Introduction

This is the annual scientific report over 2009 of the "Johann Bernoulli Institute for Mathematics and Computer Science (JBI)”, then still named "Instituut voor Wiskunde en Informatica (IWI)".

We would like to mention that over the years 1999 till 2009 Nicolai Petkov was the scientific director of the institute. In this period, the institute implemented a system for personal monitoring and stimulating the quality and productivity of its members. The number of PhD students and defenses increased by a factor of two. Due to a generation change and many retirements, nearly half of the current senior scientific personnel have been newly appointed in the concerned period.

Some statistics

In 2009 the institute contained 31 tenured scientific staff members and seven support staff members. 73 PhD candidates were enrolled, including 4 Ubbo Emmius scholarships for students from abroad, 22 PhD positions funded by the Netherlands Organisation for Scientific Research (NWO) and 16 PhD positions funded by the European Union, industry or other external funding. Also 3 postdocs worked at the institute of whom one funded by NWO.

6 doctoral dissertations were successfully defended.

A total of 75 journal papers, 22 contributions to books, 67 refereed contributions to conference proceedings and 22 other professional publications were published.

Members of the institute served as editors-in-chief, associated editors or members of the editorial boards of 24 international journals and book series.

The institute was visited by 59 foreign scientists.

Personalia

In February, Mirjam Dür has been appointed as Universitair Docent and Rosalind Franklin Fellow in the research group Systems, Control and Applied Analysis. Before coming to Groningen, she had worked as a junior professor at TU Darmstadt (Germany), and as an assistant professor at Vienna University of Economics and Business administration. She holds a PhD from University of Trier, Germany (1999). Her research field is mathematical optimization (discrete and continuous), as well as applications in other fields like economics, engineering and natural sciences.

In April 2009, Alexander Lazovik has been appointed as assistant professor in the research group Distributed Systems. Before his appointment in Groningen, he had worked for two years as an ERCIM post-doctoral fellow at INRIA (Paris) and CWI (Amsterdam). In 2006, he has worked as a summer intern at IBM TJ Watson Research (Hawthorne, NY, US). Alexander obtained his doctorate from the
University of Trento (Italy) in 2006. His research interests lie in several areas of service-oriented, distributed computing, and automated reasoning, including service composition, business process validation and execution, SOA adoption, diagnosis and automated repair. His expertise and research interests center around these application problems and methods for solving them, e.g., automated planning and constraint-solving.

Prof. dr. H.W. Broer
Scientific Director
Johann Bernoulli Institute for
Mathematics and Computer Science
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Governing body and support staff 2009

Scientific director
Prof.dr. H.W. Broer

Scientific Board
Prof.dr. J.B.T.M. Roerdink – chairman
(professor of computing science, RUG)
Prof.dr. N. Petkov
(professor of computing science, RUG)
Prof.dr. A.J. van der Schaft
(professor of mathematics, RUG)

Management team
J. de Jong-Schlukebir (controller) 0.6
A. Navest (controller) 0.5

Administrative staff

Secretary of Research Institute
H.M. Steenhuis 0.5
D.J. Hansen 0.8

Secretaries
E.D. Elshof 1.0
I. Schelhaas 0.8
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Visiting address:
Bernoulliborg
Nijenborgh 9
9747 AG Groningen
The Netherlands

Tel : 050-3633973
Fax : 050-3633800
email : research@cs.rug.nl, research@math.rug.nl
List of scientific programmes and tenured scientific staff

Mathematics

Programme 1 : Algebra
Prof.dr. J. Top

Programme 2 : Computational Mechanics and Numerical Mathematics
Prof.dr. A.E.P. Veldman
Dr.ir. R.W.C.P. Verstappen
Dr.ir. F.W. Wubs

Programme 3 : Dynamical Systems & Mathematical Physics
Prof.dr. H.W. Broer
Dr. C. Külske
Prof.dr.ir. H.S.V. de Snoo
Prof.dr. A.C.D. van Enter
Prof.dr. H. Waalkens
Prof.dr. E. Verbitskiy

Programme 4 : Geometry
Prof.dr. G. Vegter

Programme 5 : Probability and Statistics
Prof.dr. E. Wit
Prof.dr. E.R. van den Heuvel

Programme 6 : Systems, Control and Applied Analysis
Prof.dr. A.J. van der Schaft
Dr. K. Camlibel
Prof.dr. H.L. Trentelman
Dr. M.E. Dür
Computing Science

Programme 7 : Distributed Systems
Prof.dr. M. Aiello
Dr. A. Lazovik

Programme 8 : Fundamental Computing Science
Prof.dr. W.H. Hesselink
Prof.dr. G.R. Renardel de Lavalette

Programme 9 : Intelligent Systems
Dr. M. Biehl
Prof.dr.sc.techn. N. Petkov
Dr. M.H.F. Wilkinson
Dr. J.H. van Hateren

Programme 10 : Scientific Visualization and Computer Graphics
Dr. H. Bekker
Prof.dr. J.B.T.M. Roerdink
Prof.dr. A. Telea
Dr. T. Isenberg

Programme 11 : Software Engineering
Prof.dr. P. Avgeriou
Research schools

Researchers of the JBI participate in the following research schools:

1. **Mathematical Research Institute (MRI)**
   - Coordinating institution: University of Utrecht
   - Director: Prof.dr. G. Cornelissen
   - Participating JBI programme(s): 3, 4

2. **Dutch Institute of Systems and Control (DISC)**
   - Coordinating institution: Delft University of Technology
   - Director: Prof.dr.ir. P.M.J. van den Hof
   - Participating JBI programme(s): 6

3. **The J.M. Burgers Centre for Fluid Dynamics**
   - Coordinating institution: Delft University of Technology
   - Director: Prof.dr.ir. G. Ooms
   - Participating JBI programme(s):

4. **Dutch Graduate School in Logic (LOGICA)**
   - Coordinating institution: University of Utrecht
   - Director: Prof.dr. A. Visser
   - Participating JBI programme(s): 8

5. **Institute for Programming Research and Algorithmics (IPA)**
   - Coordinating institution: University of Eindhoven
   - Director: Prof.dr. J.C.M. Baeten
   - Participating JBI programme(s): 8

6. **Advanced School of Computing and Imaging (ASCI)**
   - Coordinating institution: Delft University of Technology
   - Director: Prof.dr.ir. A.W.M. Smeulders
   - Participating JBI programme(s): 9, 10

7. **School of Behavioral and Cognitive Neurosciences (BCN)**
   - Coordinating institution: University of Groningen
   - Director: Prof.dr. H.W.G.M. Boddeke
   - Participating JBI programme(s): 9, 10
1. Algebra

Group leader: Prof. dr. J. Top

Tenured staff (JBI members)  
Prof. dr. J. Top  
Source: RuG  
FTE: 1.0

Emeritus  
Prof. dr. M. van der Put  
Source: RuG  
FTE: 0.0

PhD students  
B. L. Heijne  
Supervisor: Top  
Source: NWO  
FTE: 1.0

M. A. Soomro  
Supervisor: Top  
Source: RuG  
FTE: 1.0

Guests  
M. H. Saito, Kobe, Japan  
S. Meagher, Freiburg, Germany  
M. Kuwata, Tokyo (Chuo), Japan  
M. Schütt, Copenhagen, Denmark  
A. Llorente, Valladolid, Spain  
J. Mozo Fernández, Valladolid, Spain
1.1 Research Program

1. Number theory and Algebraic geometry. Arithmetic properties of elliptic curves over a number field or a function field, like the rank of the Mordell-Weil group, the conductor, associated Galois representations, are the subject of study. Also work is done on applications to Diophantine equations, coding theory and arithmetic algebraic geometry; in particular a study of the number of rational points on curves over finite fields. Moreover, the history and the algebraic geometry of various series of models of surfaces is studied.

2. Ordinary differential equations. This concerns algebraic, analytic (e.g., multisummability) and algorithmic aspects of linear differential and linear difference equations; differential Galois theory and its applications, in particular to symbolic (algorithmic) solvability of equations; (Lie) symmetries of non-linear differential equations; isomonodromy and the six Painlevé equations.

1.2 Overview of scientific results

ad (1)

J. Top
With M. van der Put and I. Polo Blanco, Top finished research on ruled surfaces of degree 4. A joint paper, including historical aspects of the topic as well as a modern algebraic geometric perspective, has been submitted for publication. Top and Polo Blanco also published a joint paper concerning parametrizations of cubic surfaces, a subject with applications in Computer Aided Geometric Design, in the journal CAGD. The master’s thesis subject of René Pannekoek supervised by Top, resulted in a joint invited paper by Pannekoek, Top, Gonzalez Vega, Polo Blanco, and Gonzalez Sanchez. Among other results, this provides constructions of cubic surfaces over the rational numbers obtained as blow-ups of nontrivial Brauer-Severi surfaces.

The paper with master’s student Frank de Zeeuw, on a new method for proving results on Mordell-Weil ranks of certain elliptic surfaces, appeared in the Rocky Mountain Journal of Mathematics. Top also collaborated with the Japanese mathematicians T. Kodama and T. Washio. They proved results on maximal hyperelliptic curves over finite fields. This was published in the journal Finite Fields and their Applications. On a related problem, Top wrote a text for the website www.manypoints.org and he provided data concerning curves of genus 3 for this website. This work is now continued by Top’s PhD. student Afzal Soomro.

Heijne and Top proved results on binary cyclic selfdual codes. Their paper appeared in the IEEE Transactions on Information Theory.

Top supervised a joint computer science / mathematics bachelor’s project by M. IJbema on the proof assistant Isabelle. This resulted in a publication in the Archive of Formal Proofs.
**B. Heijne**
Bas Heijne published a joint IEEE Transactions in Information Theory paper with Top. He continued his PhD research on elliptic surfaces obtained as quotients of Fermat surfaces. This leads to many new examples. A paper on this is in preparation.

Heijne also participated in the summer school and conference on Elliptic Curves Cryptography in Calgary.

**M.A. Soomro**
Afzal Soomro began research on the number of points on curves of small genus over finite fields. A text concerning elliptic curves is in preparation, and data found by Soomro is intended to be presented on the website www.manypoints.org

*ad (2)*

**M. van der Put**
Van der Put and Fai Lung Tsang published a paper on discrete systems and the abelian sandpile model in the Journal of Algebra.

The joint work of Van der Put with Masa-Hiko Saito on moduli spaces, Riemann Hilbert correspondence and Painlevé equations was completed in 2009 and a joint paper has been submitted.

### 1.3 Research subjects

**B. Heijne**: elliptic surfaces.

**M. van der Put**: differential equations, difference equations, history of geometric models.

**M. A. Soomro**: curves over finite fields.

**J. Top**: arithmetical algebraic geometry, in particular: elliptic curves and surfaces, curves over finite fields, Galois representations, number theory, Drinfeld modules.
1.4 Publications

Articles in scientific journals


Other publications


1.5 External funding and collaboration

External funding

NWO. This concerns the Ph.D. position of Bas Heijne (4 years, all funded by NWO).

Moreover, Top assisted M. Afzal Soomro (lecturer at Quaid-E-Awam university in Nawabshah, Pakistan) in achieving a grant from the Faculty Development Programme of his university. The grant will be used to fund Soomro’s stay in Groningen 2009–2013, where he works on a PhD project supervised by Top.

External collaboration

See 1.2. Also, Top and Stein (Oldenburg) consider possibilities of joint Oldenburg-Groningen projects. In particular, this will involve a joint supervision of PhD student Arne Grenzenbach (2010–2013).

From August till December, Van der Put and Top supervised the Spanish PhD student Alberto Llorente, on a request of his Spanish supervisor Jorge Mozo Fernández (Valladolid).
1.6 Further information

In 2009, Top was a member of the PhD thesis evaluation committee of Jos Brakenhoff (Leiden), supervisor H.W. Lenstra, jr. He also was a member of the committee organizing the NMC2009 in Groningen.

Top is involved in the European Community project GTEM (Galois Theories and Explicit Methods), in the North German Algebraic Geometry Seminars (NoGAGS, a collaboration between Göttingen, Hannover, Berlin, Hamburg, Bremen and Groningen), and in the NWO-cluster DIAMANT.

Top also did research grant evaluations for the National Science Foundation, and served as chairman of an NWO Veni proposal evaluations committee.

Finally, Top gave several lectures popularizing math, e.g., for the Groningen “college caroussel”, for the NWD (Nederlandse Wiskunde Dagen), and for the HOVO (Hoger Onderwijs voor Ouderen). They can be found on

http://www.math.rug.nl/~top/lectures/
2. **Computational Mechanics and Numerical Mathematics**

**Group leader:** Prof.dr. A.E.P. Veldman

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<th><strong>Tenured staff (JBI members)</strong></th>
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<tr>
<td>Prof.dr. A.E.P. Veldman</td>
<td>RuG</td>
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<tr>
<td>Dr.ir. R.W.C.P. Verstappen</td>
<td>RuG</td>
<td>1.0</td>
</tr>
<tr>
<td>Dr.ir. F.W. Wubs</td>
<td>RuG</td>
<td>1.0</td>
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</tbody>
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**Postdocs**

- Dr.ir. R. Luppes               
  **source:** STW **fte:** 0.4

**PhD students**

- Ir. H.A. Bijleveld             
  **source:** ECN **fte:** 1.0  
  (supervisor: Veldman)

- Drs. H.J.L. van der Heiden (since 1-11-2009)  
  **source:** STW **fte:** 1.0  
  (supervisor: Luppes, Veldman)

- Ir. J.A. Helder (till 1-11-2009)  
  **source:** NWO-SWON **fte:** 1.0  
  (supervisor: Verstappen)

- H. Kırbas MSc  
  **source:** UE bursary **fte:** 1.0  
  (supervisors: Verstappen, Wubs)

- J. Thies, MSc  
  **source:** NWO-ALW **fte:** 1.0  
  (supervisor: Wubs)

- M. Younas, MSc  
  **source:** HEC **fte:** 1.0  
  (supervisor: Verstappen)

**Guests**

- J. Jaramillo, Universitat Politècnica de Catalunya, Barcelona, Spain
- Joong-Soo Moon, Hyundai Heavy Industries, Ulsan, Korea (9 months)
- F.X. Trias Miquel, Universitat Politècnica de Catalunya, Barcelona, Spain
2.1 Research Program

With the continuing progress in numerical mathematics and computer technology, the impact of computer simulation on society is rapidly increasing. Our group specializes in the numerical simulation of fluid dynamics and transport phenomena (Computational Fluid Dynamics CFD). On the one hand research is focussed on basic advancement of numerical algorithms; on the other hand - through extensive cooperation with external research groups - these methods are made available to advance knowledge in other (applied) areas of science and technology. In-house developed software plays an essential role in the knowledge transfer. An animated impression of the group’s research can be found at the website www.math.rug.nl/~veldman/cfd-gallery.html.

Turbulent flow Industrial simulation methods use turbulence models to keep computational effort within reasonable limits, but a price is paid in terms of accuracy. Thus research into higher-resolution methods, such as large-eddy simulation (LES) and direct numerical simulation (DNS) methods, is essential. The mathematical rationale behind our methods in this area focusses on preserving symmetry and conservation properties of the continuous flow equations.

Free-surface flow As a spin-off of our research on sloshing in spacecraft (with NLR), our main free-surface flow research concerns application in maritime and coastal engineering. Numerical simulation methods are developed to predict hydrodynamic wave loading on offshore platforms and coastal structures. Partners in this research are the Maritime Research Institute MARIN, TU Delft, Deltares and several offshore companies and shipyards. Basic tool is the in-house developed simulation method ComFLOW.

Sparse-matrix solvers The repeated solution of large systems of equations in most simulation methods makes the quest for improved matrix solvers another major research area. In-house a multilevel method (MRILU) has been developed. A major application area is the modelling of flow patterns in global ocean circulation (with UU-IMAU) and the study of the behavior of flows beyond but close to the transition point.

Bifurcation analysis Research focuses on numerical methods to investigate stability and bifurcation behaviour of large-scale problems from our other research applications. Of particular interest are the stability of the global ocean circulation and of coherent structures in turbulent flow. Cooperation is with the Institute for Marine and Atmospheric Research IMAU in Utrecht and the Dynamical Systems group in Groningen.

Bio-medical fluid mechanics Our bio-medical applications fit in the area of fluid-structure interac-
tion. In cooperation with UMCG we study arterial blood flow in elastic vessels and its influence on atherosclerosis. Also the design of voice prostheses has our attention.

**Wind energy** A new application area concerns the aerodynamic design of turbine blades. The research builds on the boundary-layer interaction approach developed (more than) a decade ago. It is carried out in cooperation with the Energy Center Netherlands in Petten.

### 2.2 Overview of scientific results

The central theme of the turbulent flow project is to model and simulate turbulence in such a way that the symmetry and conservation properties of the Navier-Stokes equations are preserved. The extension of symmetry-preserving discretization method to unstructured grids has been continued in cooperation with prof. Soria and dr. Trias (UPC, Barcelona). The symmetry-preserving regularization models have been applied to turbulent flow with heat transfer. A procedure for determining the regularization parameter has been worked out for this case (in which a unique physical length scale is lacking). Spatial filters for unstructured meshes have been studied. A novel eddy-viscosity model has been developed (as spin-off from the regularization modelling). The parallellization of the simulation code is further improved; an evaluation of parallel methods for solving the Poisson problem for the pressure is started.

![Iso-vorticity structures in a DNS of a thermal driven cavity at Rayleigh number $10^{11}$. The computations have been performed by dr. F.X. Trias (UPC, Barcelona) using a 4th-order symmetry-preserving discretization scheme.](image)
The year 2009 marked the transition between the STW-funded *free-surface* projects ComFLOW-2 and ComFLOW-3 on hydrodynamic wave loading; main collaborators are TU Delft, MARIN, Deltares and FORCE Technology Norway. The new project started in autumn, with the appointment of a post-doc and the first PhD student (out of three awarded). First emphasis in ComFLOW-3 is on modelling viscous effects during wave impact, e.g. in sloshing and side-by-side mooring. For most of the year, dr. Moon from Hyundai Heavy Industries visited the group for further development of the ComFLOW functionality (hydroelasticity).

In the research on *sparse-matrix solvers* a break through has been obtained. Based on the structure preserving direct method developed by de Niet and Wubs for Stokes flow problems, a two-level iterative structure preserving method has been constructed for Navier-Stokes flow problems, albeit currently restricted to the Arakawa C-grid. The two-level method introduced has the following properties: (i) it is very robust, even close to the point where the solution becomes unstable; (ii) a single parameter controls fill and convergence, making the method straightforward to use; (iii) the convergence rate is independent of the number of unknowns; (iv) it can be implemented on distributed memory machines in a natural way; (v) the matrix on the second level has the same structure and numerical properties as the original problem, so the method can be applied recursively; (vi) the iteration takes place in the divergence-free space, so the method qualifies as a 'constraint preconditioner'; (vii) the approach can also be applied to Poisson problems. Wubs visited I.S. Duff (Rutherford Appleton Laboratory, Harwell). Research is in progress on the feasibility of incorporating ideas of our fill reducing orderings in his codes (e.g. MA57).

The *numerical bifurcation analysis* project, initiated by dr. Lust who has left the department in 2008, focuses on the computation of self-sustaining coherent structures (unstable periodic solutions) in flow models in the turbulent regime. In this way a link with our turbulent flow research is established. A candidate for the resulting vacant tenure-track position has been selected: dr. Carpentieri; as of January 2010 he has joined the institute. His research interests are numerical methods for electromagnetics and bio-medical applications.

The *bio-medical fluid mechanics* project studies cardio-vascular flow in elastic blood vessels (in cooperation with UMCG): an example of two-way fluid-structure interaction. An overall 0D model for the global blood circulation is coupled with a detailed 3D model of the flow in the arteria carotis; the quasi-simultaneous numerical coupling is stable for all values of the physiological parameters.

The *wind energy* project, funded by ECN, has seen the theoretical analysis of unsteady three-dimensional boundary-layer interaction. The project is aimed at the aerodynamic design of wind turbine blades. The numerical coupling between boundary layer and inviscid outer flow is similar to that used in the bio-medical project mentioned above.
2.3 Research subjects

H.A. Bijleveld: aerodynamic design of wind turbines.
H.J.L. van der Heiden: extreme wave impact on offshore platforms.
H. Kırbas: exact coherent structures in shear flow.
A.J.A. Kort: local grid refinement for the simulation of turbulent flow.
R. Luppes: two-phase flow modelling for maritime and biological applications.
G. Rozema: fluid-structure interaction in viscous flows, with cardio-vascular applications.
J. Thies: spin-up in ocean climate models.
R.W.C.P. Verstappen: development of simulation methods for turbulent flow (direct and large-eddy simulation DNS/LES).
F.W. Wubs: development of a multi-level ILU preconditioner for sparse systems; application to eigenvalue and continuation problems in the simulation of ocean circulation.
M. Younas: parallel solvers for sparse systems of equations.

