University of Groningen

Faculty of Mathematics and Natural Sciences

Research Institute of Mathematics and Computing Science

Annual Report 2002
Introduction

Some statistics

In 2002 the institute comprised 24 tenured scientific staff members and six support staff members. Some 48 PhD candidates were enrolled, including five Ubbo Emmius scholarships for students from abroad, 14 PhD positions funded by the Netherlands Organisation for Scientific Research (NWO) and five PhD positions funded by the European Union, industry or other external funding. Nine postdocs worked at the institute of whom one funded by NWO and one by the Royal Dutch Academy of Sciences, KNAW.

Two doctoral dissertations were defended. A number of defences that were due in 2002 are expected to take place in 2003.

A total of 46 journal papers, three edited books, 13 contributions to books, 45 refereed contributions to conference proceedings and 16 other professional publications were published.

Members of the institute organised eight workshops. They also 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 50 foreign scientists.

Personalia

In 2001 a new chair for Bioinformatics was allocated to IWI as part of the Groningen Bioinformatics Centre (GBIC). This centre is a joint initiative of the Faculty of Mathematics and Natural Sciences and the Faculty of Medical Sciences, and is located at our institute. It has a dependence at the department of Medical Genetics. The mission of the GBIC is to carry out internationally competitive research in bioinformatics, with the emphasis on subjects relevant for existing areas of life science research and computer science at the University of Groningen and the University Medical Centre Groningen. Ritsert C. Jansen (1963) accepted this chair for Bioinformatics on March 1. After his study at the University of Groningen (Mathematical Statistics) he went to the University of Wageningen, where he obtained a PhD degree in 1995. From 1988 till 1996 he was consultant and scientist in Biostatistics at various research institutes in Wageningen, became senior scientist bioinformatics at the Plant Research International Ltd. (1997) and leader of the cluster Bioinformatics and Statistical Genetics (1999). His newly established research group in Groningen strives towards intensive collaboration between the-
oreticians of bioinformatics and experimental practitioners who generate the challenging biological or biomedical research questions and data.

L. Spaanenburg who held the chair for System Technology since 1993 left our institute. From September 1 he is appointed as professor at the University of Lund Sweden.

Willem Schaafsma retired on May 1. His academic career can be divided in two directions. He did a lot of work in the field of “Distributional Inference” and testing hypotheses, and also in the field “Size and Shape”. In this latter work he successfully collaborated with the famous statistician C.R. Rao. Schaafsma supervised many PhD students, he was always open for problems from the statistical practice and was respected as a many-sided scientist. After the earlier leave of Dehling and Mikosch (2000) and Schaafsma’s retirement the research unit Probability and Statistics has at the moment no staff members. Schaafsma’s scientific ideas however are retained for the RuG by his numerous (PhD) students who are still working at the Groningen University as esteemed scientists.

John G. Daugman (University of Cambridge) was named Johan Bernoulli guest professor for the academic year 2002/2003 by the board of the Faculty of Mathematics and Natural Sciences. Daugman (48) is with the Computing Laboratory of the University of Cambridge. He studied at Harvard University where he obtained his PhD and worked as assistant and associate professor of engineering sciences. In 1989 and 1990 he was appointed professor at Tokyo Institute of Technology on the Toshiba endowed chair in information systems. In 1990 he used a presidential young investigator award to move to Cambridge, England, where he is ever since. His idea to model the receptive fields of simple cells in the visual cortex with two-dimensional Gabor functions had a large impact on many areas of science: neurophysiology, psychology, computer science and electrical engineering. Meanwhile, thousands of articles have been published in which this idea has been used. Dr. Daugman made an important contribution to biometrical technology by developing original and effective algorithms for person identification using the iris pattern. This led to a technological break-through with wide social impact, ranging from PIN-less identification by automatic transaction machines to passport security and fast check-in at international airports. In October Daugman gave a plenary lecture for the whole academic community of the RuG.
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<td>11. BioInformatics</td>
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IWI Annual Report

Governing body and support staff

Scientific director
Prof.dr.sc.techn. N. Petkov

Advisory counsel
Prof.dr. W.C. Nieuwpoort – chairman
(emeritus, professor of theoretical chemistry, RUG)
Prof.dr. R.F. Curtain
(professor of mathematics, RUG)
Prof.dr. G.R. Renardel de Lavalette
(professor of computing science, RUG)
Prof.dr. H.A. van der Vorst
(professor of mathematics, University of Utrecht)

Management team
Prof.dr.sc.techn. N. Petkov (director) 0.6
Dr. Y.E.F.M. Jeuken (scientific policy collaborator) 0.5
J. de Jong-Schluekebir (controller) 0.5
A. Navest (controller) 0.5

Technical and administrative staff

Technicians
P.C. Arendz 0.5
H. Paas 0.5
ing. R.H. Sijtsma 0.5
J. Bokma 0.5

Secretaries
E.D. Elshof 0.35
D.J. Hansen 0.35

IWI-secretary
H. Steenhuys 0.7
Address:

Post:
P.O. Box 800
9700 AV Groningen

Visitors:
Blauwborgje 3
9747 AC 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

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<td>Programme 1</td>
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<td>Prof.dr. M. van der Put</td>
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<td>Dr. J. Top</td>
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<td>Programme 2</td>
<td>Analysis</td>
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<td></td>
<td>Prof.dr.ir. A. Dijksma</td>
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<td>Programme 3</td>
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<td></td>
<td>Prof.dr. H.W. Broer</td>
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<td>Prof.dr.ir. H.S.V. de Snoo</td>
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<td>Programme 4</td>
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<td>Prof.dr. R.F. Curtain</td>
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<td>Dr. H.L. Trentelman</td>
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<td>Prof.dr.ir. J.C. Willems</td>
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<td>Programme 5</td>
<td>Probability and Statistics</td>
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<td>Prof.dr. W. Schaafsma</td>
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<td>Programme 6</td>
<td>Computational Mechanics and Numerical Mathematics</td>
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<td></td>
<td>Prof.dr. A.E.P. Veldman</td>
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<td>Dr.ir. R.W.C.P. Verstappen</td>
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<td>Dr.ir. F.W. Wubs</td>
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Computing Science

