as lecturers. A selection is made in the table below.

name	role	conference	place	period
Geurts	keynote	European Turbulence Conference	Warsaw, Poland	Sept 12–15 (2011)
Uetz	semi/plenary	Computability in Europe (CiE 2009)	Heidelberg, Germany	July 19–24 (2009)
vd Vegt	keynote	International Conference on Spectral and High Order Methods ICOSSAHOM	Gammarth, Tunesia	June 25–29 (2012)
Schwab	plenary	Computational Neuroscience CNS	Québec, Canada	July 26–31 (2014)
Zwart	plenary	The 21st International Symposium on Mathematical Theory of Networks and Systems (MTNS 2014)	Groningen, NL	July 7–11 (2014)
Litvak	keynote	9th Workshop on Algorithms and Models for the Web Graph (WAW2012)	Halifax, Canada	June 22–23 (2012)

Organisation International Conferences

We have organised, among others, the following international conferences or workshops.

- 9th Workshop on Models and Algorithms for Planning and Scheduling Problems (MAPSP 2009, 130 participants).
- 12th Cologne Twente Workshop (CTW 2013, 80 participants).
- 2nd Dutch AMI Day on Computational Game Theory (2012, 40 participants).
- 2nd NWO-NSFC Workshop on Game Theory & Applications (2013, 40 participants).
- Dagstuhl Workshop "Analysis of Algorithms Beyond the Worst Case" (2014, 30 participants).
- ETMM Conference Series – biannual conference of ERCOFTAC (240 participants).
- DLES Workshop Series – biannual workshops on direct and large-eddy simulation of turbulence (120 participants).
- Lorentz workshops (Brain Waves (2009), Computational Neuroscience and the Dynamics of Disease States (2011), Mathematics from biology and biology from mathematics: a roundtrip in the light of suns and stars (2013), Port-Hamiltonian systems (2014). Rainfall and Marine Snow: How Small-Scale Physical Interactions have Large-Scale Consequences (2014).
- Workshop on Uncertain Dynamical Systems (WUDS 2014).
- Benelux meeting on systems and control, (Heeze, The Netherlands, 2010, 243 participants).
- DISC summer school on optimisation in control theory (2012, 45 participants).
- IWOTA-2014 - yearly workshop on operator theory and its applications (2014, $\pm$ 300 participants).

International Guests and Visiting Professorships

- Zwart was Mercator Professor at the Bergische Universität Wuppertal, Germany (2010, 2011)
- Van Gils was long term visitor at the MBI, Columbus Ohio (2013)
- Van der Vegt was visiting professor at USTC, China, in 2012, 2013 and 2014, each year for a period of two months, with a distinguished fellowship from the Chinese Academy of Sciences.
- Geurts was invited as long-term visitor to the IPAM (Los Angeles) program on Mathematical Turbulence Modelling (2010) and the Banff Center program on Regularization methods (2012).
- Stoorvogel is adjunct professor at the department EECS of Washington State University, Pullman, U.S.A. (whole period)
- Uetz was visiting professor at Zhejiang University, China (2010), at the IBM T.J. Watson Research Center, U.S.A. (2011), and the TU Berlin, Germany (2014)

Coordination of research projects, centres, etc.

We coordinate the following research programs and research centres.

- CHOIR is a research initiative at UT that aims to improve healthcare logistics by developing tailored operations research models for healthcare optimization problems from practice; see Section 4 and the narrative in Appendix A.3.4 for more details.
- COST Action "LESAID" (2008–2013): this collaborative research program in the field of large-eddy simulation for advanced industrial design was chaired by prof. Geurts and funded by the EU Framework Programme. It brought together researchers and industries from over 17 European countries. Chaired by prof. Geurts (2008–2013; 450 k€).

4 Relevance to Society

Our Department focusses its applied mathematical research on Health, Energy and High-Tech systems. In the past years significant steps were made to bring the fruits of this work in direct contact with relevant societal parties to enhance the impact of our work. This work is described here.

Health

In the field of Health an intensive collaboration developed with Dutch hospitals. The operations research groups are involved in health care planning (see also the Narrative on Health Care Logistics in Appendix A.3.4), while the computational science groups are involved in modelling and treatment of diseases (see also the Narrative on Parkinson's disease in Appendix A.3.1).

Disease Modeling

The disease modeling activities develop mathematical models to understand key dynamics in developing neurological and circulatory disease patterns. From 2009 onwards, the Applied Analysis group has changed its research focus to mathematical neuroscience. In the Smartmix program Braingain it was involved in modelling of neurostimulation for Parkinson's disease. In collaboration with the Biomedical Systems & Signals group (BSS, UT), the Amsterdam Medical Center and Philips Healthcare, network models have been developed to systematically study brain dynamics under Parkinsonian conditions. This improved the electrode implantation for deep brain surgery, which is currently used by Medtronics.

The Painsight project is funded by the STW Perspective Programme NeuroSIPE, involving the BSS and AA groups of UT and the University Medical Centre St. Radboud in Nijmegen. The project focuses on parameter identification of the nociceptive system for improved monitoring of chronic pain development. Psychophysical testing methods with controlled electrical stimulation together with mathematical closed loop identification methods were developed, to gain insight in the dynamical properties of the nociceptive system.

Epilepsy is mathematically extremely challenging as it deals with emerging global changes in brain dynamics during seizures. In collaboration with the University Medical Center Utrecht it is currently investigated how a patient specific network model of the cortex can help detect which area is responsible for the development of epileptiform activity. This project is funded by the NEF (the Netherlands Epilepsy Foundation).

The Multiscale Modeling and Simulation group developed computational modeling methods to analyse the flow of blood in the brain. Coupling high-resolution medical imagery with detailed flow-resolving simulations a patient-specific method for the risk of rupture analysis of aneurysms was developed in collaboration with the Systems and Signals group (UT) and the Neuroradiology Department at the AMsterdam Medical Center.

CHOIR

Since 2003 prof. Hans from IEBIS and prof. Boucherie (SOR) have been collaborating on the development of Operations Research methods for logistics planning in healthcare. In 2008, under the umbrella of the STW funded LogiDOC project, the hospitals LUMC, NKI, AMC, and Haga, as well as ORTEC and CTIT co-funded 6 PhD students. All PhD students are half-time in a hospital and half-time at UT, thereby directly participating in the dissemination of Operations Research methods in the clinic.

To further extend the network of hospitals and facilitate sharing of information on Operations Research solutions among hospitals, in 2008 Hans and Boucherie co-founded the research Center for Healthcare Operations Improvement and Research (CHOIR), which currently trains 10 PhD and 25 MSc students, mostly funded by healthcare organisa-

tions. The results of CHOIR have been recognized both in healthcare and operations research via various awards.

A large share of research results from CHOIR have been adopted by healthcare organisations via prototype planning tools. To further develop and implement these tools, in 2014 profs Hans and Boucherie, jointly with CHOIR alumnus dr. Nikky Kortbeek, and ORTEC co-founded the spin-off Rhythm B.V. that now has 8 employees.

Energy

The chair Discrete Mathematics and Mathematical Programming (DMMP) has set up an intensive collaboration with the chair Computer Architecture for Embedded Systems (CAES) in the field of Decentralised Energy Management (DEM), see also A.3.2. This is a new and fast developing research area, which deals with challenges for the planning and control of the future electricity grid. Key to this are so called smart grids enabling efficient use of all forms of energy through "smart" solutions taking decentralised optimisation on all levels into account.

Starting in 2007 with two projects on the influence and role of micro combined heat and power systems (financed by STW, Essent, Gasterra and E.ON), the research of the chairs DMMP and CAES has broadened to more general concepts for DEM. This has led to a novel decentralised energy management platform, called TRIANA, which core ingredients are prediction, planning and real time control.

Currently, 9 projects with 7 PhD students and 2 PostDocs are running, covering both modelling of micro grids and storage devices, as well as analysis of field tests. These projects are financed by FP7, TKI, STW perspectief, NWO, STW, EIT, and Deutsche Bundesstiftung Umwelt projects, and by industrial partners such as Alliander, RWE, Locamotion, Lochem Energy, Eaton, TU/e, CWI, Siemens, Meppelenergy, TU Delft, TNO. More details can be found on website Energy in Twente.

High tech systems

Since 2013 the research on high-tech systems is conducted within the MESA+ Institute for Nanotechnology, see also the Narrative on Discontinuous Galerkin Finite Element Methods in Appendix A.3.3. This resulted in a significant change of focus in our research after the termination of the UT research institute IMPACT in 2012. The central theme is multiscale problems, which are abundant in many industrial applications and (geo)physical problems. To advance the modelling and simulation of multiscale problems the MMS and MACS groups have focused on making mathematically consistent models accessible for computation, and to develop, analyse and apply new numerical methods.

In the field of new materials and devices for energy *Solar cells* are very promising. In a close cooperation with the MESA+ Complex Photonic Systems group, three PhD students are currently developing novel techniques to improve the absorption of interfering light. Also, the development and use of optical metamaterials in solar cells, such as photonic crystals, is an important research topic. Moreover, *nano-engineering* of novel materials to enhance thermo-electric efficiency is a field of growing importance. In a collaboration with the MESA+ Inorganic Materials Science group research is conducted by MMS on multiscale quantum systems.