2.4 Publications

Articles in scientific journals

Articles in conference proceedings


Other publications

2.5 External funding and collaboration

External funding
Most of our PhD projects are being funded externally from national and international resources: currently STW, NWO, ECN and CSA (Canadian Space Agency) (see also above). We summarize the new developments:

- Contract negotiations for the STW project on the impact of extreme waves on offshore platforms and coastal structures (budget 1.5 MEuro) have been completed. The project is embedded in the ComFLOW-3 joint industry project, coordinated by MARIN.

- The two-year (2007-2009) postdoctoral stay of Dr. F.X. Trias Miquel and the two-year (2009-2011) postdoctoral stay of Dr. J. Jarmillo are funded by two Beatriu de Pinós grants from the Generalitat de Catalunya (Agència de Gestió d’Ajuts Universitaris i de Recerca AGAUR).

- MARIN will fund a PhD project to improve the efficiency (discretization and turbulence modeling) of ship stern flow calculations. It is planned to start mid 2010.

Societal relevance
As indicated above, most of our PhD and MSc research is carried out in physical or technological applications. The most important application areas are offshore and coastal safety, ocean modeling, health care and sustainable energy (for details see above). Close cooperation exists with several university research laboratories, with all Dutch Technological Institutes (GTI’s), and with several industries: multi-nationals as well as small and medium enterprises (SME’s).

(International) national collaboration
Various bilateral contacts exist with research groups inside and outside the Netherlands, leading to e.g. joint PhD projects, traineeships for our Master’s students and/or to joint publications.

- On an international scale, a major project is the cooperation with MARIN, Deltares, TU Delft and almost twenty offshore companies and ship yards throughout Europe, the America’s and Asia, which studies hydrodynamic wave loading (ComFLOW Joint Industry Project). In 2009 the cooperation with Hyundai Heavy Industries (Korea) was strengthened by a one-year visit of one of their research scientists.

Other free-surface flow projects are cooperations with NLR, ESTEC and NASA (on liquid sloshing in spacecraft) and the University of Manitoba in Winnipeg (on embryo development in microgravity). A further, bio-medical, spin-off is the cooperation with UMCG on cardiovascular fluid dynamics.
– The research on ocean circulation models is carried out in close cooperation with the Institute for Marine and Atmospheric Research (IMAU) in Utrecht. Together with IMAU there is cooperation with Los Alamos and Sandia National Laboratories on the construction of an implicit Ocean Model based on POP. Further, the cooperation with Prof. Y. Notay from Numerical Analysis Group, Service de Métrologie Nucléaire, Université Libre de Bruxelles was continued, Prof. M. Bollhoeffer from the Technical University of Braunschweig and Prof. I. Duff from the Rutherford Appleton Laboratory continued.

– With the Energy Center Netherlands ECN (Petten) the project on the aerodynamical design of wind turbines was continued.

– Our turbulence research comprises cooperation with the Universitat Politècnica de Catalunya in Barcelona and the Universität der Bundeswehr München.

(Inter)national PhD committees
Finally, Veldman participated in two defense committees at the University of Delft.

2.6 Further information

Veldman is a member of the Directory Staff of the National Aerospace Laboratory NLR (Amsterdam) as a scientific consultant. Moreover, he is a member of the Advisory Board of the Maritime Research Institute MARIN (Wageningen). Also, he is chairman of the Dutch Contactgroup on Computational Fluid Dynamics. Further, he is on the editorial board of Computers and Fluids, Journal of Engineering Mathematics and Journal of Algorithms and Computational Technology. Veldman (co-)presented lectures at the 28th Conference on Offshore Mechanics and Arctic Engineering OMAE2008 (Honolulu, USA) and the 19th Symposium of Offshore and Polar Engineering ISOPE2009 (Osaka, Japan). Further he was invited as a keynote speaker at the Workshop for the 75th Birthday of Norman Riley (Norwich).

Verstappen stayed three weeks at the Universitat Politècnica de Catalunya (Barcelona) as visiting professor; he gave four lectures at the Centre Tecnològic de Transferència de Calor (CTTC). Further, he (co-)presented lectures at the EUROMECH Colloquium on Large Eddy Simulation for Aerodynamics and Aeroacoustics (Munich), the 2nd International Conference on Turbulence and Interactions (Martinique), the 21st International Conference on Parallel Computational Fluid Dynamics (Moffett Field), 6th International Conference Turbulence, Heat and Mass Transfer (Rome) and at the Symposium on Quality and Reliability of Large-Eddy Simulations QLES2009 (Pisa).

Wubs spent three months at the Rutherford Appleton Laboratory (Harwell, Oxford) as visiting scientist. Furthermore, a presentation was given in the combined University of Oxford/Rutherford Appleton Laboratory colloquium.
Luppes’ research was funded by STW. He gave presentations at the 28th Conference on Offshore Mechanics and Arctic Engineering OMAE2008 (Honolulu, USA) and at MARINE2009 (Trondheim, Norway).

Figure 2: Our ComFLOW computer animation of vortex shedding behind a circular cylinder featured on Dutch television (Veronica, 15 February 2009) in the TV series “Numb3rs” (episode “Blowback”).
3. Dynamical Systems & Mathematical Physics

**Group leader:** Prof.dr. H.W. Broer

<table>
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<td>RuG</td>
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<td>Prof.dr. E. Verbitskiy</td>
<td>NWO/Philips/Leiden</td>
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<td>Prof.dr. H. Waalkens</td>
<td>RuG</td>
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**Postdocs**

Dr. K. Efstathiou

<table>
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<tr>
<th>PhD students</th>
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<td>V. Ermolaev</td>
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<td>(supervisors: Külske and Van Enter)</td>
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<tr>
<td>S. Fleurke</td>
<td>Telekom</td>
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<tr>
<td>(supervisors: Külske, Dehling and Van Enter)</td>
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<tr>
<td>G. Iacobelli</td>
<td>NWO</td>
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<td>(supervisors: Külske and Van Enter)</td>
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<tr>
<td>S.J. Holtman (till September 2009)</td>
<td>NWO</td>
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<td>(supervisors: Broer and Vegter)</td>
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<td>X. Liu (from April 2009)</td>
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<td>(supervisor: Broer)</td>
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<td>A. Opuku (till September 2009)</td>
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<td>(supervisors: Külske, Broer and Van Enter)</td>
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<td>W.M. Ruszel</td>
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<td>A.E. Sterk</td>
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Guests

H. Hanßmann, UU, Netherlands
F. Wagener, UvA, Netherlands
C. Simó, University of Barcelona, Spain
R. Vitolo, University of Exeter, UK
F. Nardi, TU Eindhoven, Netherlands
F. Camia, Free University Amsterdam, Netherlands
H. Woracek, TU Wien, Austria
S. Hassi, University of Vaasa, Finland
Z. Sebestyen, Eotvos Lorand University, Budapest, Hungary
J.-P. Labrousse, Université de Nice, Nice, France
H.R. Dullin, University of Sydney, Australia
P.H. Richter, University of Bremen, Germany
R. Fernandez, Rouen University, France, University of Utrecht, The Netherlands
C. Spitoni, Leiden University, The Netherlands
3.1 Research program

The research programme Dynamical Systems & Mathematical Physics covers a broad area with a solid basis in Analysis, Geometry and Measure Theory. The research in Groningen focuses on the qualitative and quantitative theory of ordinary differential equations and other dynamical systems, the geometry of torus bundles in the phase space of integrable Hamiltonian systems, statistical mechanics and operator theory, in particular studied by stochastic approaches. Apart from pure mathematics also many applications are studied.

3.1.1 Dynamical Systems

The discipline of Dynamical Systems is concerned with mathematical models for deterministic time evolutions. A simple example is derived from the oscillator, which generally only displays periodic dynamics. If subject to periodic driving or to coupling with another oscillator, it can illustrate many parts of the Dynamical Systems research program.

One possible state of the system is resonance, where the combined system assumes one globally periodic state, the frequency of which is an integer combination of the individual periodic motions. Another possible state is multi- or quasi-periodicity, where the individual periodic motions combine in a rationally independent way. When coupling three oscillators, a third possible combined state exists, where a continuous range of frequencies is present: this is the state of chaos.

The occurrence of resonance, quasi-periodicity and chaos as well as the transitions or bifurcations in between, is the central theme of research in the current Dynamical Systems program – not only for a few coupled oscillators but for a wide class of systems.

The questions posed vary from fundamental to applied, where the focus can be on different classes of systems. Examples of this are the world of general ‘dissipative’ systems with a finite-dimensional state space, the classes of Hamiltonian or reversible systems or systems with a very low-dimensional state space. Also concrete examples are being studied, where sometimes numerical or symbolic algorithms have to be developed. The mathematics of these different levels strongly interact. For instance, in order to know what to look for in a special case, one has to know beforehand what can be expected and what is logically possible.

There is cooperation with groups in other sciences on the analysis of specific systems. This concerns the Department of Engineering, University of Bristol (Champneys, Krauskopf, Osinga), the Department of Applied Mathematics and Analysis of the University of Barcelona (C. Simó and À. Jorba) as well as the University of Utrecht (O. Diekmann, H.A. Dijkstra, J.J. Duistermaat, T. Opsteegh, F. Verhulst), Boston University (R.L. Devaney, T. Kaper) and Twente University / Radboud University Nijmegen (M. Krupa). Various PhD students and postdocs at all these institutions are involved as
well. The theoretical work is also internationally oriented and involves intensive cooperation with a.o. the universities of Dijon (R. Roussarie), Houston (M. Golubitsky), IMPA Rio de Janeiro (J. Palis, W. de Melo, M. Peixoto and M. Viana), the universities of Stony Brook and Toronto (M. Lyubich, M. Martens), the KTH Stockholm (M. Benedicks), the Université de Marseille (J.C. Poggiale and S. Troubetzkoy), the Russian Academy of Sciences (M.B. Sevryuk), resulting in joint publications on a regular basis.

3.1.2 Mathematical Physics

Mathematical Physics is the study of problems originating in physics by state of the art methods from mathematics. The research of this group covers a broad spectrum of applications ranging from celestial mechanics, atomic and molecular physics, nanostructures and microlasers to phase transitions. The mathematical methods involve techniques from statistical mechanics, stochastics and dynamical systems theory, where the time evolution can be classical, quantum mechanical or stochastic.

Statistical Mechanics and Stochastics. The contribution of statistical mechanics to this part of the programme is substantial. Both equilibrium and non-equilibrium questions are considered. In comparison with dynamical systems, the emphasis is on systems with infinitely many, rather than finitely many, degrees of freedom. Links between the two can be fruitfully studied in the thermodynamic limit, where one can consider the asymptotics of systems with a large (but finite) number of degrees of freedom. Such questions lead often to the use of stochastic methods.

The general aim of the stochastics part of the program is to understand interacting stochastic systems on a mathematical level. Even when the interaction is local, such systems typically exhibit a complex global behavior, with a spatial long-range dependence resulting in phase transitions. In this picture phase transitions are characterized by discontinuous behavior of the possible states of the system as a function of external parameters. For specifically tuned values of the parameters there can be more than one global state (=Gibbs measure). The equilibrium properties of such systems, as described by the Gibbs measures can be highly non-trivial, and in one direction of research we are focussing on these. Moreover we are also interested in the time-evolution of such measures. It was discovered a few years ago that time-evolved measures may lose (and recover) their Gibbsian nature as a function of time. We are trying to approach this phenomenon in case studies. In a related line of research we are investigating continuous interfaces. Related stochastic methods also are of use in applied problems like telecommunications, as an external PhD project with agentschap Telekom shows.

We are also working on models for temperature-dependence of $n$—vector models, on the theory of disordered systems and on models for metastability and in general on examples of phase transitions of physical and conceptual interest. We are also starting to develop the theory in relationship with the theory of networks.
The work is done in various collaborations, including in the last years J.-R. Chazottes (Paris), P. Collet (Paris), R. Fernández (Rouen, this year Utrecht), F. Redig (Leiden), A. Le Ny (Orsay), W.Th.F. den Hollander (Leiden), E. Orlandi (Rome), R. van der Hofstad (Eindhoven), M. Biskup (UCLA), H.G. Dehling (Bochum), S. Shlosman (Marseille), V. Zagrebnov (Marseille), M. Formentin (Padova), S. Romano (Pavia), K. Netocný (Prague), S. Roelly (Potsdam).

**Dynamics.** Reaction type dynamics is typically associated with the phase space transport across certain types of saddle equilibrium points. A general theory has been developed which describes how this transport is controlled by various high-dimensional invariant manifolds. The manifolds can be explicitly constructed from normal forms. This opens the way to understand many key problems in reaction dynamics like the realization of Wigner’s transition state theory for multidimensional systems. The research has a wide range of applications ranging from chemical reactions to ballistic electron transport problems and even capture and escape problems in celestial mechanics. A quantum version of the theory is being developed. Based on a quantum normal form an efficient algorithm has been developed to compute quantum reaction rates. The quantum results can be related to classical phase space structures using methods from semiclassical analysis like the Weyl calculus. This research is of central interest for recent spectroscopic results in molecular collision experiments. The research is carried out in collaboration with A. Goussev, R. Schubert and S. Wiggins (Bristol University) and G. Ezra (Cornell University).

New fabrication techniques allow one to build lasers and optical resonators on a microscopic scales. Such microcavities utilize the principle of total internal reflection and have great potential for miniaturizing spectroscopic devices and diagnostic tools. Of crucial importance for many applications is to optimize the quality factors of these devices in combination with the directionality of the optical output. This can be achieved by, e.g., a suitable choice of the morphology of the cavity boundary. Significant insight into the output directionality for a given cavity shape can be obtained on the level of the ray dynamics from studying the corresponding billiard map. Combining this with techniques from semiclassical quantum mechanics (short wavelength asymptotic) leads to the design of cavities with laser modes which are both long lived and directional. Further ideas like perturbing circular disk cavities by a point scatterer are also exploited. This research involves the collaboration with C. Dettmann, M. Sieber and G. Morozov (Bristol).

In the theory of Hamiltonian dynamics the geometry of the phase space plays an important role, in particular the bundle structure of invariant tori in integrable systems. The nontriviality of such bundles is studied by methods from differential geometry and algebraic topology, where this has led to the development of monodromy and Chern classes. These results have a counterpart in semi-classical quantum theoretical approximations where quantum monodromy helps to explain certain spectral defects. Molecular and atomic systems are also studied from this point of view. This research is carried out in cooperation with various groups like the Université du Littoral, Dunkerque (B. Zhilinski, D. Sadovskii), University of Calgary (R.H. Cushman), Utrecht University (J.J. Duistermaat, H. Hanß-
Applications of dynamical systems theory to biology provide new insights into the behaviour of biological systems. Continuing previous work on synchronization in coupled cell networks, we study in collaboration with the Chronobiology Department (D. Beersma, K. Gargar) the circadian rhythms of organisms through the use of appropriate mathematical models.

3.1.3 Analysis – Operator Theory

The central theme is the extension theory of symmetric and sectorial operators in Hilbert spaces and in spaces with an indefinite metric. This extension theory is closely connected to mathematical physics (explicitly solvable models, singular perturbations), to system theory (the realization in terms of transfer functions) and to analysis (moment problems, interpolation problems, differential operators, canonical systems).

The general framework is an abstract boundary value space for which an analogue of Lagrange’s identity holds and which gives rise to a so-called boundary relation and a corresponding Weyl function (which may be unbounded and multivalued). The Weyl function itself gives rise to functional models, like reproducing kernel Hilbert or reproducing kernel Pontryagin spaces, but also to abstract conservative systems.

The research is concerned with the development of the general theory and the applications to the above mentioned fields. This is done in collaboration with the following group of mathematicians: D. Alpay (Beer Sheva), Yu.M. Arlinskiĭ (Lugansk), J. Behrndt (Berlin), V.A. Derkach (Donetsk), A. Fleige (Dortmund), S. Hassi (Vaasa), M. Kaltenbäck (Wien), J.Ph. Labrousse (Nice), M.M. Malamud (Donetsk), M. Möller (Johannesburg), A. Sandovici (Piatra Neamt), Z. Sebestyén (Budapest), F.H. Szafraniec (Krakow), R. Wietsma (Vaasa), H. Winkler (Ilmenau), M. Wojtylak (Krakow), H. Woracek (Wien).

3.2 Overview of scientific results

Handbook and textbook in Dynamical Systems

Broer, together with F. Takens (Groningen) and B. Hasselblatt (Tufts, Boston) is editing a volume in the Handbook of Dynamical Systems series, issued by Elsevier (North-Holland), expected to appear in 2010. Together with Takens, Sevryuk (Moscow) and Vanderbauwhede (Ghent) they have three chapters in this volume. Broer and Takens finished a textbook *Dynamical Systems and Chaos*, which was published by Epsilon Uitgaven. A revised version will appear in the *Springer Applied Mathematical Sciences* series.

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KAM theory
In KAM theory several projects are running in cooperation with Broer. One paper on quasi-periodic stability of normally resonant tori, with M.C. Ciocci (London), H. Hanßmann (Utrecht) and A. Vanderbauwhede (Ghent), appeared in *Physica D* in 2009. A paper concerning the destruction of resonant Lagrangean tori, with H. Hanßmann and J. You (Nanjing), has been submitted. A chapter by Broer and Sevryuk in the Handbook volume, mentioned before, is in preparation and is expected to appear in 2010. A monograph on quasi-periodic bifurcation theory, co-authored by Hanßmann and F.O.O. Wagener (UvA) is in preparation.

Bifurcation theory and applications
A paper of Broer, Vegter, the PhD student S.J. Holtman and Vitolo (Exeter) on the recognition problem in mildly degenerate Hopf-Ne˘ımark-Sacker bifurcations was published in *Nonlinearity*. Another paper by Broer, Vegter and Holtman has been submitted. Holtman defended his PhD thesis in September 2009.

Broer, together with K. Efstathiou and I. Hoveijn from the Department of Mathematics, and D. Beersma and K. Gargar from the Department of Chronobiology have used circle maps to model the entrainment to the daily light-darkness cycle of single cells in the suprachiasmatic nucleus. A publication is in preparation.

Mathematical Physics
About the Gibbsian-non-Gibbsian program, around which the PhD projects of Ermolaev, Opoku and Ruszel are centered there were a number of developments. In this program one studies which measures can and cannot be written as a Gibbs measure for an effective Hamiltonian. This is often done in physics, although it turns out to be not always mathematically justified. Various examples of physical interest occur, e.g., in Renormalization Group theory, in the theory of disordered systems and in the study of non-equilibrium problems. For nearest-neighbour $n$-vector models with diffusive evolutions, various results were obtained, showing both preservation of Gibbsianness for short times, and loss of Gibbsianness after long times. A paper by van Enter and Ruszel appeared in *Stoch. Proc. and Appl.*. Opoku defended his thesis in September 2009. A paper by F. Redig (Leiden), S. Roelly (Potsdam) and W.M. Ruszel on Gibbsian behaviour for Gibbs measures under general stochastic evolutions, of possibly non-Markovian nature, was finished and has appeared in *J. Stat. Phys.* in the meantime. A joint paper by Van Enter, Külske, Opoku and Ruszel was accepted and has in the mean time electronically appeared in the *Brazilian Journal for Probability and Statistics*.

Van Enter, in collaboration with R. Fernàndez (Utrecht/Rouen), den Hollander and Redig (Leiden) is studying the space-time picture of the transition in simple examples. Külske and LeNy provided a complete analysis of the transition between Gibbsian and non-Gibbsian behavior as a function of time in the ferromagnetic Ising mean-field model, for non-interacting stochastic dynamics. Based on this work, the PhD research of Ermolaev aims at a similarly complete description including the low-temperature regime of dynamics and initial measure in the corresponding mean-field model, based on
different (path-large-deviation) methods.

Van Enter and Verbitskiy studied the erasure entropies especially in the two-dimensional Ising models; a paper was finished and has been accepted for publication in *Markov Processes and Related Fields*. Van Enter and Shlosman (Marseille) have started to study a model due to Pecherski which is in some sense intermediate between equilibrium and dynamical spin models.

E. Verbitskiy continued the study of algebraic dynamical systems. A joint paper with with K. Schmidt (Vienna) on the connection between Abelian Sandpile Models of mathematical physics and algebraic dynamical systems has appeared in *Comm. Math. Phys.* in 2009. This work has been continued in collaboration with D. Lind (University of Washington, Seattle), in a joint paper Entropy and Growth Rate of Periodic Points of Algebraic ZZd- actions; submitted for publication in December 2009. A joint paper by E. Verbitskiy with C.Obi, B. Schoenmakers, B. Skoric, P. Tuyls (all Eindhoven), on applications of probabilistic techniques to cryptography, has been accepted for publication in *IEEE Transactions on Information Forensics & Security* and will appear in 2010. Results by J.-R. Chazottes (Paris), P. Collet (Paris), F.Redig (Leiden) and E. Verbitskiy on concentration inequalities for non-uniformly dynamical systems have appeared in 2009 in *Ergodic Theory and Dynamical Systems*.