Programme 7 : Software Engineering  
Prof.dr.ir. J. Bosch  
Dr. R. Smedinga

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

Programme 9 : Computing and Imaging  
Dr. H. Bekker  
Prof.dr.sc.techn. N. Petkov  
Dr. J.B.T.M. Roerdink  
Dr. G. Vegter  
Dr. M.H.F. Wilkinson

Programme 10 : System Technology  
Dr.ir. J.A.G. Nijhuis  
Prof.dr.ir. L. Spaanenburg

Programme 11 : BioInformatics  
Prof.dr. R.C. Jansen
Research schools

Researchers of the IWI participate in the following research schools:

1. **Mathematical Research Institute (MRI)**
   - Coordinating institution: University of Nijmegen
   - Director: Prof.dr. J.H.M. Steenbrink
   - Participating IWI programme(s): 1, 2, 3, 5

2. **Dutch Institute of Systems and Control (DISC)**
   - Coordinating institution: University of Twente
   - Director: Prof.ir. O. Bosgra
   - Participating IWI programme(s): 4

3. **The J.M. Burgers Centre for Fluid Dynamics**
   - Coordinating institution: Delft University of Technology
   - Director: Prof.dr.ir. G. Ooms
   - Participating IWI programme(s): 6

4. **Dutch Graduate School in Logic (LOGICA)**
   - Coordinating institution: University of Amsterdam
   - Director: Prof.dr. M.J.B. Stokhof
   - Participating IWI programme(s): 8

5. **Institute for Programming Research and Algorithmics (IPA)**
   - Coordinating institution: University of Eindhoven
   - Director: Prof.dr. J.C.M. Baeten
   - Participating IWI programme(s): 8 and 10

6. **Advanced School of Computing and Imaging (ASCI)**
   - Coordinating institution: Delft University of Technology
   - Director: Prof.dr. A.S. Tanenbaum (Free Univ. Amsterdam)
   - Participating IWI programme(s): 9

7. **School of Behavioral and Cognitive Neurosciences (BCN)**
   - Coordinating institution: University of Groningen
   - Director: Dr. G.J. ter Horst
   - Participating IWI programme(s): 9
1. **Algebra and Geometry**

**Group leader:** Prof.dr. M. van der Put

**Tenured staff (IWI members)**

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<tr>
<th>Name</th>
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<tr>
<td>Prof.dr. M. van der Put</td>
<td>RuG</td>
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<td>Dr. J. Top</td>
<td>RuG</td>
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**PhD students**

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<tr>
<th>Name</th>
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<tr>
<td>Drs. M. Berkenbosch</td>
<td>RuG</td>
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<td>(supervisors: van der Put, Top)</td>
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<tr>
<td>Drs. R. Carls</td>
<td>NWO</td>
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<td>(supervisors: Top, H.W. Lenstra (UL))</td>
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<tr>
<td>Drs. G.-J. van der Heiden</td>
<td>NWO</td>
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<td>(supervisors: Top, van der Put)</td>
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<tr>
<td>Drs. R.N. Kloosterman</td>
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<td>(supervisor: Top)</td>
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<tr>
<td>Drs. L. Taelman (Ubbo Emmius scholarship)</td>
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<td>(supervisors: van der Put, Top)</td>
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**Guests**

I. Polo Blanco, PhD student, Bilbao, Spain
J. Gonzalez Gonzalez, PhD student, Bilbao, Spain
1.1 Research Program

1. *Number theory, especially elliptic curves.* 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.

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 nonlinear differential equations.

3. *Rigid analytic geometry.* In particular: Abhyankar’s conjecture, Mumford curves and applications to arithmetic algebraic geometry.

4. *Drinfeld modules.* This concerns a theory in positive characteristic which has similarities with the theory of elliptic curves and Abelian varieties.

1.2 Overview of scientific results

*ad (1) Work of Top and Auer concerning conductors of elliptic curves in characteristics 2 and 3 is in a final stage. A preprint is being prepared on this.*

Auer and Top have written a paper on the characterization of so-called Legendre elliptic curves over finite fields. This appeared in the Journal of Number Theory. An application of this to the problem of finding curves over finite fields with many points has been published in the conference book of ANTS V. A sequel of this is currently in preparation.

A joint paper of Kloosterman and E. Schaefer on the size of Selmer groups of elliptic curves, is accepted for publication in the Journal of Number Theory.

Kloosterman also proved results on the classification of so-called extremal elliptic surfaces. A paper about this has been submitted for publication in the Michigan Journ. of Math.

Kloosterman started work on the Noether-Lefschetz loci for elliptic surfaces, and on constructions of elliptic $K3$-surfaces with Mordell-Weil rank 15. Two preprints concerning this are in preparation.
Top continued his collaboration with L.N.M. van Geemen (Pavia) on arithmetic properties of certain $K3$-surfaces. A preprint on $K3$-surfaces which have Picard number 19 is in preparation.

Top and N. Yui wrote a paper on applications of elliptic curves and elliptic surfaces to diophantine problems such as the congruent number problem and the rational cuboid problem. This is accepted for publication in the Proceedings of the CMI workshop “Algorithmic Number Theory”.

Carls extended the theory of Satoh and Mestre on the construction of canonical lifts of abelian varieties. A preprint is in preparation. He also developed an algorithm for counting the number of points on elliptic curves in characteristic 3.