The study of *turbulent flows* has focused on the development and analysis of subgrid scale models and uncertainty quantification for Large Eddy Simulation, combustion, particle transport, and phase transition (boiling and evaporation). These topics are important in industrial applications, e.g., energy production and process engineering, and were conducted in close cooperation with industry (Stork). Also, the study of particulate flows in lungs is a research topic with high potential in developing new inhaler concepts.

Career destinations after graduation		Number PhD's Computational Sciene	% CS	Number PhD's Operations Research	% OR	Total PhD	% Total PhD
Faculty staff	Netherlands						
	abroad	2	6,9	5	16,7	7	11,9
Postdoc	Netherlands	9	31,0	4	13,3	13	22,0
	abroad	3	10,3	4	13,3	7	1,7
Industrie	R&D	10	34,5	8	26,7	18	30,5
	non R&D			2	6,7	2	3,4
Consultancy		3	10,3	3	10,0	6	10,2
unknown		2	6,9	4	13,3	6	10,2

Table 5: Career choices of PhD graduates.

4.1 Demonstrable products – Research products for societal target groups

Table 5 shows the career choices of the graduated PhD-students. From the graduated PhD-students approximately 45% continued with an academic career and approximately 45% went to industry and consultancy.

4.2 Demonstrable use of products – Use of research products by societal groups

STW and industry projects

The Technology Foundation STW realises the transfer of knowledge between the technical sciences and users. Only proposals with innovative research and a high potential for utilisation are funded. To ensure this, an STW proposal contains a compulsory utilisation section. Once a proposal is granted, a users committee, with members of participating companies, supervises and steers the research.

During the review period 6 STW programs have been granted and 10 were running. In particular, this involves the Maritime Research Institute Netherlands (MARIN), the Royal Netherlands Institute for Sea Research (NIOZ), ANSYS, NRG and ASCOMP, ORTEC, the Centre for Human Drug Research (CHDR) and several Dutch medical centers.

Appendix A.4 gives a list of all externally funded projects during the review period. These add to a total funding amount of 14.6 M€, and a large share of these projects is with direct industry participation, such STW projects, funding by Agentschap NL, or direct industry funding. Other research projects with direct funding from the University, international grants, or funding by the research institute CTIT are listed in Appendix A.5, and amount to another 2.1 M€.

4.3 Demonstrable marks of recognition – Marks of recognition by societal groups

Education of highly-qualified engineers

There is a strong link between our research activities and the educational programs. The development of new mathematical techniques directly contributes to the programs and supports the education of highly qualified engineers, in particular, in the Masters Program.

Spin-off companies

In 2014, in collaboration with Ortec, PhD graduate N. Kortbeek, R. Boucherie and E. Hans initiated the spin-off company Rhythm B.V. to develop software tools, and to

implement CHOIRs operations research algorithms in healthcare. In December 2014, Rhythm had 6 full-time employees.

In a unique combination of algorithm design, nanofabrication and cell biology, we have developed an algorithmic framework to *design optimal surface topographies* for biomaterials, e.g. for implants, aiming to crack the topographic code that a cell can 'read' and unravel the so-called 'toposome'. This project is a collaboration that was partially funded by KNAW, and was embedded in the research institute MIRA. The most remarkable outcomes of this project are:

- a PNAS publication: An algorithm-based topographical biomaterials library to instruct cell fate, H. Unadkat, M. Hulsman, K. Cornelissen, B. Papenburg, R. Truckenmüller, G. Post, M. Uetz, M. Reinders, D. Stamatialis, C. van Blitterswijk, J. de Boer. *Proceedings of the National Academy of Sciences of the U. S. A.*, 108(40), 2011, 16565–16570,

(also mentioned as *research highlight* in *Nature*, 478, 2011).

- a spin-off company: Materiomics with a yearly turnover of €238,000 (in 2014) and 8 (part-time) employees.

Collaborative networks

ERCOFTAC: The European Research Community On Flow, Turbulence And Combustion is a major research network across Europe, established in 1988. Prof. Geurts is the Chair of the Scientific Program Committee since 2009, guiding over 20 Special Interest Groups and over 14 national Pilot Centres.

Participation in the activities of STW, FOM, RVO, NWO, KNAW, ministries and similar organisations abroad

Van der Vegt was chairman of the Scientific Computing Community (2011–2014), is member of the FOM/NWO/Shell program committee "Computational Sciences for Energy Research" (since 2013), was member of the STW program committee for "Multiscale Simulation Techniques" program (2007–2015) and is member of the "NWO-Middelgroot" committee (since 2013).

Hurink participated in the Dutch Economic Mission to California (San Francisco) on "Sustainable Urban Deltas" (Febr. 2015).

Geurts was founding Scientific Director of 3TU.AMI (2009–2011), the Applied Mathematics Institute of the 3TU Federation.

Boucherie participated in the Dutch economic mission to Romania (Bucharest) on "Opportunities through innovation" (April 2014).

Outreach

TV broadcast EenVandaag: Energieakkoord – doorbraak of doekje voor het bloeden? (Nov. 2013), with Johann Hurink.
(Energy agreement – breakthrough or cosmetic measures)

TV broadcast RTL news: Ziekenhuizen kunnen 30% meer patiënten helpen, RTL nieuws 19:30 uur, 21 November 2013, with Richard Boucherie.
(Hospitals can serve 30% more patients)

Radio broadcast "Dit is de dag": Niet bang zijn voor wiskunde. EO Radio 1, 13 april 2011, with Richard Boucherie.
(Don't be afraid of mathematics)

Financieel Dagblad "Het aantal SEH's is politieke keuze" (Page 7, 20 juni 2011 (with Bart Veltman, Arnoud Kuiper, Erwin Hans, Richard Boucherie).
(The number of trauma wards is a political choice)

Senior staff paid for by societal groups

We have three senior staff members paid for by a societal group:

- Dr. M. de Graaf, associate prof. 0.2 fte, 01-01-2006 – 01-04-2016, Thales.
- Dr. M. Bocquel, associate prof. 0.2 fte, 01-06-2014 – 01-05-2019, Thales.
- Dr. A.K. Kuczaj, associate prof. 0.2 fte, 01-09-2013 – 01-09-2016, PMI.

5 SWOT analysis

The SWOT analysis of the Department is as follows:

- *Strengths*
  - High quality in applications of mathematics, as reflected in a large number of multidisciplinary research grants, a large international network, spin-off companies and international position in leading conferences.
  - Six tenure trackers were recently appointed, and the hiring for three additional positions is ongoing. The selection of these candidates strengthens both quality and profile of the Department in the mathematical sciences.
  - Our strong position in the Mathematics Clusters NDNS+ and DIAMANT helped secure funding for two tenure track positions (Brune, Dickinson).
  - The spectrum of applied research activities has strong contacts with other Departments and is strategically lined-up with UT research institutes. The work is of high quality and strongly connected to large technological research institutes in the Netherlands and a variety of industries worldwide, including health care organisations and energy suppliers.
  - The Department chairs two research centres (CHOIR and the Centre for Green ICT) emphasising our role in multidisciplinary research.
  - Strong contacts with industry supporting a steady second and third-tier research volume of 17% on average.
- *Weaknesses*
  - The number of personal grants was low during the review period.
  - High teaching load of staff members competes with research activities.
  - Even though the influx in the BSc program has grown considerably recently, we loose share in a currently growing market. The MSc programs have little influx from outside.
  - Small representation in KNAW, in NWO, and in EU governing boards, which limits setting research directions and success in raising funds.
- *Opportunities*
  - We have strong expertise in Optimisation and Scientific Computing which are important for research in Energy, Health and High-Tech Systems. These areas are key in Twente and appear prominently in several funding programs.
  - The research institutes at the University of Twente provide critical mass and

context for project acquisition.

  - Key themes of energy, high-tech systems and health are becoming increasingly important.

  - 3TU collaborations lead to more visibility and cooperation on the national level.

- *Threats*

  - Reduction of research funding makes it difficult for scientists to acquire projects, which especially affects Tenure Trackers.

  - Mathematics is poorly positioned in the national research agenda of the "Top Sectors" – specifically, there are few thematic programs that fit the fundamental nature of research in Mathematics.

  - Applied Mathematics, by its very nature, cannot be prime mover in attracting funding for technologically motivated research. This creates asymmetry in multidisciplinary collaborations, e.g., related to acquisition of funding.

5.1 Strategic choices for the future

With the rejuvenation of the staff by the appointment of 6 tenure trackers, and still 3 tenure track positions available, we will increase the number of personal grants. The new staff has a reduced teaching load and is being coached individually, e.g., through developing a personal research plan, where acquiring funding is explicitly addressed.

We aim to strengthen the interaction between analysis, mathematical modelling, optimisation, statistics and numerical methods. This is part of a Department-wide drive toward intensified collaboration among the staff, bringing new combinations of expertise to work in high-level fundamental and multidisciplinary programs.

The low influx of outside MSc students was recently addressed by adopting a new curriculum. This facilitates high quality MSc students to develop a tailored program with a joint basis in optimisation and computational science. To make UT more attractive for foreign students is high on the agenda of the board of the university and the management team of the faculty.