Efstathiou, in collaboration with D. Sadovskiǐ and O. Lukina, published a paper in *J. Phys. A* on the qualitative properties of an integrable approximation to the hydrogen atom in electric and magnetic fields. Furthermore, an extensive review of the subject has been approved for publication in *Reviews of Modern Physics* and will appear in 2010.

In the study of fractional monodromy Efstathiou, H.W. Broer and O.V. Lukina have shown that integrable 2-DOF systems with reverse hyperbolic corank-1 singularities have fractional monodromy. A paper has been approved for publication in *Discr. Cont. Dyn. Sys. - Series S*. Efstathiou worked on bidromy in collaboration with H. Jauslin, P. Mardesic, M. Peletier and D. Sugny from the University of Bourgogne. A paper of Efstathiou and Sugny on the qualitative properties of systems with bidromy will appear in *J. Phys. A* in 2010. The paper clarifies the concept of bidromy through the study of the parallel transport of homology cycles in integrable Hamiltonian systems in which the bifurcation diagram has a characteristic swallowtail structure. A paper on a molecular system (HOCl) with a combination of fractional monodromy and bidromy has been accepted and will appear in *Phys. Rev. Lett.* in 2010. A paper on the relation of bidromy to Picard-Lefschetz monodromy is in preparation. Efstathiou is currently working with Broer on studying fractional monodromy through the lift of the fibration to an appropriate covering space. A paper is in preparation. Together with H. Dullin in Sydney Waalkens has written a reply to a comment on their earlier paper on scattering monodromy. This reply was published in *Phys. Rev. Lett.* Finally, Efstathiou plans to study numerically the effect of the singularities of integrable Hamiltonian fibrations to the perturbed non-integrable dynamics. As a first step, Efstathiou collaborates with Carles Simó in Barcelona on the numerical study of a 2D subsystem of the hydrogen atom in electric and magnetic fields.

Concerning the research on reaction-type dynamics Waalkens has been working on the quantum me-
channical aspects of reaction dynamics. This resulted in a paper published in Few-Body Systems on a quantum version of Wigner’s transition state theory (together with R. Schubert and S. Wiggins from Bristol University) and a paper on the semiclassical computation of the cumulative reaction probability for collinear reactions published in J. Chem. Phys. (with the previous authors and A. Goussye). Together with Goussye, Schubert and Wiggins, Waalkens prepared an extensive invited review paper for the journal Adv. Quant. Chem. The paper is currently under a formal review and will be published in 2010. A paper by Waalkens and Wiggins on geometric models of the classical phase space structures governing reaction dynamics was accepted for publication in Reg. Chaot. Dyn. A collaboration of Waalkens with G.S. Ezra (Cornell University) and S. Wiggins (Bristol University) on classical reaction rates has been published in J. Chem. Phys. With R. Hales (Bristol University) Waalkens studied the classical and quantum transport through entropy barriers modelled by hard-wall hyperboloidal constrictions. A joint paper on this subject was published in Ann. Phys. (NY). In collaboration with Schubert (Bristol University) Waalkens developed a periodic orbit formula for quantum reaction through transition states. A short paper on this been submitted to Phys. Rev. Lett., and a longer paper is in preparation.

In the research on microlasers and optical microcavities a work on different polarizations of electromagnetic waves of circular microdisks cavity with a point scatterer has been completed by Waalkens in collaboration with C. Dettmann, M. Sieber and G. Morozov (Bristol). This work has been published in Phys. Rev. A. With the same coauthors Waalkens finished a work on a systematic study of the inner and outer resonances of a circular microdisk. This work was published in Europhys. Lett.. This work was moreover presented at the conference ICTON 2009, and published in the corresponding conference proceedings. With Sieber and Hales (Bristol University) Waalkens developed a trace formula (periodic orbit formula) for a microdisk cavity with a point scatterer. They started a numerical studies of the trace formula which will be completed at the beginning of 2010. A paper is in preparation.

Extension theory
The theory of abstract boundary values and Weyl functions is being carried forward (with Arlinskiî, Behrndt, Derkach, Hassi, Malamud). The decomposition of operators and forms is being studied with Hassi, Sebestyén, Szafraniec; and from a different perspective with Labrousse, Sandovici, Winkler. Extension theory and system-theoretic interpretations are being carried forward (with Arlinskiî, Hassi, van der Schaft, Zwart). Normal extensions of symmetric operators are being studied (with Hassi, Szafraniec). Sectorial relations and their factorizations are being studied with Hassi, Sandivici, Winkler. The representation of not necessarily semibounded sesquilinear forms in a Hilbert space remains a research topic (with Fleige, Hassi, Winkler). The perturbation of eigenvalues in of a self-adjoint operator is being studied in various contexts by Hassi, Sandovici, de Snoo, Winkler, and with Wojtylak. Generalized Nevanlinna functions in the setting of almost Pontryagin spaces are being studied with Woracek. Multi-variable interpretations of boundary relations are being studied with Alpay, Behrndt, Hassi. The spectral theory of canonical differential equations is being developed in terms of boundary triplets by Behrndt, Hassi, Wietsma. Moment problems are being studied with Derkach and Hassi.
PhD research
Holtman published one paper in cooperation with Vitolo (Exeter) and his supervisors Broer and Vegter, and submitted another one with Broer and Vegter. He defended his thesis in September 2009. Sterk has made good progress in cooperation with his supervisors Broer, Dijkstra (IMAU) and Simó (Barcelona). Sterk submitted two papers in collaboration with his supervisors and Renato Vitolo (Exeter) which will both appear in 2010. He will defend his thesis in October 2010. Ruszel made good progress. She wrote one paper with Redig and Roelly that was accepted in *J. Stat. Phys.*, one paper with van Enter, Külske and Opoku was accepted in *Braz. J. Prob. Stat.*., and one paper with van Enter appeared in *Stoch. Proc. Appl.*. Opoku finished another paper that was accepted (see above) and defended his thesis in September 2009. Ermolaev made good progress. He obtained a number of results on the description of mean-field models with low-temperature-dynamics, an extensive preprint is about to be finished. Iacobelli made good progress on getting familiar with the field of networks, and prepared a paper together with Ch. Külske (Bochum) which will be submitted at the beginning of 2010. Fleurke, as an external PhD student, published one paper and submitted another one which will appear in 2010 both together with Külske.

3.3 Research subjects

**H.W. Broer:** perturbation and KAM-theory, bifurcation theory, non-integrable and resonance phenomena, applications of singularity theory, exploration of complicated systems.

**A.C.D. van Enter:** lattice statistical mechanics and thermodynamic formalism, Gibbs-non-Gibbs transitions, bootstrap percolation, nonlinear vector models, disordered systems and spin-glasses, metastates and chaotic size-dependence, non-crystalline long-range order.

**K. Efstathiou:** integrable and near-integrable Hamiltonian systems, applications of Hamiltonian mechanics in physical systems, generalized monodromy, applications of dynamical systems to biology.

**V. Ermolaev:** path variational principle of mean-field measures.

**S. Fleurke:** blocking models and frequency assignment.

**S.J. Holtman:** computation of a universal four dimensional bifurcation set and associated recognition problems for maps and ODE’s.

**G. Iacobelli:** statistical mechanical models on random graphs.

**X. Liu:** stability, bifurcations and stabilisation of invariant sets in differential inclusions

**A. Opoku:** relation between short-range and long-range models.

**W.M. Ruszel:** vector models, Gibbs measures versus non-Gibbsian measures.

**H.S.V. de Snoo:** extension and realization theory with their applications to analytical problems.

**A.E. Sterk:** climate models.

**E. Verbitskiy:** lattice statistical mechanics, thermodynamic formalism, Gibbs-non-Gibbs transitions, dynamical systems and time-series prediction.

**H. Waalkens:** theoretical and application oriented aspects of Hamiltonian systems including integrable systems, monodromy, reaction type dynamics, invariant manifolds, normal forms, and semi-classical quantum mechanics (short wavelength asymptotics) with applications to micro lasers and quantum reaction dynamics.
3.4 Publications

Dissertations


Books


Chapters in books


Articles in scientific journals


**Articles in conference proceedings**


### 3.5 External funding and collaboration

**External funding**

PhD grants (supervisor Broer): Drs. Sijbo J. Holtman has an NWO grant (open competition, co-supervisor G. Vegter) and was appointed September 1, 2005. 
Drs. Alef E. Sterk has an NWO-grant in the research-area Earth- and Life Sciences, with collaboration of H.A. Dijkstra (IMAU-UU) and C. Simó (UBarcelona), appointed September 1, 2005.
Xia Liu was appointed in April 2009 on a third NWO grant (open competition Applied Mathematics) in collaboration of H. Nijmeijer (TU/e). The work concerns nonsmooth dynamical systems and singular perturbation theory.

PhD grant (supervisor A.C.D. van Enter): Drs G. Iacobelli has an NWO grant (co-supervisors C. Külske (Bochum) and R.W. v.d. Hofstad-TU/e) and was appointed on January 1, 2008.
The nation-wide NWO-cluster *Nonlinear Dynamics in Natural Sciences* to enhance the infrastructure in the mathematics research, was initiated April 2005, with proposers H.W. Broer, A. Doelman (CWI), S.M. Verduyn Lunel (UL) and A. van der Vaart (VU). The fundings are provided by the Ministeries of OCW and EZ. Groningen has become the center of the cluster, with H.W. Broer as managing director. Nodes are the CWI, UL and VU (Amsterdam) and cluster members are spread all over the Netherlands. Groningen acquired 1.7 MEuro for research infrastructure, in particular one full professor and a tenure track assistant professor in the group *Applied Analysis* and another tenure track assistant professor in the group *Dynamical Systems & Mathematical Physics*. The full professor is A.J. van der Schaft, appointed 1 September 2006, and the two tenure trackers are K. Camlibel (Applied Analysis) and H. Waalkens (Dynamical Systems), both appointed 1 September 2007.\(^1\) Moreover funding is available for 0.2 fte full professor Mathematics of Life Sciences, with the help of which E. Verbitskiy (Philips), has been appointed as professor for Mathematics of Life Sciences in the group *Dynamical Systems & Mathematical Physics* per 1 October 2007; moreover E.R. van den Heuvel (Organon) has been appointed as professor of Statistics of Life Sciences in the group Probability and Statistics per 1 January 2008.

**PhD grant (supervisor H. Waalkens):** Drs. Robert Hales has been appointed in October 2006 to work on quantum resonances and micro lasers. This research is carried out at the University of Bristol and is funded by EPSRC (British Research Council).

**Post-doctoral research grants (supervisor H. Waalkens):** Funding for two post-doc positions (three years each) has been claimed from EPSRC (British Research Council). The first concerns asymptotic and numerical approaches to the theory of optical microresonators and microlasers (in collaboration with M. Sieber and C. Dettmann at Bristol University) and Dr. Gregory Morozov worked on this project from February 2006 to April 2009. The project for the second position is entitled Quantum Transition State Theory and Dr. Arseni Goussev has been appointed to work on this project in August 2007. Both post-docs are located at Bristol University.

H.S.V. de Snoo became Mercator visiting professor at the TU Berlin for half a year.

**External collaboration**

K. Efstathiou visited the University of Barcelona in April 2009 and September 2009 for research collaborations. Efstathiou also continued a collaboration with the Université du Littoral (Dunkerque) where he visited in May 2009.


\(^1\)Waalkens got tenure immediately.
In 2009, E. Verbitskiy was a member of a research evaluation committee of the three TU mathematics institutes. For the period 2009-2013 E. Verbitskiy has been appointed to serve on the advisory committee of the MEXT-GCOE program Math-for-Industry, Japan.

H. Waalkens visited the University of Bristol in July and November 2009 for research collaborations.

H.S.V. de Snoo visited TU Berlin (Germany) as Mercator professor, for 5 months in 2009, the University of Vaasa (Finland), and Jagolonian University, Krakow (Poland).

A.C.D. van Enter visited Marseille in September and November for research collaboration.

### 3.6 Further information

H.W. Broer gave invited talks at

- AMS Conference on *Ordinary Differential Equations* in Boca Raton (USA);
- Steklov Institute (Russian Academy) Conference *Mathematical Control Theory and Mechanics* in Suzdal (Russia);
- Lorentz Center workshop *Monodromy and Geometric Phases* in Leiden;
- Lorentz Center workshop *New Directions in Dynamical Systems* in Leiden;
- Colloquium at Boston University (USA);
- Colloquium at TU Eindhoven;
- Colloquium at Carl-von-Ossietzky Universität in Oldenburg (Germany).

H.W. Broer is a member of the Royal Academy of Arts and Sciences (KNAW), afdeling Natuurkunde, sectie Wiskunde. He is coordinating editor of *Indagationes Mathematicae* (jointly with M. Keane of Wesleyan University), which forms the Proceedings of the KNAW.

Broer moreover is Division Editor of the *Journal of Mathematical Analysis and Applications* (JMAA), for the area of Ordinary Differential Equations and Dynamical Systems and Associate Editor of *Discrete and Continuous Dynamical Systems – Series S*, and member of the editorial board for *Epsilon Uitgaven*. Broer is the scientific director of the Johann Bernoulli Institute, managing director of the NWO cluster NDNS+, and chairman of the MRI board. He is also a member of the Mathematics Board of the Lorentz Center (Leiden), and he acted as scientific counselor for the Lorentz Center workshop ‘New Directions in Dynamical Systems’, organized by H. Hanßmann (UU), A.J. Homburg (UvA), G.B. Huitema, S.J. van Strien (Warwick) and F. Takens in honour of H.W. Broer’s 60th birthday.

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S.J. Holtman gave the following presentations:

- *Philips Prize* presentation at the *NMC (Nederlands Mathematisch Congres)* in Groningen;
- Presentation in the Dynamical Systems seminar at the University of Utrecht;
- Presentation in the BCANM seminar at the University of Bristol (UK);
- Presentation in the MRI seminar at the University of Exeter (UK).

A.E. Sterk gave the following presentations:

- Poster presentation at the workshop *Mathematical Challenges in Climate Science*, Lorentz Center Leiden, March;
- Poster presentation at the *European Geosciences Union General Assembly*, Vienna (Austria);
- Oral presentation at the symposium *Bifurcations and Instabilities in Fluid Dynamics (BIFD 2009)*, Nottingham (UK);
- Oral presentation in the applied maths seminar, University of Exeter (UK).

A.C.D. van Enter gave invited talks

- at the workshop *The renormalisation group and statistical mechanics.*, UBC Vancouver (Canada):
  - *Preservation and loss of the Gibbs property for the evolving XY models*, CPT Marseille (France);
  - *Preservation and loss of the Gibbs property for evolving XY models*, Universite de Provence, Chateau Gombert, Mathematiques (France);
- in the minisymposium *Interacting Random Systems*, Groningen;
- *Bootstrap percolation: questions, some answers and applications*, seminar *Dynamical Systems*, Groningen.

A.C.D. van Enter organised the Mark Kac seminar with R.W. v.d Hofstad (Eindhoven) and the Eurandom workshop, ‘Disorder and Double Disorder’, August 2009. He was also coorganiser of the Vancouver workshop, ‘The Renormalization Group and Statistical Mechanics’, July 2009. He was member of the jury for the PhD thesis of A. Balint (VU Amsterdam), title: ‘Divide and colour models’. He is editor of it Markov proc. and Related fields and of *Het Nederlands tijdschrift voor Natuurkunde*. He is member of the steering committee of the Eurandom RSS programm.
W.M. Ruszel gave the lectures

- *Gibbs-non-Gibbs properties for lattice and mean-field xy models and beyond: the lattice case*,
  statistics seminar, Groningen;

- *Gibbs-non-Gibbs properties for lattice and mean-field xy models and beyond: the lattice case*,
  Mark Kac seminar, Utrecht.

H.S.V. de Snoo gave lectures at

- TU Ilmenau (Germany);
- University of Oslo (Finland);
- Lomonosov University, Moscow (Russia);
- Lorentz Center in Leiden (poster session).

H.S.V. de Snoo coorganized the Lorentz Center workshop *Boundary relations and applications* together with Seppo Haaai (Vaasa University) and Franek Szafraniec (Krakow University).

E. Verbitskiy gave invited lectures at

- Centrum voor Wiskunde en Informatica (Amsterdam), 2 talks;
- Staff colloquium, Mathematical Institute, Leiden University;
- Conference Casimir Force, Casimir Operators and the Riemann Hypothesis, Kyushu University, Fukuoka (Japan).

H. Waalkens gave invited talks

- at the Focus Session *Transition State Theory* at the *March Meeting of the American Physical Society* in Pittsburgh (USA);
- at FU Amsterdam (seminar talk);
- University of Groningen (mathematics colloquium).
H. Waalkens coorganized the Lorentz Center workshop *Monodromy and Geometric Phases in Classical and Quantum Mechanics* with K. Efstathiou, J. Robbins and D. Sadovskii. Together with his postdoctoral student, A. Goussev, H. Waalkens organized an EPSRC funded workshop at the Bristol Institute for Advanced Studies in Bristol (UK) on Transition State Theory. With P. H. Richter he organized a two weeks summer school of the Studienstiftung des Deutschen Volkes on the subject *Classical and Quantum Chaos* in Görlitz (Germany).

K. Efstathiou gave invited talks at

- the meeting *Singularities of Planar Vector Fields, Bifurcations and Applications* on *Hamiltonian monodromy*, Luminy (France);
- the workshop *Brain Waves* on *Unstable attractors in pulse coupled oscillator networks*, Lorentz Center, Leiden;
- *Fractional monodromy in integrable Hamiltonian systems with reverse hyperbolic singularities*, University of Utrecht;
- *The hydrogen atom in electric and magnetic fields*, University of Barcelona (Spain).

K. Efstathiou coorganized the Lorentz Center workshop *Monodromy and Geometric Phases in Classical and Quantum Mechanics* with J. Robbins, D. Sadovskii and H. Waalkens.
4. **Geometry**

**Group leader:** Prof.dr. G. Vegter

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**PhD students**

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<td>F. Senguler-Ciftci</td>
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<td>S. Ghosh</td>
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<td>S. Holtman (member of Dynamical Systems)</td>
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<td>P. Pranav (Kapteyn Institute/RuG)</td>
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**Guests**

- M. Teillaud, INRIA, Sophia Antipolis, France
- M. Caroli, MSc, INRIA, Sophia Antipolis, France
4.1 Research Program

Our research topics fall within several subfields of Geometry, like Differential Geometry and Singularity Theory on the more theoretical side, and Computational Geometry on the more applied side. In collaboration with other local and international groups in Mathematics and Computer Science, this research is also focused on applications in Geometric Modeling, Dynamical Systems, and Astrophysics. The goal is to obtain constructive and certified methods for the study of geometric and topological structures arising in a wide range of scientific problems.

**GEOMETRIC APPROXIMATION.** The approximation of shapes in various representations by ‘simple’ geometric objects, like polyhedral objects or piecewise quadratic surfaces, is one of the central topics of our research program. This field has attracted a lot of interest from researchers in Computer Aided Geometric Design, where mainly numerical aspects of the problem are emphasized. However, our scope is rather different in that we focus on *topological correctness*, a criterion often disregarded in applications: the topology of the approximating object should be the same as that of the original shape.

Using and extending methods from Morse Theory and Singularity Theory, we have obtained several certified meshing methods. We work on special computational models for geometric approximation of smooth curves and surfaces, where we combine geometric properties of the shapes with the use of interval arithmetic. Other approximation methods are also in focus, like schemes using spherical in stead of piecewise linear patches, or piecewise quadratic surfaces obtained as envelopes of collections of spheres. These approximation methods have applications in geometric processing of models of large protein molecules.

Our work on Radial Basis Functions is related to the reconstruction of complicated shapes from large point samples. The goal is to design certified reconstruction methods, guaranteeing topological correctness of the output. This work is combined with our results on smooth surface meshing to extract topologically correct isosurfaces from dense samples.

4.2 Overview of scientific results

*G. Vegter*

*Complexity issues* are crucial in our research on certified geometric approximation. In several cases we have succeeded in expressing the quality, i.e., the complexity, of our approximations in terms of *intrinsic geometric invariants* of the shape to be approximated, like Euclidean or affine curvature (See the description of the results from the PhD project of Ghosh). These results have direct implications for the design of efficient approximation algorithms.