A paper concerning the complete description of the universal differential Galois group of the differential field $\mathbb{C}(\{z\})$, inspired by work of J. Martinet and J.P. Ramis, appeared.

A study of iterative differential equations in positive characteristic by M. van der Put and B.H. Matzat (University of Heidelberg) has resulted in a joint paper “Iterative differential equations and the Abhyankar conjecture”, accepted by J. reine angew. Math. Another paper by M. van der Put on this subject, namely “Differential equations in positive characteristic and inverse problems”, has been published in “Journées arithmétiques de Caen.”.

Cooperation between M. van Hoeij (Florida State University) and M. van der Put has lead to discoveries in computer algebra of differential equations. The joint preprint “Descent for differential modules and skew fields” has been submitted for publication.

Cooperation between M. Berkenbosch, M. van Hoeij and J.-A. Weil (University of Nice) has continued and a joint paper (including earlier work of M. Berkenbosch) on the Kovacic algorithm for differential equations is to be expected in 2003.
M. Berkenbosch has continued his work on moduli of differential equations. A paper on this has appeared in the book “Differential equations and the Stokes Phenomenon”.

A joint paper on Lie-symmetries of ordinary differential equations (authors W.R. Oudshoorn and M. van der Put) appeared in “Mathematics of Computation”.

Work of Top, in cooperation with P. van der Kamp and J. Sanders, let to an algebraic foundation of the theory of generalized symmetries for evolution equations. This is published in the book “Differential Equations and the Stokes Phenomenon”.

A joint paper with F. Loray and F. Recher on foliations has been submitted for publication.

ad 3 The writing on a “revised and expanded second edition” of the book “J. Fresnel and M. van der Put - Rigid analytic spaces and applications” was finished in April 2002 while M. van der Put was visiting professor at the university of Bordeaux. It is expected that this book will be published in Spring 2003 (Progress in mathematics, Birkhäuser).

Survey lectures on “Rigid geometry and Valuation theory”, presented at the international conference on Valuation theory at Saskatoon 1999, have resulted in an accepted paper “Valuation theory in rigid geometry and curves over valuation rings” that appeared in the Fields Institute Communications.

H.H. Voskuil and M. van der Put have completed their work on Mumford curves. Two joint preprints “Mumford coverings of the projective line” and “Discontinuous subgroups of PGL₂(K)” have been written. Both papers extend and clarify work of F. Herrlich, F. Kato and G. Cornelissen. The first paper has been accepted and the second one is submitted.

Inspired by rigid geometry, D. Harbater and M. van der Put have studied Abhyankar’s conjecture in higher dimension. The joint paper “Valued fields and coverings in characteristic p”, which among other things gives counter examples to this conjecture, is published in the Fields Institute Communications.

ad 4 G.J. van der Heiden has continued his work on this subject. One publication concerning an application to factorization has been accepted for publication in Math. of Comp. Two other preprints, on “the Weil pairing” and on “a local global problem” have been submitted for publication. A further preprint which applies the Weil pairing to compactification problems is on its way.
L. Taelman gave the theory of Drinfeld modules with level structures over an arbitrary base scheme of solid basis. A publication is being prepared. As an application a result by N. Elkies on high genus curves with many points was generalized.

Top continues collaboration with Chad Schoen on applications of the Drinfeld reciprocity laws from this theory to the theory of algebraic geometry; in particular to algebraic cycles.

1.3 Research subjects

M. Berkenbosch: algebraic aspects of differential equations, especially moduli problems.
R. Carls: a general orientation in arithmetic algebraic geometry; counting rational points on curves and abelian varieties over finite fields.
G.-J. van der Heiden: Drinfeld modules, a glocal-local problem, rigid geometry, compactifications of Drinfeld curves etc.
R. Kloosterman: arithmetic algebraic geometry, especially Selmer groups and elliptic curves and surfaces.
M. van der Put: rigid analytic geometry, Drinfeld modules, differential equations, difference equations, computer algebra.
L. Taelman: moduli of Drinfeld modules.
J. Top: arithmetical algebraic geometry in particular: elliptic curves, Galois representations, number theory, Drinfeld modules.

1.4 Publications

Edited books


Contributions to books


**Articles in scientific journals**


**Other publications**


### 1.5 External funding and collaboration

**External funding**

NWO (2 OIO years), EAGER (3 OIO months and travelling money), GTEM (for traveling money, estimated 3500 Euro), Socrates (student exchange).
External collaboration

See 1.2.

1.6 Further information

van der Put:
visiting professor at the University of Bordeaux during April 2002,
a main lecturer at the GTEM conference in Leiden, June 10-14, 2002,
one of the organizers of the Oberwolfach meeting “Galois theories” 7-13 July 2002,
gave a lecture at the Luminy conference “Resurgence, alien calculus, resummability, transseries” November 18-22, 2002.
has contributed to the Ph.D. thesis of A. van der Waall (Utrecht), J. Draisma (Eindhoven), J. Sauloy (Toulouse), M. Bouffet (Toulouse).

J. van Geel, in cooperation with G. Cornelissen, F. Gardeyn, M. van der Put, J. Top,
organized the conference “Moduli of Drinfeld modules” at the University of Gent on May 6-8, 2002.

J. Top:
gave invited lectures during the ANTS-V and Echidna conferences on number theory held at Sydney university in July,
supervised part of the Ph.D. thesis of A. Bandini at the Scuola Normale di Pisa (May 2002),
is book reviews editor for the journal “Nieuw Archief voor Wiskunde”.