In reaction to the poor positioning of Mathematics in the "Top Sectors", and in line with the Departments strategy, we now actively engage in the definition of new research programs within the Departments application domains. Recent examples include the Computational Science program funded by NWO and Shell, and our contribution in the setup for the 2015 NWO program "Energy System Integration: planning, operations, and societal embedding". Van der Vegt plays a leading role in the former, while the energy group of Hurink and Smit was involved in writing the call for the latter. Another example is a new program in Brain research, where Mathematics will play an essential role, involving Van Gils in a leading role on behalf of 3TU.AMI. Such initiatives will help to secure future funding for the research areas of the Department.

6 Reflection and future strategy

6.1 Reference to previous assessments

The Department of Applied Mathematics was assessed in 2009 over the years 2003–2008, followed by a midterm review in 2013 over the years 2009–2011. The recommendations of the assessment of 2009 were in part taken into account already before the midterm review of 2013, that concluded clear signs of progress. In 2013 the faculty EEMCS was reorganised leading to a reduction of the permanent staff of about 25%. It was the opinion of the Management Team, supported by the Board of the University, that the Department of Applied Mathematics should have a minimal research staff of 12fte. To substantiate this view, the Department was assessed by prof. van der Vorst. He explicitly addressed the research volume of the Department of Applied Mathematics, coherence in the Department, the embedding in the scientific institutes, and the selected application areas. Following his report, the board of the university guaranteed the research volume of the Department at the level of 12 fte. Additional staff was hired in Tenure Track positions to reach this level, and replacement of staff due to e.g. retirement is guaranteed. The position of mathematics in the UT Research Institutes was changed to a more independent position.

The assessment of 2009 raised "questions about coherence, long-term research, and visibility outside UT", "fragmentation of knowledge", and "the multidisciplinary embedding puts undesirable restrictions on the hiring of talented young researchers and excellent replacements for the retiring leaders". These points were addressed by re-organising the Department in two research lines, that share a number of application areas on which research lines interact, as well as a re-orientation of the research lines focusing on the mathematical coherence of the Department. The department is also more active in national and international initiatives. For example, the Department now participates in the three NWO clusters DIAMANT, NDNS+ and STAR , and has obtained 2 Tenure Track positions from the last funding round in these clusters. Given the more independent positioning of the Department in the context of the research institutes, the basis was laid for hiring of talented new staff. The first signs of success have been obtained in the NWO Top funding (one grant) and VENI funding (one grant).

6.2 Viability and future strategy

societal impact

Mathematical science is a key-enabler of technology for modern society. In line with this development, research is shifting from a mono-disciplinary to a multidisciplinary character, in which also societal aspects play an important role. We aim to strengthen our connection to hospitals and industry to increase our impact on society. We will do this by maintaining our network and involving the tenure trackers and our graduates to even enlarge it. At the same time, we will keep our focus areas in health, energy and high tech systems to avoid too much diversification.

Viability

By appointing 9 fte junior researchers in Tenure Track positions rejuvenation of staff is realised, see also Section 6.2. Junior staff will be actively supervised in developing their own research position, including training and supervision in the acquisition of personal grants. They are actively involved in activities of the UT Research Institutes and they are coached by an experienced person from another department. The permanent staff research volume of each of the 2 research lines of the Department will be roughly 6

fte. This volume of research fte will enable us to maintain a strong position in research funding, and also secures substantial research efforts to maintain our core mathematical expertise.

Changing world

In the next 5–10 years the Department wants to contribute to global grand challenges, in line with our current focus on health, energy and high tech systems. To realise this, we aim to increase European funding from 1% at present to 5% in 2020 and 10% in 2025. It is our challenge to create more coherence within the two research lines, but also across. We will bundle our effort for the three UT Research Institutes, thus creating bigger entities that are better positioned to acquire external funding.

7 Research integrity

7.1 Procedure for issues of scientific integrity

The UT website explains how the UT deals with issues concerning scientific integrity. The UT subscribes to the guidelines for scientific integrity, as specified in the Netherlands Code of Conduct for Academic Practice. The European code of conduct and the Singapore statement on research integrity are also relevant as well as the advice of the KNAW about correct citations.

The Executive Board established the Scientific Integrity Complaints Procedure in order to protect and guarantee scientific integrity. This procedure provides a system for reporting and dealing with possible violations of scientific integrity. This procedure is consistent with the LOWI regulations.

The first point of contact is the university's confidential advisor for scientific integrity, emeritus prof. L. (Leen) van Wijngaarden. Possible violations of scientific integrity as well as any follow-up steps can be discussed with him in all confidence. He decides whether the reported violation of scientific integrity will be dealt with by the appropriate committee, comprised of:

- Prof. J.J.A. (Jacques) Thomassen (emeritus, chairman)
- Prof. L. (Leon) Lefferts
- Prof. B.R. (Bärbel) Dorbeck-Jung (emeritus)
- Prof. P. (Piet) Bergveld (emeritus)

The decision of the committee is send to the Executive Board of UT for further action. This involves sending the advice to the complainant and the accused party. If the complainant and the accused party do not ask for further advise from the National Body for Academic Integrity (LOWI) the Executive Board determines its opinion on the complaint and takes appropriate measures.

Within EEMCS, attention to scientific integrity is given on various levels. In the first modules of the curriculum research integrity and avoiding plagiarism are already taught. Scientific integrity also receives explicit attention during the BSc and MSc projects and in the training of PhD students. When writing their theses, all students are taught how to deal with quotations, citations and references.

7.2 The Ethics Protocol in the faculty of EEMCS

Since 2012, an Ethics Protocol is used in the faculty of EEMCS to assess research proposals involving human subjects who might be harmed as a result of the research proposed. The judgment of the ethical permissibility does not include medical research. Medical research proposals must be submitted to a Medical Ethics Committee for legal reasons.

From 2012 to June 2014 a total of 46 research proposals were assessed, many of them being part of master assignments. The vast majority came from the Computer Science Department. There was one proposal from AM involved.

7.3 Data policy

Within AM there is a policy to store relevant data and take care of a regular back up of this data. Data protection and data privacy requires more actions. This is realised by the university board and extensively discussed within the faculty. In the next step the departments have to implement this according to their own situation.

New strategy

Based on the discussions about this self study the following procedures have been agreed upon and will be implemented from now on:

- PhD, MSc and BSc theses, and all paper related information, including the data used for writing the thesis and the papers are stored on a server of the UT.
- When students leave they must hand in all relevant information in a well-documented directory structure. MSc and BSc students must complete this procedure in order to get their final mark, PhD students must complete this before the public defence of the thesis.
- If relevant, data are made available online or made available on request.

On a central level, the library of UT offers support for storage of research data. UT is working on a central data policy: facilities and procedures are under development at this moment. In 2014 a UT data librarian was appointed. He provides support for durable management of research data and for setting up data management plans, which are compulsory for projects of NWO and Horizon 2020 of the EU. The 3TU.Datacentrum offers possibilities for durable archiving of research data.

8 Phd programmes

8.1 Graduate and research schools

National Research Schools

Several research groups participate in national research schools and PhD training programmes: Beta (DMMP, SOR), LNMB (DMMP, SOR), DISC (HS), JM Burgers Center (MACS, MMS). These schools and programmes offer regular PhD courses and summer schools. They all have their own rules with respect to the educational programme. The department actively participates in the management of the LNMB (Johann Hurink is director), as member of the management team (Beta, LNMB: Boucherie; DISC: Zwart), or board member (JM Burgers centre, vd Vegt, 2011–2014).

Twente Graduate School (TGS)

Since 1 January 2014 all PhD students are registered in the Twente Graduate School (TGS). As a result uniform procedures and rules apply for all PhD students:

- central registration of all PhD students in the ProDoc system
- PhD charter
- GO/NO-GO decision during first year incl. formal appointment of the promotor
- digital Training and Supervision Plan (T&SP) in the ProDoc system
- forecast and drop-out registration.

The Training and Supervision Plan is obligatory for all categories of PhD candidates. A copy of the agreed T&SP is kept in the central ProDoc archive.

The Training and Supervision Plan follows a strict format. It contains a summary of the research plan, the supervision plan (detailing e.g., the frequency of meetings with the supervisors and the role of each supervisor), and the educational program to be followed by the PhD candidate. This amounts to 30 ECs (European Credits). It is defined by the candidate and the supervisor, and approved by the Dean. The educational program can contain courses offered by the University, national research schools and international programs, such as Summer Schools. The Training and Supervision plan further details the teaching obligations of the PhD candidate.

The plan is set up within three months after the start of the PhD candidate, and is periodically reviewed and updated. A formal 'qualifier' after nine months aims to determine a conclusive assessment whether or not to proceed with the remainder of the PhD project.

succes rates PhD's

The succes rates of our PhD-candidates is given in Table 6.