In joint MSc and PhD projects with Rien van de Weygaert of the Kapteyn Astronomical Institute we
are applying topological methods to detect one- and two-dimensional structures in large cosmological data sets, representing the distribution and evolution of cosmic matter. We apply our earlier work on topologically correct approximation of isodensity surfaces of matter distribution in the universe, and combine it with the computation of topological invariants, like Betti numbers, to detect shape and structure. Pratyush Pranav was hired as a bursary student at the Kapteyn Institute to extend this work using topological persistence, a topological framework that distinguishes essential topological features from topological noise.

In collaboration with the computational geometry groups of the Freie Universität Berlin and the Technische University of Graz we continued our work on certified reconstruction in higher dimensions, leading to a joint paper on the reconstruction of geometric surfaces from point samples.

S. Ghosh
We obtained a geometric characterization of piecewise helical curves optimally approximating arbitrary curves in three-space with regard to Hausdorff distance, leading to an efficient algorithm for optimal approximation by such helix-splines.

A. Chattopadhyay
In the PhD project on Certified Shape Reconstruction ongoing work is concerned with topologically correct reconstruction of shapes from sufficiently dense point samples. We have completed our work on the application of Radial Basis Functions to certified isosurface extraction. The paradigm of certified approximation is now being extended to the computation of Morse-Smale complexes on smooth surfaces.

S.J. Holtman
In this joint PhD project with the Dynamical Systems group we extend earlier work on resonance tongues, associated with the bifurcation of periodic orbits from fixed points in systems depending on parameters, or with the birth of \( q \)-th order harmonics in families of periodic systems. We developed an algorithm to detect such resonance tongues, and explored and visualized the complicated geometry of such resonance regions in higher dimensional parameter spaces. In co-operation with Vitolo (University of Exeter) we extended our earlier work on the exploration and visualization of the complicated geometry of resonance regions in higher dimensional parameter spaces by incorporating the full bifurcation set. This work has now also been extended to continuous systems.

4.3 Research subjects

A. Chattopadhyay: certified surface reconstruction, Radial Basis Functions.
S. Ghosh: differential geometry in geometric approximation.
S.J. Holtman: geometry of resonance tongues, bifurcations sets in higher dimensional spaces.
F. Senguler-Ciftci: certified geometric approximation of curves and surfaces.
G. Vegter: certified geometric approximation, computational topology, computational differential
geometry, singularity theory and its applications, dynamical systems.

4.4 Publications

Dissertations

S.J. Holtman, *Dynamics and geometry of resonant bifurcations*, Promotor: H.W. Broer and G. Vegter, Faculty of Mathematics and Natural Sciences, University of Groningen, 18 September 2009, 132 pages.

Articles in scientific journals


Articles in refereed conference proceedings


4.5 External funding and collaboration

External funding.

The PhD positions of A. Chattopadhyay and F. Senguler-Ciftci and S.J. Holtman (PI: H. Broer, Dynamical Systems) are funded by NWO.

The PhD position of S. Ghosh is funded by the European Commission in the Information Society Technologies (IST) program, funded under the 6th Framework Program of the European Commission, project *Algorithms for Complex Shapes (ACS)*.
External collaboration.
Vegter is site-leader of the joint project *OrbiCG*, a joint INRIA-funded project of the INRIA/Geometrica project team at Sophia and the University of Groningen.

He has also been a member of the Program Committee for the SIAM/ACM joint conference on Geometric and Physical Modeling. He organized the Lorentz Center workshop *Subdivide and tile*, together with M. Teillaud (Sophia Antipolis) and R. van de Weygaert (Groningen).

He also served on the reading committee of R.I. Silveira, *Optimization of polyhedral terrains*, Utrecht University, July 2009.

Vegter visited INRIA, Sophia-Antipolis, France (two weeks in October), for joint work in the context of the project OrbiCG.

4.6 Further information

Vegter has been elected chairman of the Royal Dutch Mathematical Society (KWG). He is also on the board of the Platform Wiskunde Nederland, which aims at representing the interests of the Dutch mathematical community regarding research, teaching, technology transfer, publications and PR & communication. Vegter has been chairman of the organizing committee of the Annual Dutch Mathematical Congress 2009.

He gave the following public lectures:


- *De ruimte in de loop van de tijd*. Over de geschiedenis van het ruimtebegrip. Senioren Academie ( Hoger Onderwijs Voor Ouderen in Groningen en Drenthe), maart 2009 (in dutch).
5. *Probability and Statistics*

**Group leader:** Prof.dr. E. Wit

**Tenured staff (JBI members)**

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**PhD students**

V. Ermolaev  
(supervisor: Külske and Van Enter)  
-RUG-  
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S. Fleurke  
(supervisor: Külske, Dehling and Van Enter)  
-Telekom-  
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G. Iacobelli  
(supervisors: Külske and Van Enter)  
-NWO-  
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A. Opoku  
(supervisor: Külske)  
-RuG-  
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W.M. Ruszel  
(supervisor: Van Enter, Külske)  
-RuG-  
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5.1 Research program

This is the first full year in which the research programme Statistics and Probability has operated within the Institute. The size has remained stable within this period. Besides the Chair Prof. Dr. E. Wit, Prof. Dr. E.R. van den Heuvel (0.2 fte) and Dr. C. Külkske are working within the research programme.

The Statistics and Probability research programme has made inroads in collaborations with the other groups within the university. The objective of this research programme is to work on the methodological aspects modelling and inference. The aim is to link to the applied statistics colleagues around the university, while maintaining its applied mathematical roots. Currently the strengths of the research programme lie in statistical design, high-dimensional statistical inference with applications in the life sciences, pharmaceutical statistics and interacting stochastic systems.

5.1.1 Research focus

**Statistical genomics and high-dimensional inference.** Statistical methodology has always responded to latest developments in advances in measurement techniques and developments in the substantive sciences. At the end of the 1990s, new genomic technologies made it possible to obtain snapshots of the activity of tens of thousands of genes simultaneously. This has lead to a new impulse in areas such as experimental design, sparse inference and functional statistics.

The dimensionality of the problem in genomics has been archetypical for the types of inference required in modern high-throughput experiments in many areas of science and industry. The dimensionality of the feature space is often orders of magnitude larger than the number of observations. Moreover, the dimensionality of the space of models grows exponentially with the number of features. Such extreme circumstances has led to renewed interest in sparsity, both from a philosophical and computational perspective. Penalized likelihood methods has opened up a way for performing sparse inference. We have extended during this year out work on sparse inference in generalized linear models using methods from differential geometry.

This year the group was involved in a large successful bid for a Systems Biology Centre on Aging at the RUG. Prof. E. Wit is workpackage leader on a part of the grant, which over the next five years will involve work on explanatory approaches of genomics data via network modelling. From detailed kinetic differential equation models for the interaction of genomic particles to the graphical modelling of genetical network structures.

During this year we had several collaborative projects, involving Dr. V. Purutçuoglu (Middle Eastern Technical University, Ankara, Turkey), Dr. V. Vinciotti (Brunel University, London, UK) and Dr. L. Augugliaro (University of Palermo, Italy).
Statistics for measurement reliability. A measurement system quantifies or identifies one or more characteristics of an object. There are many types of measurement systems for measuring biological, medical, chemical and physical phenomena, including sensory measurements. Our research focuses on three distinct research questions. The first programme entails statistical modeling used to quantify the measurement value itself with respect to the standard. This part has already a prominent and long history in bioassays for example. The second programme involves statistical modelling used to validate the measurement system or quantify its performance. Estimation and construction of confidence intervals for the performance parameters is an important area. The third research interest is about reducing the effect of measurement reliability on decision making.

Collaborative work has been done with Dr. A. Di Bucchianico (Mathematics and Computer Science, Eindhoven University of Technology).

5.1.2 Interacting stochastic systems

Systems consisting of a large number of components which interact with each other in a stochastic way arise in physics, biology, social sciences, and finance. What makes them interesting is that they might show collective behavior and long range order. Our particular interest are disordered systems that pose a challenge to the mathematical physicist and probabilist.

The general of aim of this program is to understand interacting stochastic systems on a mathematical level. Even when the interaction is local, such systems typically exhibit a complex global behavior, with a spatial long-range dependence resulting in phase transitions. Here phase transitions are characterized by discontinuous behaviour of the possible states of the system as a function of external parameters. For specifically tuned values of the parameters there can be more than one global state, i.e. a Gibbs measure. The equilibrium properties of such systems, as described by the Gibbs measures can be highly non-trivial, and in one direction of research we are focussing on these. Moreover we are also interested in the time-evolution of such measures. It is was discovered a few years ago that time-evolved measures may lose (and recover) their Gibbsian nature as a function of time. We are trying to approach this phenomenon in case studies. In a related line of research we are investigating continuous interfaces.

Related stochastic methods also have use in applied problems like telecommunications, as an external PhD project with agentschap Telekom shows.

The work is done in various collaborations, including in the last years J.-R. Chazottes (Paris), P. Collet (Paris), R. Fernández (Rouen, this year Groningen-Leiden-Eindhoven), F. Redig (Leiden), A. Le Ny (Orsay), W.Th.F. den Hollander (Leiden), E. Orlandi (Rome), R. van der Hofstad (Eindhoven), M. Biskup (UCLA), H.G. Dehling (Bochum), S. Shlosman (Marseille), V. Zagrebnov (Marseille), S. Romano (Pavia), K. Netocný (Prague).
5.2 Overview of scientific results

**Statistical genomics and high-dimensional inference.** Wit and Van den Heuvel organized a NDNS+ workshop (23-25 November) on “High-dimensional inference and Complex Data”. The workshop brought a range of world-renowned speakers to Groningen and attracted 120 attendees from 12 different countries with only about half from the Netherlands.

Wit Sperrin09, together with co-authors, showed how probabilistic relabelling strategies resolve the problem of label switching in Bayesian approaches to mixture modelling. They showed how this approach has important advantages over current deterministic relabelling strategies.

The Bayesian paradigm is very helpful in situations where the likelihood is defined by repeated conditional probabilities, such as in the case of spatial problems. On the other hand, large spatial lattices typically encounter the flip side of a Bayesian approach, namely computational efficiency. To resolve this, Wit Friel09 and collaborators devised a way to calculate the normalizing constant on a large lattice efficiently, making thereby full Bayesian inference possible.

**Mathematical Physics.** Together with Prof. Dr. A.C.D. van Enter (RUG) and Prof. R. Fernandez (Université de Rouen), Külske organized the Eurandom workshop “Order, disorder and double disorder” from August 24-28, 2009.

There were a number of developments in the Gibbsian-non-Gibbsian programme, around which the PhD projects of Ermolaev, Opoku and Iacobelli are centred. Külske Formentin09a,Formentin09b published two articles on a symmetric entropy bound on the non-reconstruction regime of Markov chains on Galton-Watson trees and on free boundary condition Potts measure on random trees.

Külske together with Ph.D. Fleurke worked on the occupation probability of a parking process on a random tree. They derived a second-row parking paradox and published the results in *J. Stat. Phys* Fleurke09.

**PhD research.** Opoku completed his PhD degree in September with a successful defense. The PhD research of Ermolaev continues work on the low-temperature regime of dynamics and initial measure in the corresponding mean-field model, based on different (path-large-deviation) methods. Ermolaev has made good progress in his third year with Külske. He will stay in Groningen while completing his PhD. Fleurke as an external has made good progress: a second article has been completed and published. Iacobelli, also working with Külske has started his second year and completed and submitted an article.
5.3 Research subjects

V. Ermolaev: path variational principle of mean-field measures.
S. Fleurke: blocking models and frequency assignment.
E.R. van den Heuvel: statistics of bioassays, validating measurement systems, reducing the effect of measurement reliability on decision making.
Ch. Külkske: interacting stochastic systems, short-range vs. mean-field models, Gibbs measures vs. non-Gibbsian measures, interfaces, disordered systems, concentration inequalities, networks.
A. Opoku: relation between short-range and long-range models.
E.C. Wit: high-dimensional inference, statistical bioinformatics, statistical network modelling.

5.4 Publications

Articles in scientific journals


5.5 External funding and collaboration

External funding

SBC-EMA grant (joint grant, workpackage leader E.C. Wit): An NWO grant (lead applicants B. Groen (UMCG), B. Bakker (UMCG), M. Heinemann (GBB), F. Weissing (FWN)) was acquired with 2-4 PhD/Postdoc projects in the Theoretical Think Tank workpackage of which E. Wit is the coordinator.

External collaboration

E.C. Wit acted as the external examiner to the M.Sc. degree in Statistics and Statistical Bioinformatics at the School of Mathematics, University of Leeds.

5.6 Further information

In the beginning of the year Dr. C. Külske was promoted associate professorship. In October he accepted the post of Professor of Mathematical Physics at the University of Bochum, but agreed to stay at the RUG with a zero appointment. In September Külske’s PhD student, Alex Opoku, successfully defended his PhD thesis and was subsequently appointed as a post-doctoral researcher at the University of Leiden.

E.C. Wit gave invited lectures at the following occasions:

- “Modelling networks: top-down or bottom-up”, invited talk, GenSys meeting, Warwick, UK, 22 September 2009
6. **Systems, Control and Applied Analysis**

**Group leader:** Prof.dr. A.J. van der Schaft

**Tenured staff (JBI members)**

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<td>D. Kaba (since October 1) (supervisor: M.K. Camlibel)</td>
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<td>H. Vinjamoor (supervisor: A.J. van der Schaft)</td>
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Guests
D. Alpay, Ben-Gurion University of the Negev, Israel
I. Bomze, University of Vienna, Austria
S. Bundfuss, TU Darmstadt, Germany
K. Hamacher, TU Darmstadt, Germany
O. Kaneko, University of Osaka, Japan
H. Langer, Vienna University of Technology, Austria
B. Maschke, Universite Claude Bernard Lyon, France
A. Quadrat, INRIA Sophia Antipolis, France
P. Rapisarda, University of Southampton, UK
O. Stein, University of Karlsruhe, Germany
K. Takaba, University of Kyoto, Japan
J.C. Willems, Katholieke Universiteit Leuven, Belgium
6.1 Research Program

The research program Systems, Control and Applied Analysis (SCAA) is devoted to the analysis, control and optimization of complex systems. The mathematical research in this program is motivated by a wide range of application areas, including various fields of engineering, operations research, and systems biology.

Mathematical systems and control theory deals with the mathematical modeling, analysis and control of open systems evolving in time. The dynamics are described by ordinary or partial differential equations, or can be of a discrete nature. The dynamics is not only sought to be analyzed, but to be influenced ('controlled') and optimized as well by the addition of feedback loops and the interconnection of the open system to other dynamical systems (controller design). Other distinguishing feature is that typically the systems are described by under-determined sets of differential equations. Hence there are free variables in the system description (corresponding to 'inputs') which allow for two-sided interaction with the environment (open systems). Finally, the systems point of view is emphasized, in the sense that large-scale and heterogeneous dynamical systems are approached as being the interconnection of smaller system components, where the overall dynamics is determined by the dynamics of the components plus the interconnection ('feedback') structure. This point of view is prevailing in many areas of engineering, and is receiving increasing attention in the life sciences (systems and synthetic biology, biological feedback systems, etc.).

Mathematical optimization theory is concerned with the development of solution algorithms for mathematical optimization problems. Depending on the structure of objective function and feasible set, methods involving discrete or nonlinear features have to be developed. Special emphasis is given to nonlinear quadratic problems which at the same time involve binary variables. These problems have numerous applications in science, engineering and economics. They can be modeled as linear problems over special matrix cones (semidefinite programming, copositive programming) which permits a new approach to tackle these problems.

The members of the program have direct collaboration with colleagues working in other scientific disciplines such as robotics, power systems, mechatronics, economics, management science, and systems biology. Furthermore, there is a close local collaboration with the control engineering group at the neighboring Institute for Industrial Engineering and Management.

Structure of the program

The main lines of research in the program are:

1. **Modeling and control of multi-physics systems as port-Hamiltonian systems** (Arjan van der Schaft, Rostyslav Polyuga, Aneesh Venkatraman, Marko Seslija)
   
   *Port-Hamiltonian systems* are generalized Hamiltonian systems where the geometric structure is derived from the interconnection structure of the complex system. The aim of this
work is to provide a systematic mathematical theory for the mathematical modelling, analysis and simulation of multi-physics, mixed lumped- and distributed parameter, systems by making explicit the underlying physical structure, including energy balances and other conservation laws. Furthermore, the port-Hamiltonian framework is employed for controller design, by attaching controller port-Hamiltonian systems and shaping the Hamiltonian and other conserved quantities to a desired Lyapunov function for the controlled system, leading to physically inspired and robust control strategies.

2. Behavioral systems theory and control by interconnection (Harry Trentelman, Shaik Fiaz, Ha Binh Minh, Harsh Vinjamoor, Arjan van der Schaft)

The traditional way of modeling dynamical systems that interact with their environment is by an input-output map. However, physical systems in general do not exhibit the information flow direction that is pre-supposed by the input-output structure. In the behavioral approach, all external system variables are therefore a priori treated on an equal footing, while the mathematical model specifies a subset of the set in which the external variables take their values as being possible. This subset is called the behavior of the system. Many modeling and control questions are fruitfully studied in this novel setting. Although most of the research aims at linear differential systems it also provides inspiration for nonlinear and hybrid dynamical systems.

3. Analysis and design of piecewise-affine and hybrid dynamical systems (Kanat Camlibel, Thuan Quang Le, Devrim Kaba, Nima Monshizadeh, Arjan van der Schaft, Florian Kerber)

Hybrid systems are a mixture of interacting continuous and discrete dynamics, and arise naturally in embedded systems and physical systems modeling. Important research issues concern the systematic modelling of complex hybrid systems, the analysis of hybrid systems and their solution trajectories, the development of compositional reasoning techniques, the analysis of structural properties of controllability and stabilizability, and the design of controllers. From a mathematical point of view hybrid systems necessitate the merging of concepts and tools from continuous dynamics with those from discrete dynamics, thus linking to formal verification tools from computer science. The mathematical analysis of piecewise-affine and hybrid systems is heavily intertwined with optimization theory and non-smooth analysis.

4. Mathematical optimization theory (Mirjam Dür, Peter Dickinson, Julia Sponsel)

Mathematical optimization theory is concerned with studying structural properties and developing solution methods for mathematical optimization problems. The focus is on combinatorial problems and on nonconvex quadratic optimization problems. The studied methodology is to transform the problem into a higher dimensional matrix space, permitting to move the difficult constraints (quadratic and/or binary) entirely into a certain cone
constraint. This leads to copositive and semidefinite programming.

5. Schur analysis and operator theory in spaces with indefinite metric (A. Dijksma)
Schur analysis and operator theory in indefinite metric spaces deals with the extension of classical Schur analysis, in particular interpolation problems and the properties of the generalized Schur transformation.

6.2 Research subjects

M.K. Camlibel: piecewise affine dynamical systems, switched linear systems.
P.J.C. Dickinson: structural properties of copositive optimization problems.
A. Dijksma: operator theory with applications to Schur analysis (interpolation and rigidity problems) and approximation in varying spaces with indefinite metrics of singular differential operators by regular ones.
S. Fiaz: control by interconnection, stability analysis and synthesis, robust stabilization; rational representations.
S. Gottimukala: rational representations; stability analysis of uncertain behavioral systems.
D. Kaba: invertibility of switched linear systems.
F. Kerber: compositional analysis, bisimulation equivalence, and control of linear and hybrid systems. Assume-guarantee reasoning.
Q.T. Le: well-posedness and controllability of piecewise affine systems.
N. Monshizade: model reduction of piecewise affine systems
M. Seslija: Structure-preserving model reduction of port-Hamiltonian systems
J. K. Sponsel: copositive approaches to graph theoretic problems.
H.L. Trentelman: control in a behavioral setting; pole placement and stabilization by interconnection, implementability of system behaviors, synthesis of dissipative systems; robust stabilization, systems described by linear PDE’s, model reduction and approximation in a behavioral context.
H. Vinjamoor: control by interconnection up to bisimulation and asymptotic bisimulation. Regular feedback achievability.
6.3 Publications

Dissertations


Chapters in books


**Articles in scientific journals**


Articles in conference proceedings


Patents


6.4 External funding

6.5 NWO-STW funding

- The project "Energy-efficient design and control of mobile robotic sensor networks" (ROSE), with applicants A.J. van der Schaft, J.M.A. Scherpen (ITM, RUG), S. Stramigioli (University of Twente), was funded within the STW Perspective Programme *Autonomous Sensor Systems*.