J. Top and M. van der Put are involved in several European Community projects MEGA, EAGER, GTEM (Galois Theories and Explicit Methods).
2. **Analysis**

**Group leader:** Prof.dr. E.G.F. Thomas

**Tenured staff (IWI members)**

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<td>Prof. dr. E.G.F. Thomas</td>
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**PhD students**

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<td>(supervisor: B.L.J. Braaksma, emeritus)</td>
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<tr>
<td>G. Wanjala</td>
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**Guests**

Prof. T.Y. Azizov, Voronezh State University, Russia
Dr. Y.G. Shondin, State Pedagogical University Nizhny Novgorod, Russia
Prof. H. Langer, Technical University Vienna, Austria
Prof. D. Alpay, Ben-Gurion University of the Negev, Israel
Prof. J. Rovnyak, University of Virginia, Charlottesville, VA, USA
Dr. H. Neidhardt, Weierstrass Institute for Applied Analysis and Stochastics, Berlin, Germany
I.V. Gridneva, Ph.D. student, Dept. Mathematics, Voronezh State University, Russia
M.Y. Glaskova, Ph.D. student, Dept. Mathematics, Voronezh State University, Russia
O.V. Zhuravleva, Ph.D. student, Dept. Mathematics, Voronezh State University, Russia
Prof. B. Jefferies, University of New South Wales, Australia
Dr. I.P. van den Berg, Universidade de Evora, Portugal
2.1 Research Program

The research of A. Dijksma concerns the interplay of operator theory, complex function theory, theoretical physics, and systems theory, and mainly focusses around those problems whose solutions can be obtained via the theory of operators on spaces with an indefinite metric. For example: 1. The problem of similarity of a semigroup of contractions on a Krein space to a semigroup of contractions on a Hilbert space comes from the study of uniformly correct Cauchy problems involving certain evolution equations. 2. Generalized Nevanlinna functions appear naturally in the study of the Bessel and Laguerre equations from mathematical physics for values of the parameters that have not been considered before. 3. In quantum mechanics problems arise that involve extension theory of operators in spaces with an indefinite metric and the so-called Q-functions, which are in fact generalized Nevanlinna functions. 4. The Schur algorithm, which plays a role in system theory, can be generalized to generalized Schur functions and now also to generalized Nevanlinna functions and is related to canonical differential systems. 5. The spectra of eigenvalue problems involving ordinary and partial differential equations and boundary conditions which contain the eigenvalue parameter can under certain general conditions be studied through linearization to selfadjoint or dissipative operators in Pontryagin spaces.

R. Kuik continues work on exact asymptotics for a class of difference and differential equations.

E. Thomas continues work on his theory of infinite dimensional distributions with the goal of giving a correct mathematical description of the Feynman ‘path integral’ and related notions.

The research of G. Wanjala concerns the study of the generalized Schur transformation and the corresponding basic interpolation problem for generalized Schur functions. In particular, the effect the Schur transformation has on the coisometric and unitary realization of a generalized Schur function is studied.

2.2 Overview of scientific results

A. Dijksma Necessary and sufficient conditions under which a semigroup of bi-contractions in a Krein space is similar to a semigroup of contractions on a Hilbert space are obtained. The essentially unique factorization of certain $2 \times 2$ matrix polynomials into elementary factors has been proved using reproducing kernel space techniques and it is shown that the factorization can be obtained via the
The paper on Non-Selfadjoint Differential Operators aims to rectify a misunderstanding among some Lie group analysts to the effect that any invariant symmetric differential operator on a homogeneous space is essentially self-adjoint. The paper shows that a left invariant differential operator on a Lie group (of type I) is essentially self-adjoint iff its irreducible representations are almost all (with respect to Plancherel measure) essentially self-adjoint. This then yields an example of a left-invariant symmetric differential operator on the Heisenberg group which is not essentially self-adjoint.

Regarding Path integrals (Path distributions): So far we have been able to construct path distributions in two cases: discrete space and discrete time. These path distributions are analogous to the measures on function space, associated with stochastic processes, but with complex measures, respectively summable Schwartz distributions, as finite dimensional marginals. Work on the case of continuous space and time, along the same lines, is in progress.

2.3 Research subjects

A. Dijksma: the interplay of operator theory, complex function theory, theoretical physics and systems theory, and mainly focusses around those problems whose solutions can be obtained via the theory of operators on spaces with an indefinite metric.

R. Kuik: exact asymptotics for a class of difference and differential equations.

E.G.F. Thomas: the theory of infinite dimensional distributions with the goal of giving a correct mathematical description of the Feynman ‘path integral’ and related notions.

G. Wanjala: study of the generalized Schur transformation and the corresponding basic interpolation problem for generalized Schur functions.

2.4 Publications

Edited books


**Contributions to books**

**Articles in scientific journals**
Other publications


2.5 External funding and collaboration

*External funding*
Supported visits by the NWO grant 047-008-008 (57 kE for the period 2000-2003):
- Prof. T.Y. Azizov (Dept. Mathematics, Voronezh State University, Russia; 4 weeks), I.V. Gridneva (Ph.D. student, Dept. Mathematics, Voronezh State University, Russia; 4 weeks), M.Y. Glaskova (Ph.D. student, Dept. Mathematics, Voronezh State University, Russia; 4 weeks), O.V. Zhuravleva (Ph.D. student, Dept. Mathematics, Voronezh State University, Russia; 4 weeks), and Dr. Y.G. Shondin (Theoretical Physics, Nizhny Novgorod State Pedagogical University, Russia; 6 weeks).
- Under the Socrates program:
  - Prof. H. Langer (Dept. Mathematics, TU Vienna, Austria; 1 week).

*External collaboration*
- Prof. D. Alpay (Dept. Mathematics, Ben-Gurion University of the Negev, Beer Sheva, Israel) April 2002, 1 week.
- Prof. J. Rovnyak (University of Virginia, Charlottesville, VA, USA) April 2002, 1 week.
- Dr. H. Neidhardt (Weierstrass Institute for Applied Analysis and Stochastics, Berlin, Germany), March 2002, 1 week.