Success rates PhD-candidates

Enrollment				Graduated after								Total					
Starting year	Enrollment (male/female)		Total (M+F)	(<=) 4 years		(<=) 5 years		(<=) 6 years		(<=) 7 years		Graduated		Not yet finished		Discontinued	
	# M	# F	# Total	#	%	#	%	#	%	#	%	#	%	#	%	#	%
2006	7	2	9	2	22%	4	44%	4	44%	6	67%	6	67%	0	0%	3	33%
2007	3	0	3	1	33%	1	33%	3	100%	3	100%	3	100%	0	0%	0	0%
2008	6	5	11	1	9%	6	55%	7	64%	9	82%	9	82%	1	9%	1	9%
2009	4	2	6	1	17%	3	50%	3	50%	-	-	3	50%	2	33%	1	17%
2010	6	4	10	3	30%	8	80%	-	-	-	-	8	80%	2	20%	0	0%
2011	4	2	6	0	0%	-	-	-	-	-	-	0	0%	6	100%	0	0%
Total	30	15	45	8	18%	22	49%	25	56%	29	64%	29	64%	11	24%	5	11%

Table 6: Succes rates of PhD-candidates

A Appendices

A.1 Research staff at the institute

	Funding 1/2/3	2009 FTE	2010 FTE	2011 FTE	2012 FTE	2013 FTE	2014 FTE
Computational Science							
Full professors							
Albers, prof.dr. W.	1	0,40	0,40	0,40	0,00	0,00	0,00
Bagchi, prof.dr. A.	1	0,40	0,40	0,40	0,02	0,08	0,00
Geurts, prof.dr.ir. B.J.	1	0,32	0,37	0,40	0,40	0,40	0,40
Gils, prof.dr. S.A. van	1	0,40	0,40	0,40	0,40	0,40	0,40
Groesen, prof.dr.ir. E.W.C. van	1	0,28	0,28	0,28	0,00	0,00	0,00
Jamshidian, prof.dr. F.	1	0,08	0,04	0,00	0,00	0,00	0,00
Stoorvogel, prof.dr. A.A.	1	0,40	0,40	0,40	0,40	0,40	0,40
Vegt, prof.dr.ir. J.J.W. van der	1	0,40	0,40	0,40	0,40	0,40	0,40
Zwart, prof.dr. H.J.	1	0,00	0,00	0,00	0,00	0,07	0,40
Associate professors							
Bokhove, dr.ir. O.	1	0,40	0,40	0,40	0,40	0,04	0,04
Doorn, dr.ir. E.A. van	1	0,40	0,40	0,40	0,00	0,00	0,00
Hammer, dr. M.	1	0,17	0,00	0,00	0,00	0,00	0,00
Kersten, dr. P.H.M.	1	0,23	0,10	0,00	0,00	0,00	0,00
Polderman, dr. J.W.	1	0,16	0,16	0,16	0,16	0,16	0,16
Vellekoop, dr.ir. M.H.	1	0,27	0,00	0,00	0,00	0,00	0,00
Zwart, prof.dr. H.J.	1	0,40	0,40	0,40	0,40	0,33	0,00
Assistant professors							
Bochev, dr. M.A.	1	0,40	0,40	0,40	0,40	0,40	0,40
Brune, dr. C.	1	0,00	0,00	0,00	0,00	0,00	0,16
Brune, dr. C.	2	0,00	0,00	0,00	0,00	0,00	0,24
Frasca, dr. P.	1	0,00	0,00	0,00	0,00	0,23	0,40
Krystul, dr. J.	1	0,40	0,40	0,40	0,02	0,00	0,00
Mandal, dr. P.K.	1	0,40	0,40	0,40	0,40	0,40	0,40
Meijer, dr. H.G.E.	1	0,40	0,40	0,40	0,40	0,40	0,40
Meinsma, dr.ir. G.	1	0,40	0,40	0,40	0,40	0,40	0,40
Zagaris, dr. A.	1	0,00	0,13	0,40	0,40	0,40	0,40
Zagaris, dr. A.	2	0,13	0,27	0,00	0,00	0,00	0,00
Extraordinary chairs							
Clercx, prof.dr. H.J.H.		0,21	0,21	0,21	0,21	0,21	0,00
Kouznetsov, prof.dr. I.A.		0,00	0,00	0,07	0,21	0,21	0,21
Kuerten, prof.dr. J.G.M.		0,00	0,16	0,21	0,21	0,21	0,21
Veldman, prof.dr. A.E.P.		0,00	0,00	0,00	0,00	0,12	0,21
Researchers (incl.postdoc)							
Adytia, dr. D.	2	0,00	0,00	0,00	0,28	0,47	0,47
Ambati, dr. V.R.	2	0,90	0,90	0,45	0,00	0,00	0,00
Andonowati, dr. A.	2	0,24	0,24	0,04	0,00	0,00	0,00
Aoki MSc, E.H.	3	0,00	0,53	0,90	0,90	0,37	0,00
Goswami, A.	3	0,90	0,08	0,00	0,00	0,00	0,00
Imreizeeq MSc, dr. E.S.N.	3	0,49	0,22	0,00	0,00	0,00	0,00
Izsak, dr. F.	1	0,24	0,24	0,18	0,00	0,00	0,00
Janssens MSc, S.G.	2	0,00	0,00	0,04	0,20	0,00	0,00
Kamthe MSc, S.S.	3	0,00	0,00	0,00	0,00	0,00	0,68
Krishnannair PhD, S.K.	1	0,30	0,12	0,26	0,00	0,00	0,00
Kurula PhD, J.	1	0,00	0,00	0,23	0,45	0,00	0,00
Lourens, dr.ir. M.A.J.	2	0,00	0,00	0,00	0,45	0,00	0,00
Rhebergen, dr.ir. S.	1	0,00	0,37	0,00	0,00	0,00	0,00
Rhebergen, dr.ir. S.	2	0,00	0,38	0,00	0,00	0,00	0,00
Saha, dr. S.	3	0,13	0,00	0,00	0,00	0,00	0,00
Sollie, dr.ir. W.E.H.	1	0,00	0,24	0,08	0,00	0,00	0,00
Staniç, dr. M.	3	0,00	0,00	0,00	0,00	0,45	0,90
Vajta, dr. M.	1	0,90	0,90	0,90	0,90	0,15	0,00
Total Scientific staff Computational Science		***11,14***	***11,12***	***9,99***	***8,39***	***6,71***	***7,68***

	Funding 1/2/3	2009 FTE	2010 FTE	2011 FTE	2012 FTE	2013 FTE	2014 FTE
Operations Research							
Full professors							
Boucherie, prof.dr. R.J.	1	0,40	0,40	0,40	0,40	0,40	0,40
Broersma, prof.dr.ir. H.J.	1	0,04	0,04	0,20	0,00	0,00	0,00
Hurink, prof.dr. J.L.	1	0,20	0,40	0,40	0,40	0,40	0,40
Uetz, prof.dr. M.J.	1	0,39	0,40	0,40	0,40	0,40	0,40
Associate professors							
Hurink, prof.dr. J.L.	1	0,20	0,00	0,00	0,00	0,00	0,00
Kern, dr. W.	1	0,40	0,40	0,40	0,40	0,40	0,40
Litvak, dr. N.	1	0,00	0,00	0,07	0,40	0,40	0,40
Still, dr. G.J.	1	0,00	0,00	0,07	0,00	0,00	0,00
Assistant professors							
Boer, dr. A.V. den	2	0,00	0,00	0,00	0,00	0,00	0,07
Dickinson, dr. P.J.C.	1	0,00	0,00	0,00	0,00	0,00	0,12
Dickinson, dr. P.J.C.	2	0,00	0,00	0,00	0,00	0,00	0,18
Driessen, dr. T.S.H.	1	0,40	0,40	0,40	0,40	0,40	0,40
Goseling, dr.ir. J.	1	0,00	0,00	0,00	0,00	0,00	0,10
Litvak, dr. N.	1	0,28	0,40	0,33	0,00	0,00	0,00
Litvak, dr. N.	2	0,12	0,00	0,00	0,00	0,00	0,00
Manthey, dr. B.	1	0,13	0,40	0,40	0,40	0,40	0,40
Ommeren, dr. J.C.W. van	1	0,40	0,40	0,40	0,40	0,40	0,40
Post, dr.ir. G.F.	1	0,21	0,21	0,21	0,21	0,21	0,09
Scheinhardt, dr.ir. W.R.W.	1	0,40	0,40	0,40	0,40	0,40	0,40
Schreuder, dr.ir. J.A.M.	1	0,08	0,00	0,00	0,00	0,00	0,00
Still, dr. G.J.	1	0,40	0,40	0,33	0,00	0,00	0,00
Timmer, dr. J.B.	1	0,40	0,40	0,40	0,40	0,40	0,40
Extraordinary chairs							
Dijk, prof.dr. N.M. van		0,00	0,00	0,00	0,47	0,63	0,63
Hoede, prof.dr. C.		0,02	0,00	0,00	0,00	0,00	0,00
Researchers (incl.postdoc)							
Bikker MSc, I.A.	3	0,00	0,00	0,00	0,00	0,00	0,72
Boer, dr. A.V. den	1	0,00	0,00	0,00	0,00	0,15	0,75
Goseling, dr.ir. J.	1	0,57	0,76	0,90	0,00	0,00	0,00
Goseling, dr.ir. J.	2	0,00	0,00	0,00	0,90	0,90	0,67
Kortbeek, dr. N.	1	0,00	0,00	0,00	0,01	0,00	0,09
Kortbeek, dr. N.	2	0,00	0,00	0,00	0,00	0,09	0,00
Zonderland, dr.ir. M.E.	1	0,00	0,00	0,00	0,20	0,04	0,00
Total Scientific staff Operations Research		***5,05***	***5,42***	***5,71***	***5,79***	***6,03***	***7,42***
Total Scientific staff		**16,19**	**16,53**	**15,70**	**14,18**	**12,74**	**15,10**
Support staff							
Heres - Ticheler, B.F.J.	1	0,53	0,53	0,00	0,00	0,00	0,00
Kamphuis - Kuijpers, T.	1	0,52	0,53	0,53	0,53	0,53	0,53
Langkamp, M.	1	0,84	0,84	0,84	0,84	0,84	0,84
Mulder, J.M.	1	0,63	0,67	0,74	0,74	0,74	0,74
Slotboom - Plekenpol, M.	1	0,84	0,84	0,84	0,84	0,84	0,84
Wychgel - van Dalm, L.S.J.	1	0,39	0,42	0,42	0,42	0,42	0,53
Total Support staff		**3,75**	**3,82**	**3,37**	**3,37**	**3,37**	**3,47**
Total Staff		**19,93**	**20,36**	**19,07**	**17,55**	**16,11**	**18,58**