6.6 Internalization

- Three international promovendi have been acquired under the Ubbo Emmius scheme of the Faculty of Mathematics and Natural Sciences of the University of Groningen: Devrim Kaba, Nima Monshizade, and Shuo Zhang. Devrim Kaba is being supervised by Kanat Camlibel, Nima Monshizade by Harry Trentelman and Kanat Camlibel, Shuo Zhang by Ming Cao and Kanat Camlibel.
- The PhD students Julia K. Sponsel and Peter J.C. Dickinson followed the two week block course *Combinatorial Optimization at Work* at TU Berlin, Germany
- The PhD student Aneesh Venkatraman spent two weeks at Imperial College, London (collaboration with prof. A. Astolfi).
- The PhD student Rostyslav Polyuga was invited for a visit and a lecture at the TU Munich.
- The PhD student Marko Seslija followed a course on port-Hamiltonian systems theory at the EECI, Gif-sur-Yvette, France.

6.7 Editorial activities

M.K. Camlibel:

- Subject Editor for the *International Journal of Robust and Nonlinear Control*
Mirjam Dür:

– Member of the Editorial Board of *Journal of Global Optimization*

A. Dijksma:

– Member of the Editorial Board of *Integral Equations Operator Theory* and *Complex Analysis and Operator Theory*
– Member of the Editorial Board of *Complex Analysis and Operator Theory*
– Member of the Editorial Board of the book series *Operator Theory Advances and Applications*.

H.L. Trentelman:

– Associate editor for *Systems and Control Letters*

A.J. van der Schaft:

– Editor-at-Large for *European Journal of Control*
– Associate Editor for *Systems & Control Letters*
– Associate Editor for *Journal of Geometric Mechanics*

6.8 Further signs of recognition and news items

– Kanat Camlibel is member of the IFAC Technical Committee on Linear Systems
– Kanat Camlibel is member of the IFAC Technical Committee on Control Design
– Kanat Camlibel is member of the IFAC Technical Committee member on Discrete Event and Hybrid Systems.
– Kanat Camlibel was International Program Committee Member of the 3rd IFAC Conference on Analysis and Design of Hybrid Systems, Zaragoza, September 16-18, 2009.
– Mirjam Dür was Co-Chair (with Oliver Stein) of the EUROPT Workshop on Advances in Continuous Optimization, Remagen, Germany (July 3-4, 2009)
– Mirjam Dür spent four weeks as a guest professor at Université Paul Sabatier, Toulouse, France
– Mirjam Dür was invited plenary speaker at the 14th Belgian-French-German Conference on Optimization, Leuven, Belgium (September 2009)
– Mirjam Dür was a member of the PhD committee of Guoyong Gu at TU Delft (*Full-Step Interior Point Methods for Symmetric Optimization*)
– Mirjam Dür gave invited lectures at the universities of Twente, Eindhoven, Toulouse (France) and Ulm (Germany)

– Harry Trentelman was co-organizer of the Workshop "Open and Interconnected Systems: Modelling and Control, Brugge, Belgie, September 16-17, 2009

– Harry Trentelman received the annual teaching award 2009 “Teacher of the Year” from the teaching institute of Mathematics.

– Arjan van der Schaft was International Program Committee Member of the 3rd IFAC Conference on Analysis and Design of Hybrid Systems, Zaragoza, September 16-18, 2009.

– Arjan van der Schaft is Member of the Steering Committee of the Mathematical Theory of Networks and Systems Symposium (Biennial International Conference)

– Arjan van der Schaft is Member of the International Program Committee for the 8th IFAC Symposium on Nonlinear Control Design (NOLCOS), Bologna, September 1-3, 2010.

– Arjan van der Schaft is Member of the International Program Committee for the MTNS 2010, Budapest, July 5-9, 2010.

– Arjan van der Schaft is Member of the International Program Committee for the 4th IFAC Symposium on Systems, Structure and Control, Ancona, September 15-17, 2010.

7. **Distributed Systems**

**Group leader:**
Prof.dr.ir. M. Aiello

**Tenured staff (JBI members)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof.dr.ir. M. Aiello</td>
<td>RuG</td>
<td>1.0</td>
</tr>
<tr>
<td>Dr. A. Lazovik</td>
<td>RuG</td>
<td>0.75</td>
</tr>
</tbody>
</table>

**Administrative staff**

D.J. Hansen

RuG 0.15

**Honorary professors**

Prof.dr. S. Dustdar

TU Wien 0.0

**PhD students**

E. El-Khoury

(supervisor: Aiello)

RuG 1.0

E. Kaldeli

(supervisor: Aiello)

RuG 1.0

M.C. Doğanay

(supervisor: Aiello)

EU FP7 1.0

P. Bulanov (since 01-01-2009)

(supervisor: Aiello)

NWO 1.0

H. Groefsema (since 01-09-2009)

(supervisor: Aiello)

NWO 0.5

A. Pagani (since 01-11-2009)

(supervisor: Aiello)

RuG 1.0

A. Emerencia (since 15-11-2009)

(supervisor: Aiello)

ZonMW 1.0

V. Degeler (since 01-12-2009)

(supervisor: Lazovik)

RuG 1.0

**Guests**

D. Fernandez Duque, Stanford, USA
C. Hentrich, CSC, Germany
S. Tai, Karlsruhe Institute of Technology, Germany
7.1 Research Program

Distributed Information Systems are concerned with the delocalization of computation on several hosts and their coordination via message passing. Looking at today information systems, we remark how most of them, if not all, have a form of distribution. The key issues that emerge for research become those of addressing heterogeneity, scalability, and run-time adaptation.

In the context of distributed systems, the group focuses on a number of sub-areas: Service-Oriented Computing, Pervasive computing middleware and sensor networks. While interesting applications areas for the group are: Health care, Domotics, and Energy distribution. Before detailing the research areas of the DS group in 2009, we remark that the group has emerged in 2009 as the splitting of the Distributed Systems and Software Engineering group. The latter had originally been funded in 2007 with the arrival of Aiello at the University of Groningen.

7.1.1 Service-Oriented Computing

Service-Oriented Computing (SOC) is an emerging computing paradigm for building distributed information systems in which the concepts of distribution, openness, asynchronous messaging and loose coupling take a leading role. In this context, applications are built out of individual services that expose functionalities by publishing their interfaces into appropriate repositories, abstracting entirely from the underlying implementation. Published interfaces may be searched by other services or users and subsequently be invoked. The interest in Service-Oriented Computing is a consequence of the shift from a vision of a web based on the presentation of information to a vision of the web as computational infrastructure, where systems and services can interact in order to fulfill users’ requests. Web Services (WS), the best-known example, are the realization of service-oriented systems based on open standards and infrastructures, extending the XML syntax.

Automatic Web Service composition using automated planning techniques. The availability of services self-described opens the road for dynamic approaches to application design and execution. Of particular interest is the problem of dynamic service composition, i.e. the on-demand combination of loosely-coupled service operations in order to realise some complex objective, specified by an end-user. However, most of these proposals suffer from several limitations, including the fact that they rely on pre-defined processes, that restrict the request variety that can be effectually satisfied by the available service operations. Our approach on the contrary drives towards a domain-independent planner, relying on modeling the problem as a CSP (Constraint Solving Problem), that supports a highly adaptable domain description, an expressive goal specification language, and accommodates for sensing and incomplete knowledge. Improving the efficiency of the planner is the main focus of our current work.

Business process management and customization. Business process management is used to solve a large variety of tasks, for example to make different e-Government processes comput-
erized. When similar business processes are deployed in different organizations, one typically adapts manually a template process to the different execution environments and organizational needs. Service-Oriented Architectures facilitate the task of adaptation by exposing the functionalities needed by the process in an abstract way, decoupled from the implementation. Nevertheless, manual intervention to customize the processes is still highly necessary, making it hard to maintain the processes obtained as the result of customizations. Therefore, it is important to have a flexible and controllable customization framework for business process management.

The research is focused on application of variability management and process flexibility techniques in order to achieve the goal of controllable customization.

**Diagnosis and Diagnosability within Service-Oriented Systems.** The research focuses on a diagnosis of complex autonomous service-oriented systems and investigates the possibility of building automatic diagnosers that monitor services execution at run-time, and provide (semi-)automatic repair and recovery when needed. Service-Oriented Systems are usually evolving over time, and some changes may trigger previously valid composition to become incorrect. The goal is to create a system that detects anomalous situations that may manifest as the inability to provide a service or to fulfill Quality of Service requirements, and recovers from these situations, e.g. by triggering some repairing actions or reconfiguring the network of services. The research also aims to provide a methodology for a designer of services to design it in such a way that guarantees diagnosability and repairability of runtime failures.

**7.1.2 Middleware for pervasive systems**

Pervasive computing is a new computing paradigm that envisions a future in which computers seamlessly blend into fabric of daily life and eventually “disappear”. Domotics, in particular smart houses, is the most prominent application area of pervasive computing. At their core, models of ubiquitous computing consist of large numbers of small, inexpensive and networked processing units embedded into everyday objects.

**Fault tolerance in pervasive computing applications.** Efficient fault tolerance is a must in pervasive computing applications, especially in smart homes. We investigate fault tolerance in pervasive computing scenarios which involve large number of wireless sensor nodes, with our main focus on Byzantine fault tolerance. State of the art solutions to Byzantine fault tolerance problem are not applicable to our scenarios since connections between sensor nodes are ad-hoc, the network topology is dynamic and each node has limited computing resources. We try to build a fault tolerant middleware for smart homes which can deal with ad-hoc connections and dynamic topology. We expect to incorporate this work into the architecture developed in the context of the SM4ALL (Smart Homes for All) EU 7th framework project.

**Security and access control management in wireless sensor networks.** As wireless sensor networks become more popular, so does the need for effective security mechanisms for them. Because sensor networks may interact with sensitive data and/or operate in hostile unattended
environments, it is imperative that these security concerns be addressed from the beginning of the system design. However, due to inherent resource and computing constraints, security in sensor networks poses different challenges than traditional network/computer security. There is currently enormous research potential in the field of wireless sensor network security. Some studies show how to provide best practice when deploying large WSN, mainly at the sensor level! We focus our research on improving privacy and access control over the sensors in the context smart homes, to provide the users with a safe environment where their private daily data are not exposed to external attackers. We expect to incorporate this work into the architecture developed in the context of the SM4ALL (Smart Homes for All) EU 7th framework project.

7.1.3 Software energy infrastructures

Energy markets are undergoing important changes in latest years, especially the unbundling tendency in the energy sector is changing the rules of the game. In addition, at the same time, economies of scale for technologies once unaffordable for the end user, are helping the spread of small-scale energy generators (i.e., combined heat and power, photovoltaic panels, small-wind turbines) that allow even the end user to produce its own energy. In this landscape we envision a future energy system in which every user in the power-grid network becomes a peer who can either sell its own produced energy surplus to everybody else in the network, or buy energy from someone else, at a give point in time. The main research focus is to investigate how it is possible to exchange energy in a peer-to-peer oriented network grid both from a network topology perspective and from a software service perspective. Moreover this approach can also be a good driver to the spread of renewable energies generation, which is easier to implement at small and local scale, that can contribute reaching a zero-impact energy system.

7.1.4 Web based systems for health care

There is a paradigm shift in modern day health care towards a patient centered approach, where patients are in control of managing their disease, often through the use of web applications. For patients suffering from schizophrenia however, little has been done so far and this is often contributed to the fact that these patients have different needs with respect to the structure, content and user interface of a web site. This is why the University Medical Center Groningen (UMCG) and the University of Groningen cooperate to design an intelligent web application specifically for this group of patients. By data mining patients’ test results, health records and demographic information, relevant information and intelligent suggestions can be offered, personalized and localized for each patient. Using machine learning, the web application’s behavior can change based on how it is used. For the purpose of self-assessment, additional behavioral biometrics analysis can be performed. The main focus of the research project MyCare is on implementing methods from these fields to improve the usability of web applications for the target audience.
7.2 Research subjects

M. Aiello: service-oriented Computing, Ubiquitous computing and Domotics, Spatial Representation and Reasoning.
V. Degeler: automatic diagnosis and repair, Constraint satisfaction.
A. Emerencia: intelligent Web Applications, Data Mining, Machine Learning, Pattern Recognition, Behavioral Biometrics.
E. Kaldeli: web Service Composition, Automated Planning, Constraint Satisfaction.
A. Lazovik: automated service composition, Monitoring and repair, Automated planning, Cloud computing.

7.3 Publications

Articles in conference and workshop proceedings


Other publications


7.4 External funding and collaborations

**External funding**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Name</th>
<th>Funding Agency</th>
<th>Programme</th>
<th>PI</th>
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<tbody>
<tr>
<td>MyCare</td>
<td>A self-assessment and management of schizophrenia</td>
<td>ZonMW</td>
<td>Innovation in healthcare</td>
<td>Aiello</td>
</tr>
<tr>
<td>Amazon</td>
<td>AWS Teaching Grant</td>
<td>Amazon</td>
<td>AWS in Education</td>
<td>Lazovik</td>
</tr>
<tr>
<td>SM4ALL</td>
<td>Smart Homes for All</td>
<td>EU FP7</td>
<td>STREP project on middleware for embedded systems</td>
<td>Aiello</td>
</tr>
<tr>
<td>SAS–LeG</td>
<td>Software As a Service Architectures for Local eGovernments</td>
<td>NWO</td>
<td>Jacquard</td>
<td>Aiello</td>
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Table 1: External funding description.
<table>
<thead>
<tr>
<th>Acronym</th>
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<th>End Date</th>
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<td>MyCare</td>
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<td>230,000</td>
<td>01-10-09</td>
<td>30-09-13</td>
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<td>Amazon</td>
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<td>01-08-09</td>
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<td>SM4ALL</td>
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<td>320,000</td>
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<td>SAS–LeG</td>
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<td>260,000</td>
<td>01-07-08</td>
<td>30-06-12</td>
<td>2nd</td>
</tr>
</tbody>
</table>

Table 2: Amounts in Euro unless otherwise specified.

**External Collaborations**
Collaborations were active with the following individuals and institutions.

**Academic:**
Dr. Oliver Amft, TU/e, Dr. Guram Beshansvili, New Mexico State University, Prof. Dustdar, Technical University of Vienna, Dr. Wim van Gemert, Hanzehogeschool, Prof. Gottlob, Technical University of Vienna, Prof. George Huijema, RUG and TNO, Peter Kamphuis, Hanzehogeschool, Dr. Rolf Kunneke, TU Delft, Prof. Mike Papazoglou, University of Tilburg, Prof. Eiter, Technical University of Vienna, Prof. Han Slootweg, TU/e and Enexis, Prof. Stefan Tai, Karlsruhe Institute of Technology, Prof. Apt, Arbab CWI, Dr. Cheng, ITRI, Prof. Dague, Inria, ILLC, ISLA and ISIS, University of Amsterdam

**Industrial:**
Dr. Rix Groenboem, Parasoft, Hemmo Halzebos, Enexis Foxhol, Berto Jansen, Phase-to-phase, Dr. Heiko Ludwig, IBM, Wico Mulder, Logica, H. Zwaal, TenneT

### 7.5 Further activities

In 2009, M. Aiello was the Information Director of the *Transactions on Computational Logic* of the Association of Computing Machinery (ACM). He was member of the editorial board of the *Journal on Service Oriented Computing and Applications*, Springer. He has been in the programme committee of 18 international conferences and workshops. He has been *General Chair* of the 18th IEEE International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE 09), Groningen, June 29 - July 1, 2009, *Chair* of the Smart Homes Infrastructures and Interaction workshop, Groningen, June 30, 2009 and member of the *Advisory Board* of The First International Conference on Advances in P2P Systems (AP2PS 2009) Malta October 11-16, 2009.
Aiello has been a member of the Dutch National Research Council (NWO) Exact Sciences committee for the evaluation of the Open Competition proposals for the Astronomy, Mathematics and Computer Science areas. He has also been reviewer for the Swiss Professional Schools Grants, the UniMI per il futuro 5 per mille University of Milano grants, and member of the committee for the University of Groningen Ubbo Emmius scholarships.

A. Lazovik has been in the programme committee of 4 international conferences and workshops (ICSOC-09, WPS-09, ICIW-09, SSDU-09). He has been a member of Steering Committee of the WETICE 09, Groningen, June 29 - July 1, 2009, Chair of the Workshop for eGovernment via Software Services (WeGovS2), Groningen, July 01, 2009.

### 7.6 Awards

*M. Aiello, E. el Khoury, A. Lazovik and P. Ratelband* were awarded the Second place for the Architecture, at *IEEE 2009 Web Service Challenge* held in Vienna, July 2009.
8. **Fundamental Computing Science**

**Group leader:** Prof. dr. G.R. Renardel de Lavalette

**Tenured staff (JBI members)**
- Prof. dr. W.H. Hesselink, RuG, 1.0
- Prof. dr. G.R. Renardel de Lavalette, RuG, 1.0

**Tenured staff (other)**
- Drs. J.H. Jongejan, RuG, 0.4
- Dr. J. Terlouw, RuG, 1.0

**PhD students**
- I. Ullah, RuG, 1.0
  (supervisor: Hesselink)

**External PhD students**
- Drs. P. Dykstra, Hanzehogeschool, 0.6
  (supervisor: Renardel de Lavalette and Verbrugge (AI))
8.1 Research Program

The objective of this programme is to contribute to the understanding of the logical and mathematical foundations of computing science and to realize a two-way transfer between this fundamental research and more applied subdisciplines of computing science. Our research focuses on formal methods, which are based on concepts and theories from discrete mathematics and logic. They are applied to enhance the reliability of computer systems and computer software, and also to further the understanding of the possibilities of computing in general. The following themes are studied: programming methodology, multi-agent systems, mathematical logic.

For programming methodology, the group aims to contribute to the design, specification, and verification of sequential, parallel and distributed algorithms, programs, and systems. We prove properties of such algorithms or systems by assertional means, i.e., by reasoning about individual states and computation steps, rather than considering entire execution sequences. Even so, seemingly modest algorithms may require a host of case distinctions that a human prover finds difficult to control. In such situations, we use mechanical theorem provers for the administration of proof obligations.

Multi-agent systems is a subdiscipline of both Computing Science and Artificial Intelligence. Agents are intelligent, possibly mobile processes to which intentions can be attributed: beliefs, desires and commitments. A multi-agent system consists of agents that cooperate to perform a task. We focus on the role of social agents in the dynamics of public opinions. To study this, we build agent communication models based on dialogues, involving epistemic, dialogical and fuzzy logic. In another project, we investigate the relations between belief revision and verisimilitude.

In mathematical logic, we focus on intuitionistic logic, dynamic logic, and the proof theory of equational and related logics. Intuitionism was created by L.E.J. Brouwer; its logic, formalized by A. Heyting, reappeared as the foundation of type theory with applications in programming and theorem proving. Dynamic logic is a variant of modal logic, where reasoning about change is studied. Equational logic is the formalization of algebraic equational reasoning, used in tools like Mathematica. We focus on fundamental properties like completeness (is a given proof system strong enough to prove all true statements?) and exactness (does a certain model correspond to the structure of a logic?).

8.2 Research subjects

Dijkstra: simulation of social and mobile agents, involving dialogues and group forming.
Hesselink: design and verification of concurrent and geometric algorithms.
Renardel: proof theory of equational logic and related logics; intuitionistic logic.
8.3 Publications

Articles in scientific journals


Articles in conference proceedings


8.4 External funding, collaboration and internationalization

Hesselink collaborated with A.A. Aravind (University of Northern British Columbia) on properties of mutual exclusion algorithms.

Renardel collaborated with S.M. Zwart (Delft/Eindhoven) on verisimilitude and belief revision.
Renardel collaborated with D.H.J. de Jongh and A. Hendriks (Amsterdam) on exact models for intuitionistic propositional logic.