2.6 Further information

*B.L.J. Braaksma* was invited to lecture at a conference in Edinburgh, Scotland, June 16-21, 2002.

*B.L.J. Braaksma* and *R. Kuik* were invited to a conference in Luminy, France, November 2002, Braaksma to give the opening lecture.

*A. Dijksma* visited the Ben-Gurion University of the Negev, Beer Sheva, Israel, for
a working visit to Prof. D. Alpay, March 2-10. He attended the IWOTA workshop at the Virginia Technical University, Blacksburg VA August 2-6, (where he gave two lectures), and the MTNS conference at Notre Dame University, South Bend IN, August 12-16 (one lecture). Sponsored by NWO (grant 048-007-007) he stayed one month in Voronezh, Russia, visiting Prof. T.Ya. Azizov, September 2–October 1. Within the Socrates exchange program and partly sponsored by the Research Training Network HPRN-CT-2000-00116 of the European Union he visited Prof. H. Langer at the TU of Vienna, October 26 - November 2. Finally, he participated in an Operator Theory Workshop at the TU Berlin, December 6 and 7, 2002.


*E. Thomas* was invited by the University of New South Wales, Australia, (UNSW), for a month stay (6-1 to 4-2). Prof. B. Jefferies (UNSW) briefly visited Groningen (29-5, 1-6).
3. *Dynamical Systems & Analysis*

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

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<tr>
<td>Drs. R. Vitolo</td>
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<td>(supervisors: Broer, Takens and Simó (University of Barcelona))</td>
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<td>Drs. J. Hoo</td>
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<td>(supervisors: Broer, Vegter)</td>
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<tr>
<td>Drs. I. Gullikers</td>
<td>RuG &amp; NWO</td>
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<td>(supervisors: Van Maanen, Broer and Van Streun)</td>
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<td>Drs. K. Saleh</td>
<td>KNAW</td>
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<td>(supervisors: Broer, Tuwankotta and Soewono (Institut Teknologi Bandung))</td>
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<td>Drs. A. Sandovici</td>
<td>RuG</td>
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<tr>
<td>(supervisors: de Snoo and Hassi (University of Vaasa))</td>
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**Guests**

- Prof. R. Roussarie, Université de Bourgogne, France
- Prof. A. Vanderbauwhede, Rijksuniversiteit Gent, Belgium
- M.C. Ciocci, Rijksuniversiteit Gent, Belgium
- Dr. H. Hanßmann, RWTH Aachen, Germany
- B. Sommer, RWTH Aachen, Germany
- Dr. R. Cushman, Universiteit Utrecht, The Netherlands
- Prof. S. Hassi, University of Vaasa, Finland
- Prof. S. Troubetzkoy, University of Marseille at Luminy, France
Guests (cont.)
Prof. M. Jakobson, University of Maryland, USA
Prof. Z. Sebestyén, Eötvös Loránd University, Budapest, Hungary
3.1 Research program

The research programs Dynamical Systems and Analysis have a solid common basis, well founded in Mathematical Physics. The connecting elements are ordinary differential equations, or in general evolution equations. One specific common interest consists of the spectral theory of Schrödinger operators.

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 sometimes 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 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 Physics Department, VU Amsterdam (Profs. D. Lenstra and B. Krauskopf), the Department of Engineering, University of Bristol as well as the KNMI and the University of Utrecht (Dr. T. Opsteegh, Prof. F. Verhulst). Var-
ious PhD students and postdocs of all these institutions are involved as well. The theoretical work is internationally oriented and involves intensive cooperation with a.o. the universities of Dijon (R. Roussarie), Houston (M. Golubitsky), Barcelona (C. Simó and À. Jorba), Gent (A. Vanderbauwhede) and IMPA Rio de Janeiro (J. Palis and M. Viana) resulting in joint publications at a regular basis. In part both the fundamental and the more applied research is directed to mathematical physics and also embedded in the FOM-program of the same name. The PhD student Hoo, and earlier Van Noort, is a FOM OiO.

3.1.2 Analysis – Operator Theory

The central theme is the extension theory of symmetric and sectorial operators in Hilbert spaces and in Pontryagin spaces. This extension theory is closely connected to mathematical physics, in particular to explicitly solvable models and singular perturbations. Also there is a connection to system theory, cf. the realization of Herglotz-Nevanlinna functions in terms of transfer functions of conservative systems. Finally we mention the intimate relationship with analysis, in particular with moment problems, interpolation problems, differential operators and canonical systems.

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

The research in this section is concerned with the development of the general theory and the applications to the above mentioned fields. This is done in collaboration with a large group of mathematicians: Yu.M. Arlinskiǐ (Lugansk), S. Belyi (Troy), V.A. Derkach (Donetsk), A. Fleige (Dortmund), S. Hassi (Vaasa), J.P. Labrousse (Nice), M.M. Malamud (Donetsk), M. Möller (Johannesburg), Z. Sebestyén (Budapest), F.H. Szafraniec (Krakow), E.R. Tsekanovskǐi (Niagara).

3.2 Overview of scientific results

KAM theory
In KAM theory several projects are running. At the fundamental level there is cooperation of Broer with R. Cushman (Utrecht) and F. Fassò (Padova), regarding the persistence of Hamiltonian monodromy under non-integrable perturbations,
which has its consequences at the level of semi-classical quantization. A paper has been submitted. Another project of Broer is jointly with A. Vandebauwde and M.C. Ciocci (Gent), in which a reversible quasi-periodic bifurcation problem approaches its solution. This project is strongly related to the PhD research of Jun Hoo (RUG), who also is preparing a paper. Finally a joint paper of Broer with H. Hanßmann (RWTH Aachen), F.O.O. Wagener (Amsterdam), A. Jorba and J. Villanueva (Barcelona) regarding an internal-external resonance was submitted.