A.2 Fifteen output highlights

Research publications

1. Arthur, D. and Manthey, B. and Röglin, H. (2011) *Smoothed analysis of the k-means method.* Journal of the ACM, 58 (5). 19:1–19:31. *** ISI Impact 2,37 ***

   The Journal of the ACM is the top-end outlet in the theory of algorithms. This paper settles the smoothed complexity of the k-means method, which is one of the most widely used clustering algorithms in practice. It shows that the k-means method on a randomly perturbed point set has polynomial expected computation time, thereby giving a theoretical justification for its popularity in practical applications. This work already has more than 70 citations since its first publication in 2009.

2. Benning, M. and Brune, C. and Burger, M. and Müller, J. (2013) *Higher-order TV methods - enhancement via Bregman iteration.* Journal of Scientific Computing, 54 (2–3) pp. 269–310. *** ISI Impact 1,71 ***

   Total variation (TV) regularization dating back to the fundamental work of Rudin, Osher and Fatemi, and its generalization TGV, have become standard techniques for first resp. higher-order nonlinear diffusion in imaging and inverse problems. We address the systematic error of such processes (contrast loss) via inverse scale spaces and Bregman iteration. This paper establishes theory for nonstandard eigenfunctions and functional estimates in the space of functions with bounded variation. Efficient primal-dual convex optimization methods are introduced and settle a framework for enhanced reconstruction methods in future biomedical applications. This work already has more than 40 citations since its first publication in 2013.

3. den Boer, A.V. and Zwart, B. (2014) *Simultaneously learning and optimizing using controlled variance pricing*. Management science, 60 (3). pp. 770-783. *** ISI Impact 1,86 ***

   This paper studies how to learn the optimal selling price of a product from sales data. A key result is that without price experimentation, one cannot learn the optimal price. In addition, the paper proposes a well-performing pricing policy and shows that it is asymptotically optimal. This paper is making impact in theory in practice: scholars from major U.S. business schools (Columbia, Stanford, Chicago) build forth on it, and the pricing algorithm in this paper is implemented by several firms. The journal, Management Science, is one of the field's top journals, with an acceptance rate of less than 5 percent in the area stochastic models and simulation.

4. van der Bos, F. and Geurts, B.J. (2010) *Computational error-analysis of a discontinuous Galerkin discretization applied to large-eddy simulation of homogeneous turbulence.* Computer methods in applied mechanics and engineering, 199 (13–16). pp. 903–915. *** ISI Impact 2,62 ***

   Large-eddy simulation of turbulent flow is rapidly developing into a method of choice for advanced industrial design of high-tech fluid-mechanical systems. A major challenge is the prediction of realistic error bars on top of the controlled capturing of dynamic flow structures. A computational analysis of the total simula-

tion error occurring in discontinuous Galerkin finite element methods was executed and optimal refinement strategies and model parameters were identified. An optimal exchange of dissipative influences between Galerkin stabilization and subgrid modeling was established.

5. Dickinson, P.J.C. and Gijben, L. (2014) On the computational complexity of membership problems for the completely positive cone and its dual. Computational Optimization and Applications, 57 (2). pp. 403–415. *** ISI Impact 1,28 ***

   The main result of this paper was an important one in the field of copositive optimisation which had for a long time been assumed to be true. However a proof of it was lacking, as such a proof required taking care of a number of technical detais. This paper provided such a proof, confirming this important result (currently 44 Google Scholar citations).

6. van Gils, S.A. and Janssens, S.G. and Kouznetsov, I.A. and Visser, S. (2013) *On local bifurcations in neural field models with transmission delays.* Journal of Mathematical Biology, 66 (4–5). pp. 837–887. *** ISI Impact 2,37 ***

   The Applied Analysis group has changed its main research focus to mathematical neuroscience in 2009, unique for the Netherlands, adding medical imaging to its research agenda in 2014. The main mathematical contribution to neuroscience has been the development of an abstract framework for neural field equations, as described in this paper and as invited talk presented at the 1st Conference on Mathematical Neuroscience (2015).

7. Francesco, B. and Carli, R. and Frasca,P. (2012) Gossip coverage control for robotic networks: Dynamical systems on the space of partitions. SIAM Journal on Control and Optimization 50, no. 1, pp. 419–447.

   In a series of papers the design of communication of self-propelled robots is studied. It was shown shown that optimal collective goals can be achieved by only using asynchronous communications between pairs of robots. The main results have appeared in the SIAM Journal on Control and Optimization (2012), obtaining the bi-annual Best Paper award, and have been widely influential (currently 48 Google Scholar citations).

8. Goseling, J. and Gastpar, M. and Weber, J. H. (2013) Random access with physical-layer network coding. In: Proceedings of the Information Theory and Applications Workshop (ITA) 2013, 10–15 Feb 2013, San Diego, CA, USA. pp. 1–7. IEEE.

   This paper studies the fundamentals of random access in wireless communication systems. A new type of access mechanism is proposed for which it is proven that it outperforms all existing mechanisms. This work provides directions for the development of future networking protocols, where random access will be one of the performance bottlenecks.

9. Heydenreich, B. and Müller, R. and Uetz, M.J. and Vohra, R. (2009) *Characterization of revenue equivalence.* Econometrica, 77 (1). pp. 307–316. *** ISI Impact 3,82 ***

   Econometrica is the premium outlet in mathematical economic theory. The paper provides a completely new, graph theoretic characterization of what many Economists consider one the most important concepts in auction and mechanism

design theory, namely revenue (or payoff) equivalence. The new characterization can be used in cases where all previously known theorems remain silent (67 Google Scholar citations).

10. Litvak, N. and van der Hofstad, R. (2013) *Uncovering disassortativity in large scale-free networks.* Physical review E Statistical, nonlinear, and soft matter physics, 87 (022801). pp. 1–7. *** ISI Impact 2,31 ***

    Physical Review E is a top journal for publishing new fundamental results on complex networks. The paper studies degree-degree dependencies in complex networks. Such dependencies affect important processes on networks, for example, infection and information spreading. The paper states that the commonly used dependency measure suffers from serious drawbacks, for example, it is unable to reveal negative correlations in large networks. A new measure is proposed, that is able to reveal strong (positive or negative) dependencies in large graphs. This work has received 28 citations since its publication in 2013.

11. Saberi, A. and Stoorvogel, A.A. and Sannuti, P. (2012) Internal and external stabilisation of linear systems with constraints. Systems & Control: Foundations & Applications. Birkhäuser, New York.

    Controller design for linear systems is well understood. However, as soon as constraints come into the picture there are only very limited tools available. This book is the culmination of several years of research and, for the first time, presents powerful tools to design controllers for linear systems subject to constraints. Both input constraints and state constraints are discussed.

12. Vanberkel, P.T. and Boucherie, R.J. and Hans, E.W. and Hurink, J.L. and van Lent, W.A.M. and van Harten, W.H. (2011) *Accounting for inpatient wards when developing master surgical schedules.* Anesthesia & Analgesia 112 (6), pp. 1472–1479. *** ISI Impact 3,30 ***

    The results of this paper on the impact of surgical schedules on the occupancy at the inpatient ward have enabled the Netherlands Cancer Institute to open a sixth operating theatre without increasing the amount of staff at the inpatient ward. The results have also been recognised in operations research via the Canadian Operations Research Society's Practice Prize 2012, and indicate the close interaction between CHOIR and healthcare organisations.

13. van der Vegt, J.J.W. and Rhebergen, S. (2012) *HP-Multigrid as Smoother algorithm for higher order discontinuous Galerkin discretizations of advection dominated flows. Part I+II: Optimization of the Runge-Kutta smoother.* Journal of computational physics, 231 (22). pp. 7537–7583. *** ISI Impact 2,14 ***

    The hp-multigrid as smoother algorithm, which is developed using a detailed multilevel analysis, provides a new approach to obtain fast solvers for higher-order accurate discontinuous Galerkin discretisations of advection dominated flows.