8.5 Further information

Hesselink is an editor of the international scientific journal Science of Computer Programming. He is a member of the Board of the Dutch Research School IPA (Institute for Programming Research and Algorithmics).
Renardel is member of the Board of the Dutch Research School in Logic, the Board of the Dutch Society for Theoretical Computer Science, the VIDI selection committee for the division Physical Sciences of the Netherlands Organisation for Scientific Research (NWO-EW), and the Academic Advisory Board of the NUFFIC-funded project Strengthening ICT Training and Research Capacity in the Four Public Universities in Uganda (2007-2011).
9.  Intelligent Systems

Group leader: Prof.dr.sc.techn. N. Petkov

Tenured staff (JBI members)                        | source  | fte  \\
Dr. M. Biehl (tenure track)                      | RuG     | 1.0  \\
Prof.dr.sc.techn. N. Petkov                      | RuG     | 1.0  \\
Dr. J.H. van Hateren                              | RuG     | 0.0  \\
Dr. M.H.F. Wilkinson                              | RuG     | 1.0  \\

PhD students

G. Azzopardi (since October 1) (supervisor: Petkov) | RuG     | 1.0  \\
K. Bunte (supervisor: Biehl)                       | NWO     | 1.0  \\
I.E. Giotis (since September 1) (supervisor: Petkov) | RuG     | 1.0  \\
F.N. Kiwanuka (supervisor: Wilkinson)              | NUFFIC  | external  \\
G. Papari (supervisor: Petkov)                     | NWO     | 1.0  \\
P. Schneider (supervisor: Biehl)                   | RuG     | 1.0  \\
A. Witoelaar (supervisor: Biehl)                   | RuG     | 1.0  \\
E. Mwebaze (co-supervision: Biehl)                 | NUFFIC  | external  \\
A. Offringa (co-supervision: Biehl)                | Kapteyn Institute | external  \\
Guests
W. Arlt, University of Birmingham, UK
G. de Haan, Techn. University of Eindhoven and Philips, The Netherlands
B. Hammer, Technical University of Clausthal, Germany
G. Ouzounis, Democritus University of Thrace, Alexandroupoli, Greece
J. Quinn, Makerere University, Kampala, Uganda
F. Rossi, INRIA Rocqencourt, France
F.-M. Schleif, University of Leipzig, Germany
A. Smeulders, University of Amsterdam, The Netherlands
D. G. Stork, Ricoh Innovations and Stanford University, USA
F.-M. Schleif, University of Leipzig, Germany
M. Viergever, University of Utrecht, The Netherlands
L. van Vliet, Techn. University of Delft, The Netherlands
9.1 Research Program

Our mission is to perform high quality research with emphasis on publishing in top international journals, and to train graduate students how to conduct such research, with attention to interdisciplinary aspects and applications in life sciences and health care.

Our research program concerns a variety of interrelated topics from image processing and analysis, computer vision, pattern recognition, machine learning and brain-like computing.

As to our strategy, we will continue to put forward methods and develop algorithms in the general area of Intelligent Systems. We will participate in the grand challenge of giving computers the abilities to perceive (e.g. see), analyse, learn and enhance human creativity. Various applications in other disciplines, such as life sciences, medicine, and astronomy, will give an additional inspiration for our work. Notably, life-science, biomedical and health-care applications form an important focus for the future research of the group and a number of long-term collaborations have been started.

The group participates in the school of Behavioural and Cognitive Neurosciences (BCN) and the European graduate school on Neurosensorics with the computational neuroscience aspects of its research. It participates in the Advanced School of Computing and Imaging and contributes to its course programme. The group plays an instrumental role in the Intelligent Systems specialization of the MSc programme in Computer Science, giving courses in Computer Vision, Pattern Recognition and Neural Networks. These graduate courses are followed also by many artificial intelligence students.

Biologically motivated computer vision

Models of information processing in the visual cortex are developed and used in computer algorithms. This research is relevant for the areas of image processing, computer vision, pattern recognition, visual perception, and computational neuroscience. Our goal is to understand how people see and to deploy principles of natural vision in computer algorithms for artificial vision. Using facts from neuroscience and visual perception, we build models of visual information processing in the brain and use them in computer simulations to obtain insights and derive practical computer vision algorithms.

One example is a model of a grating cell that we developed [Petkov, Kruizinga: 1997 Biological Cybernetics 76: 83-96] and used in a texture operator [Kruizinga, Petkov: 1999 IEEE Trans. on Image Processing 8: 1395-1407], [Grigorescu, Petkov, Kruizinga: 2002 IEEE Trans. on Image Processing 11: 1160-1167]. By means of computer simulations we demonstrated that grating cells may play an important role in the disambiguation of edge information in early vision (texture vs. contours).

Another example is our model of non-classical receptive field inhibition, also called surround suppression, in orientation selective neurons [Petkov, Westenberg: 2003 Biological Cybernetics...
We demonstrated that the biological role of this inhibitory mechanism is quick pre-attentive detection of object contours and region boundaries in natural images that are rich in texture. We proposed various contour detection algorithms that deploy this mechanism and showed that they are more effective in detecting object contours and region boundaries than traditional computer vision algorithms for edge detection [Grigorescu, Petkov, Westenberg: 2003 *IEEE Trans. on Image Processing* 12: 729-739], [Grigorescu, Petkov, Westenberg: 2004 *Image and Vision Computing* 22: 609–622], [Papari, Campisi, Petkov, Neri: 2007 *EURASIP J. on Advances in Signal Processing*, Article ID 71828]. This work has been extended by applying gestalt principles to edge grouping [Papari, Petkov: 2008 *IEEE Trans. Image Processing* 17: 1950-1962], [Papari, Petkov: Proc. SPIE 2008, vol. 6812, art. no. 68121B].

We also studied the orientation and speed tuning properties of spatio-temporal 3D Gabor and motion energy filters with surround suppression as models of time-dependent receptive fields of simple and complex cells in primary visual cortex (V1) [Petkov, Subramanian: 2007 *Biological Cybernetics*, 97: 423-439]. We demonstrated how these filters are related to motion detection, noise reduction, texture suppression and contour enhancement.

In the same line of research we model the detection of contour segments and shape representation in areas V4 and TEO of visual cortex.

Another result of our research that is inspired by psychological research on the human visual system is a method for the evaluation of the robustness of shape recognition algorithms to incompleteness of contours [Ghosh, Petkov: 2005 *IEEE Trans. on Pattern Analysis and Machine Intelligence* 27: 1793-1804].

After Hans van Hateren joined the group in 2007, this direction of the research programme was extended with computational modelling of image processing by retinal neurons.

*Image processing and computer vision*

In shape analysis we study geometrical approaches in which a feature point is characterized by the spatial arrangement of other feature points around it. The collection of local geometrical descriptors for the different feature points of an object is used as a shape characteristics of that object [Grigorescu, Petkov: 2003 *IEEE Trans. on Image Processing* 12: 1274-1286].


On the applications side, we collaborate with researchers from the University of Leon, Spain, in the area of automatic classification of boar spermatozoa [Sanchez, Petkov, Alegre: 2006 *Cellular and Molecular Biology*, 52: 38-43], [Petkov, Alegre, Biehl, Sanchez: 2008 *Comp. in Biol. and Medicine* 38: 461-468]. We also collaborate with the Department of Dermatology of the University Medical Center Groningen on the application of content based image retrieval.
and expert systems to dermatological problems and with the Department of Ophthalmology on the automatic detection of diabetic retinopathy.

Connected filters are a comparatively new field of research within mathematical morphology. They are edge preserving operators which have found use in noise removal, texture analysis, image compression and description, and feature extraction. Research on connected operators in our group entails algorithm development (including parallelization), development of new classes of filters, applications to 2-D and 3-D medical images, and the development of new connectivity measures for these filters for increased robustness. Recently, content-based image retrieval (CBIR) has been added to the list of application areas. One line of this research links to visual cortex modelling: developing morphological analogues of texture operators based on models of certain visual cortical cells. It is hoped these morphological counterparts will be an order of magnitude faster, whilst retaining the useful properties of the cortical cell models. Finally, fast visualization based on connected attribute filters is being explored. Recently, work has begun expanding this line into hyperconnected filters and attribute-space-connected filters, which increase the flexibility of perceptual groupings available, and allow dealing with overlap explicitly.

Segmentation is a core problem in image analysis, and methods based on both simple thresholding methods and more advanced methods such as watersheds and deformable models are being explored. Application areas are many, but the focus lies on biomedical imaging, both macroscopic (MRI, CT) and microscopic. New application domains in astronomy are also being explored.

**Machine learning and neural networks**

The term *machine learning* has been coined for an area of computer science which deals with the analysis of example data for, e.g., supervised classification or regression problems. Furthermore, unsupervised learning addresses problems like clustering, dimension reduction, or correlation analysis.

In our research group, learning algorithms are developed and employed for data driven parameter adaptation in, for instance, neural networks or other adaptive systems. We are currently mainly interested in prototype based learning schemes. In the context of supervised learning they provide typical representatives of the classes which can be used to parameterize distance based classification schemes. A prominent example for such techniques is the very flexible and successful Learning Vector Quantization (LVQ). Similarly, in unsupervised Vector Quantization (VQ), the prototypes are used to represent large amounts of data by means of clustering or dimension reduction.

A key question in all distance or similarity based learning is the choice of a suitable distance measure or metrics. The technique of Relevance Learning plays a most important role in this context. A quite general distance measure is parameterized and adapted in the training phase,
together with the prototypes. Hence, the classifier and a discriminative similarity measure are identified in the same data driven process. We have extended the basic idea of relevance learning to algorithms which account for correlations of features. The main aim of these matrix-based relevance algorithms is two-fold: to achieve better classification performance and to obtain deeper insight into the structure of the data. Furthermore, rank controlled and regularized versions of matrix relevance learning have been developed which provide discriminative low-dimensional projections of the data. This technique constitutes a powerful tool for avoiding overfitting and oversimplification effects. At the same time, it can be used for the discriminative visualization of classification problems in high-dimensional data.

In our theoretical investigations we aim at a better understanding of algorithms, learning processes and their performance. In the framework of model situations, we study the dynamics of on-line learning and systematically compare different algorithms. Similar investigations, which borrow basic concepts from statistical physics, concern the typical properties of large learning systems in the context of batch- or offline training. The ultimate goal of these studies is to design and optimize practical training algorithms.

Consequently, we aim at testing the developed methods in real world applications. Recently, we have addressed several classification problems in bioinformatics and the analysis of medical data. An important example concerns tumor classification based on metabolomics data. Another project deals with the analysis of tiling microarray data and the potential detection of novel genes.

As an additional area of research, projects in the modelling and simulation of nano-structured crystal surfaces are being pursued.

### 9.2 Overview of scientific results

**Biologically motivated computer vision**

G. Papari defended his doctoral dissertation *“Explorations in the fields of contour detection and artistic imaging”* with highest honors (*cum laude*). Much of it concerns contour detection, involving biologically motivated mechanisms, such as surround suppression and gestalt grouping.

We continued to work on the modeling of the detection of contour segments and shape representation in areas V4 and TEO of visual cortex. Currently we work on improving the robustness of the system and potential applications. We intend to publish on this topic in 2010.

**Image processing and computer vision**

In the article *“Continuous Glass Patterns for Painterly Rendering”* [Papari, Petkov: 2009 *IEEE Trans. on Image Processing* 18: 652-664] we proposed a new algorithm for painterly rendering
of photographic images. We extract edges from an input image and use the edge orientation field to generate a Glass pattern that we subsequently convert into texture that is added to the input image in order to give it an artistic touch. We also published a few papers on artistic imaging in various conference proceedings (see list of publications). For web-enabled implementations of these algorithms, see http://www.cs.rug.nl/~imaging/glassart/java/Main.html, http://www.cs.rug.nl/~imaging/PSIVT2009/java/Main.html.

First results of our collaboration with the Department of Dermatology were published in the article "Color Representations for Content Based Image Retrieval in Dermatology" [Bosman, Petkov, and Jonkman: 2009 Skin Research and Technology, doi: 10.1111/j.1600-0846.2009.00405.x]. In this paper we show that the CIE-L*a*b color representation and the use of the difference of the colors of healthy and diseased skin are most effective in content-based image retrieval of dermatological images. A more general approach to the same problem and improved results were presented in the article "Adaptive Metrics for Content Based Image Retrieval in Dermatology" [Bunte, Petkov, Biehl, Jonkman: 2009 Proc. ESANN 2009 129-134].

Progress in our work on boar sperm analysis was published in the article "Estimation of boar sperm status using intracellular density distribution in grey level images” [Sanchez, Petkov: 2009 LNAI 5400: 169-184].

In terms of connected filters, we have developed new attributes based on surface area in 3D, including algorithms for aparameters such as sphericity. These attributes improve detection of vessel structures in time-of-flight magnetic resonance angiograms. They were also used in segmentation of urinary track stones. The results were published in the proceedings of the International Symposium on Mathematical Morphology 2009 and the International Conference on Image Processing 2009.

One key problem in so-called contraction-based second-generation connectivity is that of over-segmentation or fragmentation. This means that structures bridging gaps between objects of interest become fragmented into single-pixel sets. One way to deal with them is through partial connections proposed by Serra. We have also extended an alternative approach to deal with the oversegmentation problem of contraction-based connectivity to grey scale images. It has been shown that though grey-scale filters are not easily implemented, pseudo pattern spectra can be devised, and improve diatom identification. These results were accepted for publication in Pattern Recognition.

Work on CBIR is continuing, with extensions to incorporate color and spatial information into pattern spectra. A comparison of spatial pattern spectra has been made and has been published in the proceedings of the International Symposium on Mathematical Morphology 2009.

This year several important properties of hyperconnections and related operators were proven. The axiomatics of hyperconnectivity needs to be strengthened by an extra axiom, to ensure consistent definition of hyperconnected components. With this improved axiomatics, we can show that standard, structural morphology is a special case of hyperconnectivity. This is important
because connectivity is also a special case of hyperconnectivity. This means that hyperconnectivity bridges the gap between structural and connected morphology. This implies that there should be a continuum of filters which are increasingly shape preserving as we approach the connectivity end of the spectrum. We show that reconstruction using reconstruction criteria, and path openings both can be seen as part of this continuum. The first results of this theoretical work have been published in the proceedings of the *International Symposium on Mathematical Morphology 2009*.

The axiomatics of attribute-space connections were also strengthened somewhat, improving on the results in the *Image and Vision Computing* paper of 2007. Attribute-space connectivity, proposed by Wilkinson, is an alternative to hyperconnectivity. At the time of its conception, it was unclear whether the two concepts were fundamentally different. This issue was resolved by a proof that any hyperconnection is an attribute-space connection, but not every attribute-space connection is a hyperconnection. Thus attribute-space connections form a superset of hyperconnections. This does not mean that hyperconnections are no longer of interest: hyperconnections deal with overlap by definition of an overlap criterion, whereas attribute-space connections deal with overlap by transforming the image to a nother domain, in which the overlap is resolved. These different approaches may be useful in different circumstances. This this result has been published in the *International Symposium on Mathematical Morphology 2009*.

Ouzounis and Wilkinson developed one of the first practical hyperconnected attribute filters based on so called $k$-flat zones, were $k$ is a tunable parameter denoting the allowed range of grey-level variation within a flat zone. These allow filters to become more robust to noise and other unimportant low contrast image features. A fast algorithm based on the Max-tree was developed which allows interactive setting of $k$ and visualization of filtering results, based on earlier work on interactive visualization and attribute filtering in 3D. In 2D, the method shows much promise in separation of galaxies from stars, which is important for automatic source extraction in astronomy. In historical documents, it has proven very strong in removing background detail whilst preserving letters. An example is shown in Fig. 3. The results have been accepted for publication in *IEEE Trans. Pattern Anal. Mach. Intell.*.

**Machine learning**

Several journal and conference publications emerged from our theoretical investigations of learning dynamics and off-line learning. For instance, in the journal article *Phase transitions in Vector Quantization and Neural Gas* [Witoelar and Biehl, *Neurocomputing* 72: 1390-1397 (2009)] we study and compare systematically several established algorithms for off-line unsupervised training of prototype systems from clustered data. Here, discontinuous transitions are identified which dominate the learning process and may cause inevitable practical problems.

The formulation of matrix based relevance learning is addressed in two publications which appeared in the highly rated journal Neural Computation. In the article *Adaptive Relevance Matrices in Learning Vector Quantization* [Schneider, Biehl, and Hammer, Neural Computation...
Figure 3: Processing a historical document: (a) original image showing much detail in the background; background removed by (b) anisotropic diffusion; (c) connected attribute filter (d) hyperconnected attribute filter.
the concept of matrix relevances is established and first applications to benchmark data sets are presented. The flexibility of the approach is demonstrated in the publication Distance learning in discriminative Vector Quantization [Schneider, Biehl, and Hammer, Neural Computation 21:2942-2969] which incorporates relevance matrices in the so-called Robust Soft LVQ, a density estimation based variant of LVQ. Further conceptional extensions of the method have been published in several conference contributions and book chapters.

Numerous publications concern the application of LVQ and relevance learning in a variety of contexts. As one example, the paper Adaptive Metrics for Content Based Image Retrieval in Dermatology, [Bunte, Biehl, Petkov and Jonkman, Proc. ESANN, 129-134 (2009)] concerns an application in the medical domain. Another contribution to a major conference addresses the potential use of relevance LVQ for visualization tasks: Nonlinear Dimension Reduction and Visualization of Labeled Data [Bunte, Biehl, and Hammer, Proc. CAIP 2009, pages 1162-1170, (2009)].

The very recent investigation of the use of divergences as alternative distance measures has resulted in the accepted conference contribution Divergence based Learning Vector Quantization (Mwebaze, Schneider, Schleif, Haase, Villmann, and Biehl, Proc. ESANN 2010, in press) Several accepted journal and conference publications indicate that our research activities will continue to yield significant results. To name just one example, the paper Regularization in Matrix Relevance Learning discusses the important issue of rank control in matrix learning and has been accepted for publication recently (Schneider, Bunte, Stiekema, Hammer, Villmann, and Biehl, IEEE Trans. Neural Networks, in press.)

9.3 Research subjects

G. Azzopardi: shape, modeling of visual cortex.
M. Biehl: machine learning, LVQ, neural networks, scientific computing.
K. Bunte: adaptive distance measures in LVQ, visualization of labeled data sets.
A.C. Emerencia: computer support of schizophrenic patients.
I. E. Giotis: CBIR and expert systems in dermatology.
F.N. Kiwanuka: Medical volume analysis using (hyper)connected filters.
R. Nakibuule: classification of video sequences, detection of traffic jams.
E. Mwebaze: causality detection in medical data, divergence based LVQ.
A. Offringa: pattern recognition in radio-astronomical data.
G. Papari: contour detection, non-photorealistic rendering.
N. Petkov: contour detection, non-photorealistic rendering, shape, CBIR, health care.
P. Schneider: feature selection and matrix relevance learning.
F. Tushabe: multimedia applications of mathematical morphology.
M.H.F. Wilkinson: morphological image analysis, biomedical modelling.
A. Witoelar: typical properties and dynamics of prototype based learning.
D. Zhang: detection of diabetic retinopathy.

9.4 Publications

Dissertations


Book Chapters


Edited volumes


Articles in scientific journals

- P. Schneider, M. Biehl, B. Hammer, Distance Learning in Discriminative Vector Quantization, *Neural Networks*, 21, 2009, 2942-2969.

Articles in conference proceedings


**Other publications**


9.5 External funding and collaboration

External funding

The position of Papari was partially financed by a grant to Petkov in the open competition 2003 of NWO Exact Sciences. The position of Kerstin Bunte is financed by a grant to Biehl and Petkov in the open competition 2006/07 of NWO. The positions of Tushabe and Kiwanuka are funded through a grant by NUFFIC. The position of Emerencia is financed by a grant to Aiello and Petkov from NWO Medical Sciences, 2009.

External collaboration

Biehl collaborates with B. Hammer from the Technical Univ. Clausthal-Zellerfeld, Germany, in the context of the theory of Learning Vector Quantization and algorithm development. Practical applications of LVQ are explored together with F.-M. Schleif in Leipzig, Th. Villmann in Mittweida/Germany, and with M. Strickert in Gatersleben/Germany. The application of LVQ to adrenal tumor classification is the starting point for an intense collaboration with W. Arlt from the University Hospital Birmingham/UK. Biehl has signed Erasmus-Socrates agreements with Profs. Riegler (Wolffenbüttel), Hammer (Clausthal), and Villmann (Mittweida).

Petkov was, together with X. Jiang (Münster), co-chair of the 13th International Conference on Computer Analysis of Images and Patterns CAIP 2009, Münster, Germany, Sept. 2-4, 2009, and co-editor of the proceedings (Springer LNCS vol. 5702). He visited the Institute for Physiology (Bocheva, Vasilev) of the Bulgarian Academy of Sciences, Sofia. He visited and gave talks at INSA Lyon (Jolion, Wolf) and the Universities of Geneva (Pun, Voloshunovskiy), Hagen (Halang), Münster (Jiang), Durham (Findlay), Dublin (Ghosh, Lacey), Malaga (Gonzalez), and Sevilla (Real). He and Papari lectured in the advanced course Front-end Vision of the graduate school ASCI (organised by ter Haar Romeny at the Technical University of Eindhoven). He participated in the Summer School on Cognitive Science in Sofia and the European Conference on Visual Perception in Regensburg. He collaborates with Jonkman from the Department of Dermatology on the application of content based image retrieval and expert systems to dermatologic problems. Together with Biehl he collaborates with Wolffenbuttel from the LifeLines project of the University Medical Center Groningen on the large scale analysis of patient data for the relation of genotype and phenotype. Together with Aiello he started collaboration with Wiersma and Sytema from the Department of Psychiatry on a computerized system for the support of schizophrenic patients. He also started collaboration with Hooymans and Jansonius from the Department of Ophthalmology on the detection of diabetic retinopathy. He collaborated with Doro from the Department of Ophthalmology of Columbia University, Edward S. Harkness Eye Institute, on determining retinal nerve fiber orientation. Petkov has signed Socrates-Erasmus agreements between the RuG and the TU Vienna, Univ. of Salerno, Univ. of Leon and Univ. of
Wilkinson collaborates with the Dermatology department of the University Medical Centre Groningen on hand eczema analysis. A further collaboration with the Department of Biomedical Engineering, University of Groningen, concerning image analysis of scoliosis is also underway. This year a collaboration with the Kapteyn Institute has been initialized, to explore the use of connected filters, and especially vector-attribute filters in automatic source extraction in image data bases. He has started a collaboration with L. Najman (ESIEE, Paris) on mathematical morphology, and in particular topological watersheds, and with Jean Serra (same institute) on connectivity theory. He visited and lectured at Makerere University in Kampala Uganda in April 2008, and is external supervisor for PhD students there.