**Bifurcation theory**

In cooperation with M. Golubitsky (Houston) and Vegter (RUG) the geometry of resonance tongues was investigated in a general (universal) setting. A joint paper with Broer has been submitted. A joint work of Broer with Vegter and the former collaborators Lunter and Hoveijn was accepted for the Springer LNM series. Bruin and Van Noort made a joint analysis of a 1:3 resonance in a perturbed conformal system. A paper has been submitted. The project of Broer on 1 dimensional Schrödinger equations with periodic of quasi-periodic forcing with Simó and Puig (Barcelona) and Levi (Pennsylvania State University) is still in progress. One paper has been submitted and several others are in preparation.

**Extension theory**

The theory of abstract boundary values and Weyl functions has been carried forward (Derkach, Hassi, Malamud, de Snoo); several papers are in preparation. The theory of singular perturbations of selfadjoint operators is being further investigated. A paper (Derkach, Hassi, de Snoo) on this topic has been accepted by *Mathematical Physics, Analysis and Geometry*. A review paper (Hassi, Malamud, de Snoo) on M.G. Kreǐn’s theory of nonnegative extensions of nonnegative operators has been submitted. Further developments are being studied in a paper with Z. Sebestyén. A paper (Arlinskiǐ, Hassi, de Snoo) on the extension theory of Kreǐn and Ovcaenko is being prepared. A paper on a related theme (Arlinskiǐ, Hassi, de Snoo, Szafrańiec) is also in preparation. The representation of matrix valued Nevanlinna functions (Belyi, Hassi, de Snoo, Tsekanovskiǐ) is being carried forward. A paper on the general realization result is being prepared. A paper on spectral properties of Schrödinger operators (Hassi, Möller, de Snoo) has been submitted; a continuation for Schrödinger operators with the eigenvalue parameter appearing rationally is in preparation. The general theory of boundary value problems for trace normed canonical systems (de Snoo, Winkler) is being studied; a first paper has been submitted. The representation of not necessarily semibounded sesquilinear forms in a Hilbert space (Fleige, Hassi, de Snoo) remains a research
PhD research
Vitolo’s research, motivated by the publication below, studied a theoretical model with quasi-periodic Hénon-like attractors. This contributes to structuring the strange attractors for 3D diffeomorphisms. A preprint is available. Hoo started a paper on normal linear stability of quasi-periodic tori, where the classical results with simple eigenvalues are generalized to the case of multiple eigenvalues, suitable for resonant bifurcations. Saleh started his work on quasi-periodic bifurcations subordinate to singularities of higher codimension. Sandovici started has work on extension theory; a first paper concerning operators with a discrete spectrum is finished.

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.
H.P. Bruin: Bifurcation theory in conformal dynamics, statistical properties of low-dimensional dynamics.
I. Gullikers: Reinvention of geometry.
J. Hoo: Quasi-periodic bifurcations in a strong resonance: combination tones in gyroscopic stabilisation.
V. Naudot: Bifurcation theory, asymptotic properties of hyperbolic and semi-hyperbolic germs.
M. van Noort: Resonance phenomena with inverted pendulum as a case study, combination of analytical and both formal and numerical methods, bifurcations ‘at infinity’.
K. Saleh: Applications of KAM Theory in dynamical systems.
A. Sandovici: Symmetric restrictions of symmetric operators and their selfadjoint extensions.
H.S.V. de Snoo: Extension and realization theory with their applications to analytical problems.
H. Winkler: Spectral theory of differential operators and systems in definite and indefinite inner product spaces.
3.4 Publications

Articles in scientific journals


Articles in conference proceedings


3.5 External funding and collaboration

External funding

Dr. H.P. Bruin is a 3-year postdoctoral KNAW-fellow. Drs. J. Hoo was appointed as a FOM OIO in the program Mathematical Physics at February 1, 2001. Drs. K. Saleh was appointed on a KNAW PhD-grant at January 1, 2002.

In the open NWO competition a PhD project was awarded on the subject *Geometry and Dynamics of Resonant Bifurcation*. Co-supervisor is Vegter (RUG). This project fits in the joint research program, as mentioned earlier, with Simó (Barcelona), Golubitsky (Houston) and Levi (Penn State University).

3.6 Further information

- A summerschool course on KAM-theory was given by H.W. Broer at Twente University in June 2002. This was a course for graduate and PhD students on behalf of the Mathematics Research Institute. Broer gave invited talks at conferences at Twente University and at the ITB-Bandung and was plenary speaker at the ENOC conference in Moscow. H.W. Broer was a member the programme committee of the workshop ‘Hamiltonian Dynamical Systems’, at Imperial College London, February 2002. H.W. Broer also is a member of the programme committee for EQUADIFF2003, to be held in Belgium, July 2003. He also served as jury member for the PhD defence of Tuwankotta at Utrecht University.

- *H.P. Bruin* has given invited conference talks at the Universities of Warwick, Marseille (Luminy), the Banach Institute (Warsaw) and the University of Kyoto. He spent six weeks at the Mittag-Leffler Institute (Stockholm) as a guest researcher in the 2002-2003 program *Probability and Conformal Mappings*. He has also two week paid a separate research visit to Luminy. A result with D. Schleicher on *Symbolic dynamics of quadratic polynomials*, was accepted in the Mittag-Leffler Preprint Series (2002), cf. http://www.ml.kva.se/preprints/archive2001-2002.php

- V. *Naudot* gave invited talks at the Universities of Leiden and Kyoto.