14. Zagaris, A. and Gear, C.W. and Kaper, T.J. and Kevrekidis, I.G. (2009) *Analysis of the accuracy and convergence of equation-free projection to a slow manifold.* ESAIM: Mathematical Modelling and Numerical Analysis, 43 (4). pp. 757–784. *** ISI Impact 1,03 ***

    The paper concerns nonlinear dimension reduction, a vibrant trans-disciplinary research field that aims to resolve fundamental problems in the study of large

dynamical systems. The authors characterise completely the reduction method at the heart of equation-free modelling, putting the latter on a firm footing and empowering it in its mission of bridging scales in massive complex systems.

15. Zwart, H. and Le Gorrec, Y and Maschke, B. and Villegas, J. (2010) *W*ell-posedness and regularity of hyperbolic boundary control systems on a one-dimensional spatial domain ESAIM: control, optimisation and calculus of variations 16 (04), pp. 1077–1093 *** ISI Impact 1,28 ***

    For partial differential equations controlled and observed at the boundary of their spatial domain it is hard to identify which functions class can be used for the in- and outputs. This is the first paper in which for a large class of controlled pde's this problem is solved.

A.3 Narratives

A.3.1 Parkinson's disease

Parkinson's disease (PD) is characterised by the cell death of neuronal brain cells producing the signalling molecule dopamine. Due to resulting shortage of dopamine, the dynamics of neuronal cells changes, most notably abnormal synchronisation of neuronal activity occurs. Such changes complicate the information processing in the brain, resulting in symptoms, such as tremor, rigidity and slowness of movement.

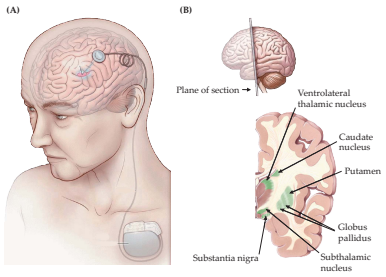


Figure 4: (A) Schematic representation of the implantation of a deep brain stimulation system. (B) The basal ganglia area. Reproduced from with permission of The New England Journal of Medicine, (Okun, 367(16):1529–1538, 2012).

Deep brain stimulation (DBS) is a surgical treatment where an electrode is implanted to stimulate a specific brain region. DBS is a well-established treatment when medication is no longer effective for PD. DBS is meant to desynchronise pathological oscillations, as they are thought to be the main cause of the symptoms. Despite the high clinical success rate, the way in which the pathological activity originates in the brain and how DBS can compensate it are still unresolved questions.

Modulation of abnormal brain activity by neurostimulation was one of the topics in the Smart Mix programme BrainGain (2007–2013). Marcel Lourens was PhD in this project in the Applied Analysis group. In his thesis he studied network models of the basal ganglia and he analysed unique human data that were obtained during deep brain surgery by dr. Lo Bour (Amsterdam Medical Center). Especially important for the clinic is the finding that the sensorimotor part of the subthalamic nucleus (STN) distinguishes from the remaining STN with respect to coherence in the beta band, firing rate and burst activity [1]. This helps to discriminate the STN sensorimotor part for the placement of the DBS electrode. Presently, Lourens works at Medtronic as senior analyst and his insights are translated into the products that Medtronic develops for DBS.

Abnormal synchronization of neural activity in the basal ganglia is the subject of the PhD student Bettina Schwab (funded by NWO and MIRA). Her finding that electric coupling via gap junctions is more prominently present in Parkinson patients attracted considerable attention at the CNS meeting in Quebec (2014) [2]. It may turn out to be of importance for the treatment of patients.

The modeling studies have initiated collaboration between the UT (prof. van Gils, dr. Bour), MUMC (prof. Temel) and Medtronic (dr. Decré), where in a patient study the effect of neuronal plasticity on optimal stimulation protocols will be investigated.

1 M.A.J. Lourens, H.G.E. Meijer, M.F. Contarino, P. van den Munckhof, P.R. Schuurman, S.A. van Gils, and L.J. Bour, "Functional neuronal activity and connectivity within the subthalamic nucleus in Parkinson's disease," Clin. Neurophysiol., vol. 124, no. 5, pp. 967–981, 2013.

2 B.C. Schwab, T. Heida, Y. Zhao, S.A. van Gils, and R.J.A. van Wezel, "Pallidal gap junctions-triggers of synchrony in Parkinson's disease?," Movement Disorders, 29, pp. 1486–1494, 2014.

A.3.2 Decentralised energy management

The world of energy is changing rapidly and moves away from the use of high carbon emitting fossil fuels to renewable energy sources (RES), such as wind, solar, hydro and biogas. As a consequence, the former centralised system with unidirectional flows, now gets a decentralised system with bidirectional flows. To avoid a cost explosion for construction, maintenance and reinforcement of the future electricity grid, new innovative solutions are needed and can be achieved only by multidisciplinary research. The common vision is that the energy grid has to move to a smart grid; a grid that allows for efficient use of all forms of energy through the use of "smart" solutions. These solutions come in by adding information and communication technologies on all levels in the grid, which will allow improved forecasting, modelling and control methods from decentralised level up to the national levels of the grid. The kernel of a future smart control of the electricity grid will be decentralised energy management (DEM) systems.

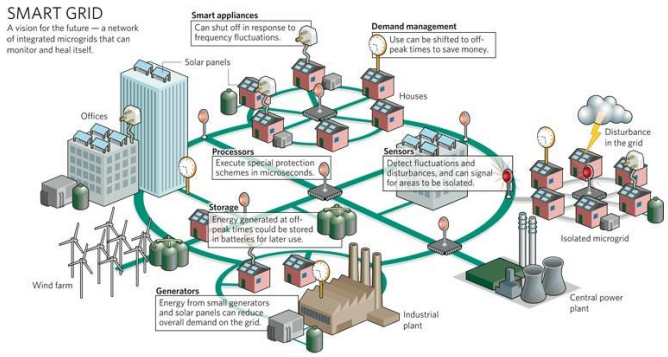


Figure 5: A grid (from https://smartgridtech.wordpress.com/smart-grid/).

The chair Discrete Mathematics and Mathematical Programming, in cooperation with the chair Computer Architecture for Embedded Systems, has set up a joint energy systems research collaboration "Energy in Twente" (see www.utwente.nl/energy). Under the supervision of Johann Hurink and Gerard Smit three PhD students from Mathematics and Computer Science developed in the years 2008–2012 a novel decentralised energy management concept, called TRIANA. The core ingredients of TRIANA are the three steps prediction, planning and real time control. The underlying scientific concepts involve knowledge from Mathematics, Computer Science and Electrical Engineering. Meanwhile a version of TRIANA has been implemented in a simulator, which is used to gain insight in various research questions concerning energy. This simulator is being extended within several follow up projects carried out by the researchers from ET. Currently 7 PhD students and 2 PostDocs are working in this field, financed by projects from FP7, TKI, STW perspectief, NWO, and STW.

TRIANA is also the underlying concept of a Home Energy Controller (HEC), which has been realised within a project financed by the German energy company RWE and the Deutschen Bundesstiftung Umwelt. This HEC is now tested and used within a kindergarten in Haren (Germany) and a field test in the south of Germany. Furthermore, within several ongoing projects the TRIANA concept is integrated in steering tools for specific smart grid applications of involved industrial partners.

The current research within ET is focusing on, but are not limited to, the DEM concept TRIANA, micro-grids, power quality, electrical energy storage and system integration over different energy forms.

A.3.3 Discontinuous Galerkin finite element methods

Discontinuous Galerkin (DG) finite element methods are well suited for the accurate solution of partial differential equations since they provide an excellent framework to construct adaptive, higher order accurate numerical discretizations on unstructured meshes. The Mathematics of Computational Science (MACS) group, under the guidance of prof. Jaap van der Vegt, has made substantial contributions to the analysis, development and application of novel DG methods. In particular, DG methods for various types of fluid dynamics applications that are highly relevant for (geo)physics and industrial applications were developed in close collaboration with industry and national research laboratories, e.g. MARIN, Shell, Tata Steel, Océ Technologies, National Aerospace Laboratory NLR, which also provided financial contributions.

A highlight in our research has been the development of space-time DG methods, in which discontinuous basis functions, both in space and time, are used. The space-time DG method is particularly useful for free boundary problems. In his PhD thesis (2010) Sander Rhebergen developed novel space-time DG methods for nonconservative hyperbolic partial differential equations and applied these methods to compute dispersed multiphase flows, e.g. granular flows relevant for the steel industry. Henk Sollie introduced in his PhD thesis (2010) space-time multi-fluid elements, which allow the accurate computation of interfaces in multi-fluid flows. A novel way to preserve the Hamiltonian structure of nonlinear potential flow water waves in a space-time DG discretisation was presented by Elena Gagarina. In this thesis (2014) she derived and analysed a space-time (dis)continuous Galerkin method that preserves the Hamiltonian structure of nonlinear potential flow water waves also at the discrete level. This allows for excellent long time simulations of nonlinear water waves. Her results compare very well with experiments conducted by MARIN, see Fig. 6.