9.6 Further information

Biehl is associated editor of the journal Pattern Recognition and Neural Processing Letters. In 2009, he furthermore co-edited a special issue of Neurocomputing. Biehl is member of the scientific committee of the European Symposium on Artificial Neural Networks (ESANN) conference series. He is also member of the International Programme Committee of the 10th IASTED International Conference on Artificial Intelligence and Applications (AIA 2010) in Innsbruck/Austria. He furthermore acts as a publicity co-chair for the 11th ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD 2010, London).

Biehl co-organized a Dagstuhl seminar on Similarity-based learning on structures, together with B. Hammer, T. Villmann, S. Hochreiter, and S. Cremers. The seminar brought together ca. 40 invited speakers for one week in February 2009.

Petkov is member of the editorial boards of J. of Neural, Parallel and Scientific Computations (Dynamic Publ.), Int. J. for Computational Vision and Biomechanics (Serials Publ.) and Int. J. of Hybrid Intelligent Systems (IOS Press). He was member of the Programme Advisory Council Scientific Computing of Forschungszentrum Jülich GmbH till 2009 and member of the evaluation committee ”Middelgroot” of NWO.

He is member of the steering committee of the CAIP (Int. Conf. on Analysis of Images and Patterns) series of conferences and was co-chair (with X. Jiang) of CAIP 2009 that was held in Münster, Germany, Sept. 2-4. He was member of the program committees of the following international conferences: the 22nd Australasian Joint Conf. on Artificial Intelligence AI09, Melbourne, Australia, Dec. 1-4; the 14th Iberoamerican Congress on Pattern Recognition, CIARP’2009, Guadalajara, Mexico, Nov. 15-18; the 15th Int. Conf. on Image Analysis and Processing ICIAP 2009, Vietri sul Mare, Salerno, Italy, Sept. 8-11; Int. Conf. on Imaging Theory and Applications - IMAGAPP 2009, Lisboa, Portugal, Feb. 5-8; Special Session on Intelligent Analysis of Images and Videos (IAIV 2009) organized as a part of 13th Int. Conf. on

In 2009 he reviewed papers for *IEEE Trans. on Image Processing*.

His publications in the period 1999-2009 included in the Web of Science (WoS) of Thomson Scientific collect 370 citations. According to the Essential Scientific Indicators of Thomson Scientific, the threshold for inclusion in the top-1% group of most cited computer scientists in this period was about 140 citations.

His master student Sander Land was awarded the best master thesis prize in the area of ICT by the Royal Dutch Society of Sciences (Kon. Hollandsche Maatschappij der Wetenschappen) for his thesis ”Content-based image retrieval in dermatology”.

Wilkinson, together with Philippe Salembier of the Universita Polytècnica de Catalunya, Barcelona Spain were invited to contribute a feature article to *IEEE Signal Processing Magazine*. He was member of the program committee of the 2009 IEEE Pacific-Rim Symposium on Image and Video Technology (PSIVT’09), and reviewer for ICIP 2009. He was co-chair of the *International Symposium on Mathematical Morphology 2009* in Groningen, together with Jos Roerdink. He is treasurer of the Dutch Society for Pattern Recognition and Image Processing (NVPHBV). He was invited to lecture at the ESIEE in Paris, at the University of Semarang and the ITS in Surabaya, Indonesia. He was keynote speaker at the SITIA 2009 conference in Surabaya. Finally, he is member of the Cluster Computer Vision Noord Nederland, a consortium of companies and academia seeking to stimulate the field of computer vision in the Northern Netherlands.

**Impact**

A number of our research articles in the period 1998-2009 belong to the group of highly cited publications in Computer Science, Electrical Engineering or Physics according to the number of citations they collect in the Web of Science of Thompson Scientific:

- **top-1%**:

- **top-10%**:
We made available some of our image processing algorithms as web-enabled applications at http://matlabserver.cs.rug.nl where external researchers can use them with their own image material. This internet site gets around 100 unique visitors per day from around 80 different countries per month (since 2003).

10. **Scientific Visualization and Computer Graphics**

**Group leader:** Prof. dr. J.B.T.M. Roerdink

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Guests

H. Strasburger (University of München, University of Göttingen, Germany)
F. Verbeek (Leiden Institute of Advanced Computer Science, The Netherlands)
P. Ogao (Makerere University, Kampala, Uganda)
I. Wadembere (PhD student, 2 month research visit, Makerere University, Kampala, Uganda)
P. Isenberg (PhD student, 3 month research visit, University of Calgary, Canada)
10.1 Research Program

The research group Scientific Visualization and Computer Graphics carries out research in the area of scientific visualization, information and software visualization, computer graphics and innovative interfaces using large, touch-sensitive displays. With respect to applications, the research concentrates on fundamental and applied problems from the life sciences (in particular functional brain imaging and bioinformatics), astronomy, and large-scale software engineering.

*Scientific visualization*

Visualization of large data sets requires advanced techniques in image processing and segmentation, hierarchical data management, and data reduction. Data volumes generated by scientific simulations can easily grow into the range of gigabytes. In a functional neuroimaging experiment (PET, fMRI), a large number of data volumes is obtained, thus increasing data size even further. Both the increasing size and complexity of these data ask for new techniques for interactive visualization. The possibility of interaction during evaluation will significantly reduce the time required to interpret and present results. In such interactive data visualization, the speed of the data processing stage should be comparable to that of the visualization step. We address this demand by developing efficient algorithms and/or by mapping the involved computations to programmable Graphics Processing Units (GPUs), which are capable of outperforming CPUs for certain compute-intensive applications.

*Software visualization*

Software visualization has recently rapidly grown to become one of the important research fields within Information Visualization (InfoVis). The goal of software visualization is to provide methods, techniques, and tools that assist the entire range of activities in the software engineering discipline. These activities include software design, architecting, development, understanding, and maintenance. Software maintenance is by far the most expensive and time-consuming activity within software engineering, accounting for over 80% of the total resources in the field. Of these, over 50% are dedicated to program understanding.

Software visualization targets the maintenance and understanding challenges by offering new, scalable and intuitive visual representations and interactive navigation and analysis methods for all aspects of a software product, including source code, program structure and behavior, documentation, and evolution. Effective use of software visualization in practice requires a tight integration of software visualization techniques and tools within the classical software analysis, forward, and reverse engineering pipelines. We call this approach *visual software analytics*, the application of visual analytics techniques to software engineering. Finally, assessing the actual impact in practice of newly developed methods requires designing and conducting detailed user studies involving software engineers working on concrete large-scale problems in the field.

*Perception-based visualization*

A rapidly growing area within the visualization research field is perception-based visualization.
Here one takes advantage of knowledge about the human visual system to improve current visualization techniques. The underlying idea is that a better understanding of biological vision will lead to artificial visual stimuli that are better adapted to our visual system. On the other hand, by studying visual stimuli in artificial environments, visualization technology can contribute to human vision research. An important issue is which ‘visual cues’ of a scene (such as shape, size and distance of objects) can be used to encode independent information dimensions.

**Non-photorealistic and illustrative rendering**

Non-photorealistic rendering (NPR) is a sub-area of computer graphics that is inspired by a long tradition of artistic and illustrative depiction. We apply NPR techniques to illustration and visualization problems in medical, technical, and other domains. We also work on combining NPR methods with other rendering techniques to create hybrid rendering styles for illustration and visualization. In addition, we work on identifying the differences between hand-drawn and computer-generated images and to understand what this means for a viewer. One of the goals of this work is to improve NPR techniques to better be able to mimic hand-drawn techniques. Another goal is to be better able to target NPR rendering to achieve certain goals, which do not necessarily have to be the same as those of hand-drawn images or illustrations.

**Innovative interfaces**

In order to use the developed visualization techniques successfully, it is vital to provide effective and intuitive interfaces. In our research in this area we concentrate on interfaces to use non-photorealistic and illustrative rendering techniques that are used, for example, for visualization applications. We employ novel touch-sensitive, large displays that enable users to make use of a larger screen area, interact with applications using direct-touch or pens, and work in groups to profit from collaborations.

**Applications**

In functional neuroimaging techniques such as fMRI, the goal is to detect significant changes in brain activity. Since these changes are small and distributed over the whole brain and the images are noisy, the detection process is complex, requiring image processing to obtain high quality images, mathematical and statistical analysis for quantitative characterization of significant effects, and volume visualization for interpretation of the results. A second goal is to study connectivity between brain regions, making use of structural (e.g., Diffusion Tensor Imaging) and functional imaging data.

In bioinformatics, the group is involved in a research program aiming to reconstruct the cellular processes, metabolic potential (metabolome) and gene regulatory networks of selected organisms (gram-positive bacteria and Archaea), by in-silico analysis of all proteins encoded by their chromosome. Research focuses on tools for interactive visualization of gene regulatory networks, metabolic pathways, and integration of gene expression data with volume visualization, based on knowledge from the scientific literature, information encoded in distributed databases, and experimental data. Also, evaluation of the effectiveness of visualization methods is part of this research.
The group participates in a research effort on problems from astronomy. Astronomical data sets are growing to enormous sizes. Modern surveys provide not only image data but also catalogues of millions of objects, each object with hundreds of associated parameters. To explore these data sets effectively, new and scalable tools must be developed that can cope with the sheer data volume which has entered the tens of terabytes regime. In this research the focus is on feature extraction and interactive visualization techniques for high-dimensional data.

In software engineering, the group participates in research targeting the understanding and reverse-engineering of large software systems. Modern industrial software systems span thousands of files and millions of lines of code, developed by tens of programmers during many years. Our research focuses on scalable and robust techniques for the static analysis of such systems written in C, C++, Java, and .NET in order to extract syntactic and semantic information such as calls, dependencies, control and data flow graphs, duplications, and quality metrics, and visualize these using combinations of techniques from scientific and information visualization.

### 10.2 Overview of scientific results

**Scientific visualization** We developed a physically-motivated method for surface reconstruction that can recover smooth surfaces from noisy and sparse data sets without orientation information. By a new technique based on regularized-membrane potentials the input sample points are aggregated, leading to improved noise tolerability and outlier removal, without sacrificing much with respect to detail (feature) recovery. An efficient morphological active surface model for volumetric image segmentation was proposed based on methods from mathematical morphology. We developed accelerating wavelet-based video coding on graphics hardware using CUDA. Finally, a screen space fluid rendering with curvature flow was developed which is simple to implement, has real-time performance with a configurable speed/quality trade-off, and smoothes the surface to prevent the fluid from looking “blobby” or jelly-like; see Figure 4 for an example. Most methods were also implemented on modern graphics processing units (GPUs).

**Perception-based visualization**

We developed a neurophysiologically plausible population code model for feature integration which explains visual crowding. Crowding is the phenomenon that an object in the peripheral visual field is more difficult to recognize when surrounded by other objects. Crowding places a fundamental constraint on human vision that limits performance on numerous tasks. Our new model for crowding is based on the principles of population coding. Using simulations, we demonstrated that this model coherently accounts for fundamental properties of crowding, including critical spacing, compulsory averaging, and a foveal-peripheral anisotropy. Altogether, these results suggest that crowding has little immediate bearing on object recognition but is a by-product of a general, elementary integration mechanism in early vision aimed at improving
Figure 4: Comparing Gaussian (a) and screen-space curvature flow (b) on NVIDIA logo. Taken from: W.J. van der Laan, S. Green, and M. Sainz, Screen Space Fluid Rendering with Curvature Flow. In Proc. I3D 2009: The 2009 ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games, pp. 9198, 2009.

Software visualization and program understanding

Within this new research line, work has continued on developing techniques for visualizing combinations of software architecture diagrams and quality metrics. These techniques, integrated in a UML visualization environment, enable users such as software architects and designers to analyze large software systems by combining structural information, software metrics extracted directly from source code, and design-level metrics using novel techniques such as shading and texturing.

A separate related research direction, visual reverse engineering, has produced several new methods for interactive static analysis and understanding of large C and C++ software systems, including the scalable presentation of various software metrics and identification of design patterns. The developed methods have been integrated in a so-called interactive reverse-engineering environment which tightly combines in-depth static analysis and visual presentation using techniques such as table lenses, metric textures, and zoomable code views; see Figure 5 for an example.

Following the visual analytics metaphor, we have applied and validated our interactive software visualizations and analyses to several problems in collaboration with industrial partners (SolidSource BV, ASML, Continental, NXP, and Momentum) and the open-source community (KDE). Extensive case studies have led to a better understanding of the requirements and perceived value of the proposed methods for their end users, and subsequent refinements of the proposed visual analysis techniques.
Non-photorealistic and illustrative rendering
We developed a technique for visualizing fiber tracts that were extracted from DTI data of the human brain. This technique uses hardware-assisted line rendering that emphasizes closely bundled fibers while abstracting regions with less coherent fiber orientations (see Figure 6). This is realized by adding a depth-dependent halo around each rendered line. Apart from being powerful in visualizing brain fibers, this technique also works for other line data such as particle traces from gaseous or fluid flow as well as particle data such as elevation measurements from satellite-based radar. This technique was published at the world’s leading publication venue for scientific visualization, IEEE Visualization 2009, and received the Best Paper Award of the conference. In addition, a poster of the technique received the Best Poster Award at the SIREN 2009 meeting in Twente, the Netherlands.

Innovative interfaces
In collaboration with the University of Calgary, Canada, we continued the work on using the hand-posture based interaction that support the exploration and visualization of vector field and flow datasets. We evaluated the interaction technique with pairs of two people to investigate, in particular, collaboration aspects that affect the work using the interface. The evaluation showed that the developed techniques support collaborative exploration of unknown datasets and, in particular, discussions between participants as well as the continuous development and testing of hypotheses.

In addition, we explored interaction concepts for digital concept sketching (see Figure 7). Here we make use of the border of the drawing surface to allow interaction with the paper orientation, thus providing a user-controlled way of mode changing. This technique is now being extended and further developed to support the interaction with 3D visualization spaces on large touch surfaces. In particular, we are investigating the navigation though simulated astronomical 3D data as well as 3D illustrative medical visualizations.

Visualization in functional neuroimaging
Work continued in the area diffusion tensor imaging (DTI), which is an MRI-based technique enabling the visualization of nerve fibers and connectivity of brain regions. We proposed a fast method for calculating trajectories of fiber bundles in the brain by applying Dijkstra’s shortest path algorithm to a weighted graph constructed from DTI data. Also, a novel tensor interpolation method was introduced that allows DTI streamlining to overcome low-anisotropy regions and permits branching of trajectories using information gathered from the neighbourhood of low-anisotropy voxels met during the tracking. The interpolation method is performed in Log-Euclidean space and collects directional information in a spherical neighbourhood of the voxel in order to reconstruct a tensor with a higher linear diffusion coefficient than the original.

Bioinformatics visualization
Unraveling regulatory mechanisms remains a major challenge in the analysis of transcriptome experiments. Existing applications identify putative motifs from gene lists obtained at arbitrary
cut-offs and require many additional manual processing steps. We developed a stand-alone application Motifator which identifies the most optimal parameters for motif discovery and creates an interactive visualization of the results. Discovered putative motifs are functionally characterized, thereby providing valuable insight in the biological processes that could be controlled by the motif. This is joint work with the Dep. of Molecular Genetics of the University of Groningen.

**Astronomical visualization**
We continued work on accurate density estimation which is required for establishing relations between the spatial arrangement of galaxies and the distribution of various attributes in parameter space. We also started work on clustering and subspace ranking for explorative visualization of high-dimensional astronomical data sets. This is joint work with the Kapteyn Astronomical Institute of the University of Groningen.

### 10.3 Research subjects

- **H. Bekker**: visualization of diffusion tensor imaging data.
- **H. Byelas**: software visualization.
- **A. Crippa**: visualization of functional neuroimaging data.
- **O. Ersoy**: software visualization.
- **M.H. Everts**: visualization of diffusion tensor imaging data.
- **B.J. Ferdosi**: visualization of astronomical data.
- **M. Gerl**: capturing and reusing hand-drawn hatching styles for illustration.
- **T. Isenberg**: non-photorealistic and illustrative rendering; computer graphics interaction and innovative interfaces.
- **W. van der Laan**: multiscale visualization based on adaptive morphological wavelets; graphics hardware computing.
- **J.B.T.M. Roerdink**: scientific visualization; morphological and wavelet-based multidimensional data processing; neuroimaging; bioinformatics.
- **A.C. Telea**: software visualization and program understanding; information visualization; multiscale skeletons.
- **L. Yu**: interactive visualization of cosmological simulations.

### 10.4 Publications

**Dissertations**


**Edited books**


**Contributions to books**


**Articles in scientific journals**


**Articles in conference proceedings**


**Other publications**


### 10.5 External funding and collaboration

*External funding*

Currently the following externally funded projects are carried out in the group:

– Scalable analysis and visualization of high-dimensional, astronomical data sets (ASTROVIS) (2006–2010); jointly with Kapteyn Astronomical Institute, University of Groningen. Funding: Netherlands Organization for Scientific Research (NWO): two PhD students, one postdoc.

External collaboration

Roerdink collaborates with the Visualization and Interactive Systems Institute, University of Stuttgart (prof. T. Ertl), Imperial College, London, UK (dr. A.M. Wink), Dep. of Telecommunication and Information Processing of the University of Ghent, Belgium (dr. A. Pizurica), and Univ. of Makerere, Uganda (dr. P. Ogao, co-supervised PhD student). He participates in the Groningen Neuroimaging Center of the local research school BCN (Behavioural, Cognitive and Neurosciences), and collaborates on visualization problems related to neuroimaging with the Dep. of Clinical Neurophysiology of the University Medical Center Groningen (prof. dr. N.M. Maurits) and the Lab. for Experimental Ophthalmology of the University of Groningen (dr. F.W. Cornelissen). In the area of Bioinformatics, he collaborates with the Dep. of Molecular Genetics of the University of Groningen (prof. dr. O.P. Kuipers). He has a joint project with the Kapteyn Astronomical Institute of the University of Groningen on scalable visualization of astronomical data (prof. Th. van der Hulst, prof. E. Valentijn).

Isenberg collaborates with the Innovations in Visualization group University of Calgary, headed by Prof. Dr. S. Carpendale, on interactions on large displays. In addition, he participates in a collaboration with the PURPL lab at Purdue University, USA, headed by Prof. Dr. D. Ebert, on non-photorealistic rendering and illustration. He also collaborates with Professors Dr. B. Wyvill and Dr. Amy Gooch at the University of Victoria, Canada, on synthesis evaluation and of pencil drawing. Nationally he is collaborating with Philips Research in Eindhoven and with artists and illustrators at the Academie Minerva, Groningen. Finally, he started a collaboration with Prof. Dr. Domingo Martín Perandrés at the University of Granada, Spain.

Telea collaborates with the MaBioVis group at the INRIA/CNRS LaBRI institute in Bordeaux, France (prof. G. Melancon, prof. M. Delest, dr. Auber) and the Visualization group at the Eindhoven University of Technology, the Netherlands (prof. J. J. van Wijk, dr. D. Holten) on multiscale methods for large graph visualization. Other collaborations include visualization group at the University of Salamanca (prof. R. Theron) on evolution visualization and SolidSource (Eindhoven, the Netherlands) on industrial user studies for the efficiency and effectiveness of visual software analytics methods. He co-supervises one PhD student with the School of IT and Computing, University of Makerere, Uganda (prof. P. Ogao).

10.6 Further information

Roerdink has a joint appointment with the Faculty of Medicine. He is on the editorial board of the Journal of Mathematical Imaging and Vision, member of the Eurographics Association and Senior Member of the IEEE. He was reviewer for a large number of international journals, and member of the program committees of EuroVis 2009, ISMM 2009, ICIP 2009, IWClIA09, IEEE Visualisation 2009, and CAIP 2009. He was member of the PhD reading committees of A. Broersen (TU Eindhoven), D. Reniers (TU Eindhoven), G. Pápari (RUG), T. Peeters (TU Eindhoven), and T. Ivanovska (Jacobs University Bremen). He co-organised (with M.H.F.
Wilkinson) the International Conference on *Mathematical Morphology and its Application to Signal and Image Processing*, August 24–27, 2009, Groningen. He gave invited lectures at the IPA-ASCI Lentedagen, Helvoirt, the Netherlands, at the workshop Visualization in Medicine and Life Sciences (VMLS), Bremerhaven, Germany, and at the meeting on Visual Computing in Medicine, Bremen, Germany.