- Two seminars at a national level were continued in 2002: A seminar on KAM theory (organization: H.W. Broer, H. Hanßmann and F.O.O. Wagener)
and a seminar on the interaction between Dynamics and Ergodic Theory (organization H.P. Bruin, K. Dajani, C. Kraaikamp).

– H.S.V. de Snoo gave invited talks at Technische Universität Berlin (December 2001), at the Banach Memorial Conference in Lviv, at the Banach Institute in Warsaw, and at the University of Vaasa. He spent a month at the University of Vaasa, and paid a research visit to Niagara University.

– H. Winkler gave invited talks at the Operator Theory Conference in Timisoara, at the Technische Universität Wien, and at the Technische Universität Berlin.

– A. Sandovici gave a talk at the Differential Geometry Conference in Iaşi.
4. Systems and Control

**Group leader:** Prof. dr. R.F. Curtain

**Tenured staff (IWI members)**

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<td>Dr. H.L. Trentelman</td>
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**Postdocs**

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<td>Dr. O.V. Iftime</td>
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**PhD students**

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<td>J.W. van Dijk</td>
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<td>R. Zavala Yoe (Ubbio Emmius scholarship)</td>
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<td>M. Opmeer</td>
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**Guests**

- Prof. M.A. Kaashoek, VU, Amsterdam, The Netherlands
- Prof. B. King, Virginia Polytechnical, University, Blacksburg, Virginia, USA
- Prof. H.J. Woerdeman, The College of William and Mary, USA
- Prof. A.J. van der Schaft, UT, Enschede, The Netherlands
- Prof. H. Kwakernaak, UT, Enschede, The Netherlands
- Dr. H. Zwart, UT, Enschede, The Netherlands
- Dr. G. Meinsma, UT, Enschede, The Netherlands
- Dr. A.J. Sasane, UT, Enschede, The Netherlands
- Dr. B. Jacob, Dortmund University, Germany
- Dr. H. Glüssing Lürssen, Oldenburg University, Germany
Guests (cont.)
Dr. T. Cotroneo, Merrill Lynch International, London, UK
Dr. P. Rapisarda, University of Maastricht, The Netherlands
Dr. G. Golo, UT, Enschede, The Netherlands
4.1 Research Program

The aim of the research in the Systems and Control group is the development of mathematical tools for the modeling of open dynamical systems and of algorithms for their control. There are two lines of research:

- The behavioral approach to systems and control (Belur, Çamlibel, van Dijk, Trentelman, Willems, Zavala Yoe)
- Infinite-dimensional systems theory (Curtain, Iftime and Opmeer)

4.1.1 The behavioral approach to systems and control

The basic purpose of systems theory is the study of dynamical systems that interact with their environment. Viewing systems as embedded in their surroundings should be a normal feature of models in physics, engineering and economics, but, in mathematics it is rather uncommon to formalize this interaction. Examples of areas where this aspect is essential are signal processing and control, and it is this last area which is emphasized in our research.

The traditional way of modeling a dynamical system is by an input-output map or relation. However, physical systems in general do not exhibit the information flow direction that is pre-supposed by the input-output structure. This objection has led us to develop the behavioral approach. In this setting, all manifest system variables are a priori treated on an equal footing. The model then specifies a subset of the set in which the manifest variables take their values as being possible. This subset is called the behavior of the system. However, when modeling systems as interconnection of standard components, as is common practice in computer-assisted object-oriented modeling tools, one invariably encounters (auxiliary) latent variables in addition to the manifest variables that the model aims at. Our approach is based on this triptych: manifest variables, behavior and latent variables.

Many questions are studied in this setting. Controllability, pole placement, observability, observers and Lyapunov stability are some classical questions that we are pursuing in this novel framework. Further, state construction and LQ- and H-infinity control. Most of the work aims at linear differential systems.
Ongoing work

Synthesis of dissipative systems in a behavioral setting (M.N. Belur, H.L. Trentelman, J.C. Willems, Zavala Yoe)

Development of the behavioral approach to H-infinity- and robust control, dissipative systems, quadratic differential forms, Lyapunov theory for systems described by high order differential equations. We start with polynomial matrix representations of a dynamical system (either a kernel or an image representation) and obtain analogous representations of the controller. This problem leads to interesting interactions between polynomial matrices in one and two variables.

Control as interconnection (M.N. Belur, M.K. Camlibel, H.L. Trentelman)

The purpose of this research project is the formulation of control and representation problems and algorithms in the context of behaviors. The starting point is a set of behavioral equations, for example a system of differential equations \( R \left( \frac{d}{dt} \right) w = 0 \) with \( R \) a polynomial matrix. We view control as interconnection, that is, adding a new system of differential equations \( C \left( \frac{d}{dt} \right) w = 0 \). The resulting closed loop system has been studied w.r.t. stabilization, pole assignment, invariant factor assignment, etc.

Modeling and control of distributed systems (J.W. van Dijk, H.L. Trentelman, J.C. Willems)

This program deals with studies on controllability and observability of systems of constant coefficient PDE’s through the behavioral approach. Special emphasis is on the extension of the concept of dissipative distributed parameter systems to the multidimensional case, and on the study of distributed Hamiltonian and variational systems. We aim at developing a behavioral theory of H-infinity control and H-infinity filtering for the class of systems described by linear partial differential equations with constant coefficients.

Algorithms in systems and control (P. Rapisarda, H.L. Trentelman)

This project focuses on algorithmic issues in modeling and control. Several algorithmic problems arising in classical systems and control theory can be treated successfully using methods from the behavioral setting. In particular we study the problems of polynomial J-spectral factorization and problems concerning the algebraic Riccati equation.
4.1.2 Infinite-dimensional systems theory

In many application areas, systems are most accurately described by partial differential equations or delay difference equations, for example, large scale flexible space structures, noise suppression in large cavities and process control, where there are considerable delays in control implementation. Control problems for such systems can be formulated in an analogous way to those for lumped parameter systems (those described by ordinary differential equations) in state-space form, if one introduces a suitable infinite-dimensional space and suitable operators, instead of the usual matrices. Infinite-dimensional systems theory is concerned with the extension of more familiar theory to this more general setting, insofar this is possible. Control design in this context is a synthesis of this theory, taking into account numerical, physical and implementational aspects.