To speed up the implementation of advanced DG discretisation, the MACS group has been developing, in collaboration with the Multi-Scale Mechanics group, the public domain C++ hpGEM DG software, which can be freely downloaded at www.hpGEM.org.

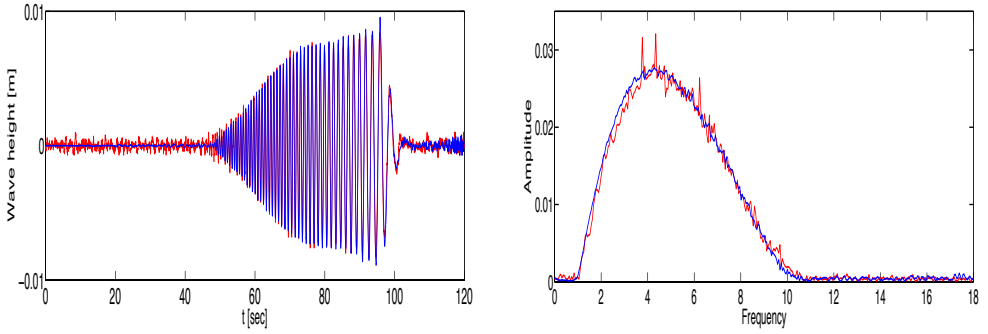


Figure 6: Measured (red) and computed (blue) wave height and spectra in MARIN wave basin (1m deep, 195.4m long); PhD Thesis Elena Gagarina.

A.3.4 Health care logistics

Health care expenditures are rapidly growing and in western countries are expected to increase from roughly 10% of GDP in 2010 to roughly 20% in 2035 under the current resource allocation policies. This increase is partly due to improved medical techniques and devices, but to a large extent due to our ageing population. Sustaining the current quality of care seems to require an increasing work force, which is in stark contrast with the reducing workforce due to ageing.

Figure 7: Helicopter view on hospital reduces waiting list. Source: "STW update July 2014, pp 20–21". Illustration infographic: Anke Nobel.

Efficient planning of operating theatres reduces wasted hours of staff. Optimising patient admission, and allocation of resources, reduces waiting times. Balancing the number of patients in wards reduces peaks and therefore increases the efficiency of nursing care. Efficient rostering of staff allows for more work to be done by the same number of people. Many of these issues involve delay due to randomness and/or suboptimal scheduling. Operations research is the natural theory to tackle these problems to maintain or increase quality of care for a growing number of patients without increasing the required resources. Whilst operations research directly targets improving efficiency, it can also have the knock on effect of increasing job satisfaction, as experienced work load is often dominated by those moments at which the work pressure is very high. It also improves patient safety since errors due to peak work load will be avoided.

The Center for Healthcare Operations Improvement and Research (CHOIR) achieves a unique collaboration of operations research / operations management research related groups from the faculties BMS and EEMCS, and healthcare providers across the Netherlands. This guarantees a scientific approach to healthcare optimization in which we thrive to bridge the gap between scientific research and practice. This collaboration also extends to the spin-off Rhythm B.V. Since its start in 2003, CHOIR has realised over 75 scientific publications in operations research and medical journals, 7 PhD students have graduated, 10 PhD students are currently pursuing their PhD, and yearly roughly 25 MSc students complete their MSc thesis. In 2012 CHOIR hosted ORAHS, a healthcare logistics international top conference.

From an application perspective, CHOIR focuses on the simultaneous optimal allocation of multiple resources, be it through interaction among departments or through allocation of multiple appointments in multidisciplinary schedules. For example, CHOIR is proud of its scientific and practical results on the joint optimisation of the Master Surgical Schedule for the operating theatre, bed occupancy at the wards, and nurse rostering. The approach has been developed in 3 consecutive PhD theses and includes a combined scheduling and stochastic optimisation approach. The results have enabled the Dutch Cancer Institute to open a sixth operating theatre while increasing the quality of care and quality of labour at its wards without increasing the ward staff level, and have enabled the Academic Medical Centre Amsterdam to re-design its wards and nurse-rosters. The results have also been recognised via the ORTEC excellence in advanced planning award 2012, and the Canadian Operations Research Society's Practice Prize 2012.

A.4 Externally funded projects

Project Name	Start	End	Funding Agency	Funding amount
Prediction of wave induces motions and forces in ship offshore and dredging operations	01/01/12	01/01/15	Agentschap NL	93750,00
Realisation of reliable and secure resedential sensor platforms	01/07/10	01/07/14	Agentschap NL	275531,00
Dynamic test floor controller	01/06/09	01/08/12	Agentschap NL	216867,00
Smart synthesis tools	01/06/05	17/10/11	Agentschap NL	205057,00
Nanoned: Optical switching by NEMS-modeling & simulation	01/07/05	31/12/09	BSIK	291900,00
BRICKS/IS3: Decision support systems for logistic networks and supply chain optimisation	01/01/04	01/01/10	BSIK	277302,00
BRICKS NACM	01/01/04	01/01/10	BSIK	193578,00
BRICKS/PDC2: QoS differentiation mechanisms - scheduling algorithms	01/01/04	01/01/10	BSIK	209928,00
Neubau einer Kindertagesstätte als Energiepuffer für regenerative Energien	01/06/12	01/06/15	Deutsche Bundesstiftung Umwelt	39190,00
Scr based design and validation of highly automated atm	01/01/07	31/08/11	EU 6e Kader	155399,00
Adaptive high-order variational methods for aerodynamic appl	01/09/06	01/01/10	EU 6e kader	172000,00
New tools and algorithms for directed network analysis	01/05/12	01/05/15	EU 7e kader	312318,00
European research training in monte carlo based innovative management and processing for an unrivalled leap in sensor exploitation	01/01/10	01/01/14	EU 7e Kader	204806,00
Hybrid energy grid management	01/01/14	01/01/16	EU Overig	150000,00
Computing seismic waves within minimal pollution error	01/09/14	01/09/19	FOM	39686,00
Efficient solar cells	01/06/13	01/09/17	FOM	77897,00
Development of numerical methods for turbulence -Ultimate Turbulence	01/04/13	01/11/17	FOM	21961,00
Droplets in turbulent flow	01/10/10	01/07/15	FOM	28000,00
Deploying security measures to intercept simultaneous threats	01/10/14	01/10/18	Industry	240420,00
Elastic wave propagation modeling in complex geological models	01/09/14	01/09/18	Industry	310000,00
Home energy controller	01/06/14	01/01/16	Industry	50000,00
Waiting time ana personnel capacity optimization	01/10/13	01/10/15	Industry	150000,00
Ltr smart radio	01/06/13	01/09/17	Industry	350000,00
Statistiek en algoritme voor schuifregelmethode	01/04/13	01/01/14	Industry	59851,00
Multi appointment scheduling in health care	01/04/13	01/04/17	Industry	285000,00
Multiscale modeling and summulations of aerosol	01/09/12	01/09/16	Industry	305000,00
Multiscale simulation methods of aerosol generation and transport in structure-resolved product-geometies	01/09/12	01/09/16	Industry	190000,00
Load designer	01/10/09	01/03/10	Industry	35000,00
High precision inkjet printing system	01/01/08	01/07/15	Industry	206450,00
Simulation of heat and mass transport processes in a tobacco plug	01/01/08	01/01/13	Industry	536000,00
Essent- deel c	01/01/07	01/01/11	Industry	100000,00
Dchp-e.on	01/01/07	01/12/10	Industry	170000,00
Volatility smile modelling for interest rate derivates	01/12/06	01/12/10	Industry	165000,00
Scheduling of a fleet of micro chip appliances	01/11/06	30/04/11	Industry	200000,00
Particle filters and their application to target tracking	01/10/05	01/10/09	Industry	175495,00
Multi-armed bandit problems with underlying discrete-choice models	01/11/14	01/11/17	NWO	250000,00
Tenure Track P. Dickinson	01/04/14	01/04/19	NWO	125000,00
Tenure Track C. Brune	01/01/14	01/01/19	NWO	240000,00
Towards efficient simulation of non markovian queueing networks	01/09/12	01/09/16	NWO	208032,00
Control of partial differential equations	01/09/12	01/09/14	NWO	17950,00
Nonlinear dynamics of natural systems	01/05/12	01/05/14	NWO	100000,00
Intex interference exploitation in wireless networks	01/01/12	31/12/14	NWO	207882,00
Semigroups with an inner function calculus	01/10/11	01/10/15	NWO	205013,00
Smoothed analysis of belief propagation	01/09/11	01/09/15	NWO	213693,00
Semigroups with an inner function calculus	01/10/10	01/10/15	NWO	205013,00
Postdoc A. zagaris	01/09/09	01/09/10	NWO	60000,00
Compatible mathematical models for coastal hydrodynamics	01/05/09	15/09/13	NWO	197424,00
From spiking neurons to brain waves	01/04/09	01/04/13	NWO	184135,00
Nearshore tsunami modelling and simulation	01/07/08	01/07/12	NWO	213495,00
Control and analysis for the stability of hybrid and embedded systems	01/03/08	01/03/12	NWO	177371,00
QNOISE: Queueing networks of interacting servers	01/12/07	01/02/09	NWO	55156,00
Hamiltonian-based numerical methods in forced-dissipative climate predictions	09/10/06	01/11/11	NWO	184214,00
CASIMIR/DE GRAAF: Minimisation of energy consumption	01/01/06	01/01/10	NWO	0,00
Geometric aspects of quantum theory and integrable systems	01/11/05	01/11/09	NWO	132750,00
Wave propagation and reflection seismology	01/10/05	15/07/10	NWO	233563,00
Bounds on stable semigroups	01/09/05	01/01/11	NWO	165029,00
NetRank: Ranking of nodes in complex stochastic networks	01/01/05	01/07/09	NWO	164245,00
Brain-computer and computer-brain interfaces	01/09/07	01/09/13	Smartmix	196681,00
FASTfem: Beharviour of Fast Ships in Waves	01/12/13	01/01/18	STW	356084,00
Energy autonomous smart micro grids	01/01/13	01/08/17	STW	200223,00
Boiling flow regime maps for safe designing	01/09/12	01/09/17	STW	195492,00
Deterministic wave modelling and simulation for offshore and harbour applications	01/02/12	01/09/16	STW	561389,00
Polydispersed granular flows through inclined channels	01/10/10	01/10/14	STW	237227,00
Parameter identification of the nociceptive system for improved monitoring of chronic pain development	01/04/10	01/04/14	STW	187727,00
Logistical design for optimal care	01/09/08	01/08/13	STW	189731,00
Control of aerosol migration with temperature gradients	01/03/08	01/11/12	STW	173232,00
A numerical wave tank for complex wave and current interactions	01/03/08	01/12/12	STW	492052,00
Logistical design for optimal care	01/02/08	01/08/13	STW	189731,00
Scheduling a fleet of micro-chp appliances	01/02/08	01/03/12	STW	198232,00
Extreme surface waves, models, simulations and experiments	01/09/06	01/07/13	STW	597000,00
Personalized climate and ambient control for zero-energy buildings	01/01/13	01/01/17	STW/NWO	415000,00
Dynamic Real-time control of Energy streams in buildings	01/04/11	01/04/15	STW/NWO	400000,00
Total project funding				**14.623.152,00**