*Isenberg* was reviewer for numerous international journals and conferences, co-organized (with Bruch Gooch and C. Kaplan) the 7th *International Symposium on Non-Photorealistic Rendering and Animation (NPAR 2009)*, August 1–2, 2009, New Orleans, USA, and co-organized (with Petra Isenberg, M. Sedlmair, Dominikus Baur, and Andreas Butz) the *Collaborative Visualization on Interactive Surfaces Workshop (CoVis 2009 at VisWeek 2009)*, October 11, 2009, Atlantic City, USA. He also served as publicity chair for the *ACM Conference on Interactive Tabletops and Surfaces (ITS 2009)* and the *International Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging (CAe 2009)* and was member of the program committees of IEEE Visualization 2009 and CAe 2009. He is a member of ACM, ACM SIGGRAPH, IEEE, and the Eurographics Association. He gave invited talks at the University of Granada, Spain, the IllustraVis 2009 Symposium at Bergen, Norway, at the University of Magdeburg, Germany, at Clemson University, USA, and at INRIA Saclay, France.

*Telea* was elected steering committee member of IEEE VISSOFT and ACM SOFTVIS, the main venues for software visualization research, as well as general chair for ACM SOFTVIS 2010, to be organized for the first time as part of the IEEE VisWeek conference series. He was on several program committees, notably EuroVis’09, IEEE Visualization‘09, VAST’09, VISSOFT’09, VAST’09, and KAV’09. He gave several invited talks at INRIA Aviz (Paris, France), CNRS LaBRI (Bordeaux, France), LINA Laboratory (Nantes, France), ASML (Veldhoven), NXP (Eindhoven), and Continental (Stuttgart, Germany). He is a member of ACM and the Eurographics Association.

*Awards.* Everts, Bekker, Roerdink and Isenberg received the *Best Paper Award* at IEEE Visualization 2009, the top conference in the field of visualization, and the *Best Poster Award* at SIREN 2009, the Scientific ICT Research Event Netherlands.
Figure 5: Integrated reverse-engineering environment for large C and C++ code bases. The proposed solution combines static analysis (parsing, syntactic and semantic analysis, and fact querying and extraction) in a single interactive visual metaphor. Hypothesis forming, refinement, and validation is assisted by several scalable visualizations for text, metrics, and relational data based on techniques such as generalized table lenses, bundled edge layouts, texture-annotated UML diagrams, and pixel-based text views. Taken from: A. Telea, H. Byelas, L. Voinea, A Framework for Reverse Engineering Large C++ Code Bases, Elec. Notes in Theoretical Comp. Sci, 2009.
Figure 6: Example of depth-dependent halos used for the visualization of fiber tracts that were extracted from DTI data of the human brain. Taken from: M.H. Everts, H. Bekker, J.B.T.M. Roerdink, and T. Isenberg, *Depth-Dependent Halos: Illustrative Rendering of Dense Line Data*. IEEE Transactions on Visualization and Computer Graphics, 15(6):1299–1306, 2009.
Figure 7: Interface for digital concept sketching using the interface boarder as an active interaction surface.
11. **Software Engineering**

**Group leader:**
Prof.dr.ir. P. Avgeriou

**Tenured staff (JBI members)**

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<th>Name</th>
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**Tenured staff (other)**

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**Postdocs**

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**PhD students**

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<td>A.W. Kamal</td>
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<td>A. Kontogogos</td>
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<tr>
<td>U. van Heesch</td>
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Guests
N. Guelfi, University of Luxembourg, Luxembourg
S. Lukosch, TU Delft, the Netherlands
K. Stol, Lero, Ireland
C. Hentrich, CSC, Germany
11.1 Research Program

The Software Engineering research program is concerned with theoretical and practical aspects of engineering software and software-intensive systems. The program focuses on one particular field of Software Engineering: Software Architecture. Software Architecture is one of the key disciplines that can help to deal with the hard but also interesting challenges that we are facing in our century: increasing integration of Systems and Software Engineering; focus on the end user and the offered added value; increasing demand on software dependability; dealing with rapid, accelerating change; continuous distribution, mobility, interoperability and globalization; emergence of ultra-large systems (systems of systems); demand for reusability and legacy integration; proliferation of data- and computation-intensive applications; the trend of autonomous or self-managing software; the combinations of biology and computing.

The group aims to contribute in architecting industrial software-intensive systems that meet quality standards by carrying out joint research projects with universities, research institutes, and industrial partners, thus combining academic know-how with industrial practice. The research topics of the group include pattern-based architecture design and evaluation, architectural patterns and pattern languages, architecture-centric evolution, architectural knowledge management and architecting Software as a Service. These topics are further elaborated in the following paragraphs.

Pattern based architecture design and evaluation. Software architecture must balance the quality attributes of the system to be built. However, major architectural decisions have consequences that affect the quality attributes. Software architecture patterns are a powerful tool in architecture design and evaluation, but their impact and use has not been systematically researched. We have analyzed the impact of architecture patterns on quality attributes. We have investigated the interaction of architecture patterns and quality attribute tactics used to improve software reliability. We have designed and validated a method for reviewing architectures based on architecture patterns. We have created a general model of the interaction of patterns, quality attributes, and quality attribute tactics. This includes a notation to annotate architecture diagrams with information about how tactics are to be implemented. This will help architects produce strong architectures, review them effectively, and understand the architecture of existing systems. We have used patterns and the interaction of patterns and tactics in low-cost architecture reviews, and have developed an architecture pattern-based architecture review method that is low cost. We are currently investigating the impact of implementing quality attributes in multi-pattern architectures.

Architectural patterns and pattern languages. Modeling architectural patterns effectively in a system design is a challenging task. This is because of the inherent pattern variability and because pattern participants do not match the architectural abstractions present in current modeling languages. Our research work is aimed at solving the aforementioned problems. We have proposed to categorize the solution participants of architectural patterns and document the relationships among participants of different patterns by studying several existing system designs.
We are devising a process that uses pattern participants and relationships among participants of different patterns for effectively expressing several pattern variants in system design. For the practical implementation of our work, we are developing a pattern modeling tool called Primus that supports modeling architectural pattern variants, architectural views synchronization, source code generation, etc.

**Architecture-centric evolution.** In the context of the Darwin project, we collaborate with Philips Healthcare, aiming to develop methods and tools for optimizing system evolvability, i.e. the ability of a system to evolve easily in the face of changing requirements. In this project, our research is performed in an empirically manner exploring forward and reverse engineering processes to construct and maintain architecture views. In particular, we have developed a reverse architecting approach to construct execution architecture views of an MRI system, a real large and complex software-intensive system. The architecture views constructed or recovered using our approach correspond to a set of pre-defined execution viewpoints defined as part of our research. Both the views and viewpoints, provide architectural information about the actual MRI system runtime structure and behavior in a top-down fashion. This information is useful for architects and designers to understand the actual MRI system behavior, conduct dependency analysis activities, and identify the impact and propagation of changes, which is important to efficiently respond to changing requirements.

**Architectural knowledge management.** There is a growing awareness of the importance of Architectural Knowledge (AK) in the software architecture community. Within the context of the Griffin project, we investigate this notion of AK in the context of an envisioned architectural knowledge grid. This knowledge grid is an omnipresent knowledge infrastructure for capturing, publishing, sharing, and managing architectural knowledge. Currently, we are (1) investigating a collaborative architecting process based on architectural knowledge and (2) developing an accompanying tool suite that demonstrates one way to support the process; (3) carrying out AK sharing and evaluating the AK sharing quality in several industrial case studies.

Additionally we work on supporting and documenting AK using patterns. Documenting architectural decisions when applying patterns in software architecture preserves an important part of the thinking and rationale that went into the decisions, while demanding a reasonable effort from the architect. Architectural patterns and pattern languages contain reusable architectural knowledge in the form of well proven solutions to recurring design problems. We have developed a meta model to capture relevant architectural knowledge entities from patterns and pattern languages and to link these entities to architectural decisions. This helps to reduce the documentation effort, because only those aspects have to be described in architecture documentations, that are specific to the application, whereas generic parts can be copied from the pattern description. We have developed a publicly available online repository for all kinds of software engineering related patterns that can also be used to document architectural decisions related to patterns (www.patternrepository.org). We will use this repository as a basis for further research in the field.
Architecting Software as a Service. During the architecting process, an important amount of knowledge is used and produced. However, it is important to capture not only the resulting design, but also the early design decisions, including their rationale. Our research focuses on integrating various software systems, from an architectural knowledge perspective, with immediate applicability in Dutch municipalities' IT landscape. The research is part of the SAS-LeG (Software As Service for the varying needs of Local eGovernments), a joint project of the University of Groningen, Cordys, and local municipalities of the north of the Netherlands, aiming to find solutions for a more effective e-Government (http://www.sas-leg.net/).

11.2 Research subjects

P. Avgeriou: software architecture design and evaluation, patterns and pattern languages, architectural knowledge.

J. Bosch: software product lines, compositional software engineering, software ecosystems.

T.B. Callo Arias: reverse architecting, execution architecture, views and viewpoints.

C. DelRosso: software architecture design.

M. Denne: ROI-driven software development.

N. Harrison: architecture patterns, pattern-based architecting and review processes, quality attributes and tactics.

J.H. Hartmann: software supply chains.


A.W. Kamal: architectural patterns, pattern variants, modeling, UML.

A. Kontogogos: architecting software as service, variability modeling.

P. Liang: architectural knowledge sharing, requirements reasoning.

A. Maccari: software architecture reviews.

R. Smedinga: oo-approach, architecture design decision representation.


11.3 Publications

Articles in scientific journals


**Articles in conference and workshop proceedings**

Book chapters


Technical reports


11.4 External funding and collaborations

External funding

In 2009, *Avgeriou* obtained an International Young Scientist grant funded by NSFC (Natural Science Foundation of China), entitled STAND (Semantic-enabled collaboration Towards Analysis, Negotiation and Documentation on distributed requirements engineering). Projects funded in the previous years and running in 2009 are *NWO Jacquard—GRIFFIN* (Avgeriou, Liang); *NWO SenterNovem Bsk—DARWIN* (Avgeriou, Callo); *NWO Hefboomsubsidie* (Avgeriou, Liang); *NWO Jacquard—SAS-LEG* (Avgeriou, Kontogogos).

External Collaborations

The group works together with the Astron Foundation, Philips Research, Getronics PinkRoc cadce, CIBIT, LogicaCMG and the VU University Amsterdam in the context of the GRIFFIN research project. Furthermore the group works together with Philips Healthcare and the Embedded Systems Institute in Eindhoven, in the context of the Darwin research project. Finally it collaborates with Cordys, EGEM, and Project Wonen, Welzijn Zorg (WWZ) in the context of the SAS-LEG project. It had short-term collaborations with Neopost BV and Siemens/TomTom in the context of the research project of Harrison. It has signed Socrates-Erasmus agreements between the RUG and Tampere Technical University (Finland), Technical University of Crete (Greece), Universidad Rey Juan Carlos (Spain), University of Limerick (Ireland), Vaxjo University (Sweden). Avgeriou is the co-supervisor of Klaas-Jan Stol, a PhD student at Lero.
Irish Software Engineering Research Centre, University of Limerick (joint supervision with M. Ali Babar) and serves as the external advisor of Nuno Flores, University of Porto, Portugal.

### 11.5 Further activities

**P. Avgeriou** was member of the editorial board of *Transactions on Pattern Languages of Programming*, Springer. He was member of Hillside Europe (http://hillside-europe.net/) and a member of the ERCIM Working Group on Rapid Integration of Software Engineering techniques (http://rise.uni.lu). He co-organized the following events: *Thematic Track on Pragmatic and systematic approaches in applying patterns*, European Pattern Languages of Programming (EuroPLoP’09), July 8-12, 2009, Irsee, Germany; *Fourth Workshop on SHAring and Reusing architectural Knowledge (SHARK’09)*, 31st Int. Conf. on Software Engineering (ICSE 2009), Vancouver, Canada, May 16-24, 2009; *The 2nd Workshop on Empirical Assessment in Software Architecture (EASA’09)*, collocated with the 8th Working IEEE/IFIP Conference on Software Architecture (WICSA) and the 3rd European Conference on Software Architecture (ECSA), 14 September 2009, Cambridge, UK; the *Workshop for eGovernment via Software Services (WeGovS2)*, in the 18th IEEE International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE), June 29-July 1, 2009, Groningen. He gave invited talks on the Colloquium on Software Architecture, K.U. Leuven, 11th September 2009 (about Execution viewpoints); on the Software Engineering Radio - http://www.se-radio.net/ (about Architectural Knowledge Vaporization). He was a discussion panelist on Services in e-Government at the 18th IEEE International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE); on SOA Pattern Languages, at the Dagstuhl seminar 09021 on Software Service Engineering. He was the external opponent for 4 PhD defences: in Tampere University of Technology (Finland), in VU Amsterdam (two defences), in Katholieke Universiteit Leuven (Belgium).

**Jan Bosch** was Editor of Science of Computer Programming (Elsevier) and general chair for the 4th International Conference on Communication System Software and Middleware (COM-SWARE 2009), Limerick, Ireland, June 2009. He gave keynote presentations at the following events: the 6th International Conference on Innovations in Information Technology, Al Ain, United Arab Emirates (December 2009); the Practical Product Lines 2009 conference, Amsterdam, Netherlands (October 2009); the 2009 Ericsson Process, Methods and Tools conference, Linkoping, Sweden (October 2009); the Brazilian Symposium on Software Quality (SBQS 2009), June 2009, Ouro Preto, Brazil; the Ericsson Software Product Line Seminar, February 2009, Stockholm, Sweden.

**N. Harrison** was member of the editorial board of *Transactions on Pattern Languages of Programming*, Springer. He was co-editor of special issue of *Transactions on Pattern Languages of Programming on Applications of Patterns*, Springer. He was member of Hillside Europe (http://hillside-europe.net/). He was member of the Board of Directors, of Hillside USA (http://hillside.net). He co-organized the following events: *Thematic Track on Pragmatic and systematic approaches in applying patterns*, European Pattern Languages of Programming (EuroPLoP’09), July 8-12, 2009, Irsee, Germany; *Fourth Workshop on SHAring and Reusing architectural Knowledge (SHARK’09)*, 31st Int. Conf. on Software Engineering (ICSE 2009), Vancouver, Canada, May 16-24, 2009; *The 2nd Workshop on Empirical Assessment in Software Architecture (EASA’09)*, collocated with the 8th Working IEEE/IFIP Conference on Software Architecture (WICSA) and the 3rd European Conference on Software Architecture (ECSA), 14 September 2009, Cambridge, UK; the *Workshop for eGovernment via Software Services (WeGovS2)*, in the 18th IEEE International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE), June 29-July 1, 2009, Groningen. He gave invited talks on the Colloquium on Software Architecture, K.U. Leuven, 11th September 2009 (about Execution viewpoints); on the Software Engineering Radio - http://www.se-radio.net/ (about Architectural Knowledge Vaporization). He was a discussion panelist on Services in e-Government at the 18th IEEE International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE); on SOA Pattern Languages, at the Dagstuhl seminar 09021 on Software Service Engineering. He was the external opponent for 4 PhD defences: in Tampere University of Technology (Finland), in VU Amsterdam (two defences), in Katholieke Universiteit Leuven (Belgium).
in applying patterns, European Pattern Languages of Programming (EuroPLoP’09), July 8-12, 2009, Irsee Monastery, Bavaria, Germany.

R. Smedinga was secretary in the board of Stichting Nioc (http://www.nioc.nl), responsible for organizing conferences on computing science education.

11.6 Distinctions

The work of T.B. Callo Arias, P. Avgeriou, and P. America on predefined sets of architecture viewpoints, has been included as a representative example in the new definition of the ISO/IEC CD1 42010 standard on *Systems and software engineering - Architecture description*. 
Colloquium Computing Science 2009 – List of Speakers

- November 30
  Fons J. Verbeek, Section Imaging & BioInformatics, Imagery & Media group, Leiden Institute of Advanced Computer Science, Leiden University
  From imaging to imagination

- November 17
  Prof.dr. Pieter Adriaans, University of Amsterdam
  Some observations on computation and information

- November 23
  Klaus Toennies, University Magdeburg, Germany
  Hierarchical models of shape and appearance for segmentation and object detection in medical images

- November 16
  Frank-Michael Schleif, University Leipzig
  Sparse models for the decomposition of spectral data

- November 12
  John Quinn
  Extreme Traffic Monitoring using Probabilistic Inference

- October 19
  Jasper van de Gronde
  Heavy Metal Scavengers with a Vertical Gas Drive

- October 16
  Prof.dr. Hans Strasburger, University of Mnchen
  Indirect vision and the crowding effect

- October 16
  Ronald van den Berg, University of Groningen
  Measuring and Modeling Visual Crowding & Clutter

- July 13
  David Fernandez Duque, University of Sevilla
  A logic for reasoning about space and time

- 29 June
  Thomas Villmann
  Adaptive eigen analysis for functional data

- June 25
  Michael Seifert, Leibniz Institute of Plant Genetics and Crop Plant Research Getersleben, Germany
  HMM-based detection of polymorphic regions in genomes of Arabidopsis ecotypes
– June 15
  Prof.dr. Nicolas Guelfi
  Sesame: a model-driven process for the test selection of small-size safety-related embedded software

– June 3
  Prof.dr. E.O. de Brock
  Transactions in ORM

– May 11
  Dr. Stephan Lukosch, Delft University of Technology
  Facilitation Audio-based Collaborative Storytelling for Informal Knowledge Management

– April 20
  Lai Xu, (SAP Research, Switzerland)
  SOA4All: The modelling and execution composite service and processes in a lightweight manner

– April 20
  Paul de Vrieze (SAP Research, Switzerland)
  An ontological approach to handling web service change

– April 23
  Chris Huyck, Middlesex University
  Cell Assembly Robots: Vision and Cognitive Modelling

– January 12
  Georgios K. Ouzounis
  Connected Attribute Filters For Medical Image Enhancement and Segmentation

– January 19
  David J. Smith, University of Birmingham, UK
  Experimental and computational investigation of sperm swimming
Colloquium Mathematics 2009 – List of Speakers

– December 15
  Holger Waalkens, University of Groningen
  Classical and Quantum Reaction Dynamics in Multidimensional Systems

– December 8
  Jan C. Willems, K.U. Leuven
  Energy flow in interconnected systems

– December 1
  Jan van Maanen, Freudenthal Institute, Utrecht University
  Applications convince. The case of the early calculus

– November 10
  Sonja Smets, Dept. Artificial Intelligence and dept. of Philosophy, University of Groningen
  An abstract Dynamic-Logical Setting for Quantum Mechanics

– October 27
  F. Camia, VU Amsterdam
  Two-dimensional statistical mechanics and the Schramm-Loewner Evolution

– September 29
  Mirjam Dür
  Optimization over matrix cones, and how this helps to solve nonconvex optimization problems

– September 17
  AIO Colloquium: Sijbo-Jan Holtman
  Dynamics and geometry near resonant bifurcations

– September 2
  AIO Colloquium: Alex Opoku
  Gibbs properties of transforms of lattice and mean-field rotator models

– June 2
  Prof.dr. Oliver Stein, University of Karlsruhe, Germany
  Lifting Mathematical Programs with Complementarity Constraints

– April 7
  Dr. Sieb Kemme, Commissie Toekomst Wiskundeonderwijs (cTWO)
  Wiskunde in voortgezet en hoger onderwijs: nu en straks

– April 6
  Dr. Bruno Carpentieri, CRS4 Bioinformatics Laboratory, Pula (Italy)
  Computational Modelling of Some Challenging Applications in Electrophysiology and in Aeronautical Design
– April 6
Dr. Sergey Korotov
Bisection algorithms for the finite element methods

– March 26
Dr. Huo-Yuan Duan, Division of Mathematics, University of Dundee, UK
L2-projected FEM for singular solution in Maxwell’s equations

– February 27
Laurent Stolovitch, CNRS-Université de Nice, France
Normal forms of analytic perturbations of quasihomogeneous vector fields

– January 27
Holger Dullin, School of Mathematics and Statistics, University of Sydney
From Molecules to Gymnasts: How to rotate without angular momentum

– January 20
AIO Colloquium: Ha Binh Minh
Model reduction in a behavioral framework