A.5 Other projects

Project Name	Start	End	Funding	Funding amount
Mechanisms for Decentralised Service Systems	15/02/12	15/02/16	3TU.AMI / UT	175000,00
Local discontinuous Galerkin methods for phase transition problems	01/12/11	01/12/15	China Scholarship Council	82400,00
Contributions to cooperative game theory	01/09/08	01/09/12	China Scholarship Council	82400,00
Fractional Programming in Cooperative Games	01/09/08	01/09/12	China Scholarship Council	82400,00
Extensions of the Shapley value	01/09/08	01/09/12	China Scholarship Council	82400,00
Design and Complexity of Optimal Mechanisms	01/01/11	01/01/15	CTIT	182000,00
Road Pricing Mechanisms	01/02/10	01/02/14	CTIT	182000,00
Queueing and Traffic	01/09/10	01/09/15	CTIT	178000,00
Interacting Hospital Departments and Uncertain Patient Flows	01/09/08	01/09/11	CTIT	178000,00
Control and communication for automated driving	01/09/14	01/09/18	CTIT / UT	182000,00
Copositive programming and related problems	01/01/11	01/01/14	Higher Education Commission Pakistan	81000,00
Networked and Hybrid Systems	01/01/14	31/12/15	UT	100000,00
Multi-armed bandit problems with underlying discrete-choice models	01/07/14	01/07/19	UT	178000,00
Random Walks in the Quarter Plane	01/09/13	01/09/14	UT	89000,00
Waiting time and Personnel Capacity Optimization	01/09/13	01/09/17	UT	89000,00
Graph Partitioning and Related Problems	01/06/13	01/06/14	UT	42000,00
Hamiltonian Properties of Graphs	01/10/11	01/09/12	UT	42000,00
Removable Edges in Four-Connected Graphs	01/10/08	01/10/09	UT	42000,00
Total funding				**2.069.600,00**

A.6 H-indices

Group	Name	H - index
AA	*Brune, dr. C.*	10
AA	*Gils, prof. S.A. van*	20
AA	Groesen, prof. E.W.C.	19
AA	*Kuznetsov, prof. Yu.A.*	36
AA	*Meijer, dr. H.G.E.*	13
AA	*Zagaris, dr. A.*	8
DMMP	*Broersma, prof. H.*	25
DMMP	*Dickinson, dr. P*	7
DMMP	*Hurink, prof. J.L.*	30
DMMP	*Kern, dr. W.*	26
DMMP	*Manthey, dr. B.*	14
DMMP	Post, dr. G.F.	14
DMMP	*Still, dr. G.*	19
DMMP	*Uetz, prof. M.J.*	19
HS	*Frasca, dr. P.*	16
HS	*Mandal, dr. P.K.*	8
HS	*Polderman, dr. J.W.*	13
HS	*Stoorvogel, prof. A.*	29
HS	*Zwart, dr. H.J.*	22
MACS	*Bochev, dr. M.A.*	14
MACS	*Bokhove, prof. O*	17
MACS	*Thornton, dr. A.R.*	12
MACS	*Vegt, prof. J.J.W. van der*	16
MMS	*Clercx, prof. H.*	30
MMS	*Geurts, prof. B.J.*	31
MMS	*Kuerten, prof. H.*	21
SOR	*Boer, dr. A.V. den*	5
SOR	*Boucherie, prof. R.J.*	25
SOR	*Doorn, dr. E.A.*	24
SOR	*Dijk, prof. N.N. van*	28
SOR	*Litvak, dr. N.*	17
SOR	*Ommeren, dr. J.C.W. van*	12
SOR	*Scheinhardt, dr. W.R.W.*	15

The numbers were evaluated on September 25, 2015.

A.7 3TU Applied Mathematics Institute

The three universities of technology in the Netherlands – Delft University of Technology, Eindhoven University of Technology and the University of Twente – have joined forces in the 3TU.Federation. The Applied Mathematics Institute – 3TU.AMI – is one of the nine Centers of the 3TU.Federation. It is a collaboration of the mathematics sections of the three Dutch Universities of Technology, to strengthen research, education and knowledge transfer. The management board of 3TU.AMI consists of the three deans: Rob Fastenau (Chair, TUD), Jakob de Vlieg (TUe) and Peter Apers (UT). The management team: Arnold Heemink (TUD), Luc Florack (TUe) and Anton Stoorvogel (UT) together with the Scientific Director Kees Vuik have a meeting every month, where decisions are made about funding opportunities, research collaboration, teaching development, etc. The board and MT are supported by the 3TU.AMI secretaris Ton Langendorff, secretary Dorothee Engering and PR Emiel van Elderen. The budget of 3TU.AMI is 650,000 euro per year. The main tasks of 3TU.AMI are: teaching, research and outreach. These activities are discussed below in more detail.

Outreach

Our website and flyer are used to present 3TU.AMI to the general public. We have yearly conferences where academic and industry people meet and learn from each other. Every year we organise together with Matheon the mathecalender contest. From December 1 to 24 an exercise should be made every day by high school pupils. The winner gets a certificate and a price (laptop, iPad) to celebrate this. The input from 3TU.AMI was instrumental to publish the book "Succesformules" and 3TU.AMI paid part of the costs for the Deloitte report "Mathematical sciences and their value for Dutch economy". A couple of math oriented companies are also related with 3TU.AMI. We have half year meetings with them, they define internships for MSc students and we collaborate on funding applications. Finally 3TU.AMI is one of the key players in the PWN innovation committee and has recently giving input for the Deltaplan.

Education

For 3TU.AMI good education in mathematics, both for the own bachelor and master curricula but also for so-called "service" teaching is of primary importance. For this reason a yearly event is organised: 3TU.AMI InterTU Studiedagen. In this event people involved in "service" teaching, explain the new developments and methods which are used and give an evaluation of the results. Most of the funding 3TU.AMI receives is also used to further develop the teaching skills and educational material. Various projects have been done. The most important ones are: blended learning, connection high school and university and education of high school teachers. The final project is done by a double appointment of a high school teacher: he/she works part time at one of the TU's and part time at a high school. Recently, we also start a collaboration with 3TU CEE: Centre for Engineering Education. At this moment we send a large funding proposal to the 3TU Federation in order to increase our 21th century teaching capabilities in the near future.

Research

From the start, 3TU.AMI is used as a vehicle to coordinate collaboration and concentration on the mathematical research. For instance, financial mathematics is ended at the UT, therefore it is strengthened at the TUD. We organised our research around a couple of themes: health, logistics, energy, water, and data science (big data). After a fast start it appeared that logistics has reached its goals, so it remains an important research direction but does not need the coordination of 3TU.AMI anymore. This motivates us to define a new theme: data science (big data). Around these themes workshops, funding applications, international speakers etc are organised. In the second period (2014–2017) funding is also available for research (tenure track) positions. 3TU.AMI chooses for two options: first strengthen some understaffed existing groups and second initiate a couple of new activities around the subject stochastics. In the final subject we have the following spread of topics: numerical solution of stochastic differential equations in finance (TUD), random walks with application in wireless sensor networks (UT), and medical statistics and stochastics (TUe).