The questions studied for these systems in this project are related to well-posed linear systems, robust control for dissipative systems and to adaptive control and observation.

Ongoing work

Absolute stability problems with applications to tracking (R.F. Curtain, H. Logemann of Bath University, UK and O.J. Staffans of Åbo Akademi University, Finland)

We seek conditions for the stability of an infinite-dimensional linear system under a large class of nonlinear feedbacks. This has direct applications to robust tracking of infinite-dimensional linear systems using low gain integral control.

Dissipative systems

(R.F. Curtain and G. Weiss of Imperial College, London, UK). A large class of flexible structures with collocated actuators and sensors are stabilized by applying static output feedback and the control is usually implemented on the boundary. This can be mathematically formulated as a stabilization problem for well-posed linear systems. We have obtained various sufficient conditions for exponential stability of the closed-loop system and we are working on sufficient conditions for strong and weak stability.

Adaptive control for positive-real infinite-dimensional systems (R.F. Curtain, K. Ito and M. Demetriou of NC State University, USA)
The aim is to construct adaptive observers and controllers for positive-real infinite-dimensional linear systems.

**Spectral factorization problems for infinite-dimensional systems** (R.F. Curtain, M. Opmeer and A.J. Sasane of Twente University)

Spectral factorization problems occur naturally in the solution to many control problems. So finding explicit solutions to various spectral factorization problems in terms of the state space parameters $A$, $B$, $C$ is an important step in the solution to the problem. We seek to do this for significant classes of infinite-dimensional linear systems.

**Reciprocal systems** (R.F. Curtain and M. Opmeer)

The class of well-posed linear systems represents a large class of infinite-dimensional systems that are suitable for modelling a wide variety of control problems for linear partial differential equations and delay equations. A significant problem in applying the theory is that the generating operators are unbounded and so the mathematical analysis is complicated. A novel approach developed by our group is to translate control problems for a well-posed linear system into equivalent control problems for its reciprocal system that has bounded generating operators. Due to the bounded generators this equivalent problem is more amenable to algebraic and numerical computations. It represents a promising novel approach to control design for well-posed linear systems.

**LQG balancing and approximation for distributed parameter systems** (R.F. Curtain, M. Opmeer and B. King of Virginia Polytechnical University, Blacksburg, USA)

Truncations of LQG-balanced realisations provide reduced order models of finite-dimensional systems that are useful in the design of low order controllers. We are developing a theory for the infinite-dimensional counterpart that we plan to test numerically on various benchmark PDE models developed by the group of B. King.

**Ordering of the solutions to Riccati equations** (R.F. Curtain, O.V. Iftime and H.J. Zwart of Twente University)

Algebraic Riccati equations may have infinitely many solutions and in finite dimensions they have a natural order. We seek to examine if this is the case in infinite dimensions.

**A mathematical formulation of interconnection structures in physical systems** (O.V. Iftime and G. Golo of Twente University)
Most of the current modelling and simulation approaches to physical systems are based on some sort of network representation. The physical system under consideration is seen as the interconnection of a number of systems, possible from different domains (mechanical, electrical e.a.). We focus on the mathematical description (in Hilbert and Banach spaces) of the interconnection structure.

Suboptimal Hankel norm approximation problem (O.V. Iftime and A. Sasane of Twente University)

Model reduction is an important engineering problem in which one aims to replace an elaborate model by a simpler model without undue loss of accuracy. One way to measure the accuracy is the Hankel norm. The connection between the sub-optimal Hankel norm approximation problem and a $J$-spectral factorization problem in algebras with a band structure is studied.

Optimal Hankel norm approximation problem (O.V. Iftime)

For the Wiener class of transfer functions a solution of the optimal Nehari problem was obtained via equalizing vectors. The aim is to use equalizing vectors to describe a solution of the optimal Hankel norm approximation problem.

### 4.2 Overview of scientific results

The behavioral approach to systems and control

The main emphasis in the research concerned with the behavioral approach to systems and control during 2002 has been on the following related topics:

- Synthesis of dissipative systems
- Control as interconnection
- Hamiltonian and variational systems
- Systems described by PDE’s.

Within the project on the synthesis of dissipative systems there has been much progress. In a two-part paper that has appeared in the *IEEE Transactions on Automatic Control* we have developed a general theory of synthesis of dissipative systems. This problem is a generalization of the classical H-infinity control problem for finite-dimensional linear systems, which lies at the basis of robust control. The
problem is to find, for two given system behaviors and a given supply rate, a dissipative system behavior that is wedged in between the two given behaviors, and that has the maximal number of inputs. In the two-part paper we have given necessary and sufficient conditions for the existence of such system behavior. Moreover, we have shown how the well-known classical result by Doyle, Glover, Khargonekar and Francis for state space systems follows from our results as a special case.

Also in 2002, in the context of the Ph.D. research of Belur, these results have been extended to the synthesis of strictly dissipative systems. This problem is a generalization of the classical strict suboptimal H-infinity control problem for finite-dimensional linear systems. The results on this have been reported in a paper that has been submitted to *Systems and Control Letters*. Finally, within the context of the synthesis of dissipative systems, results have been obtained on algorithmic issues involved in the verification of the existence conditions, and on the computation of the controlled system behaviors and controllers. These results have been described in a paper that has been accepted for publication in *Mathematical and Computer Modelling of Dynamical Systems*.

Within the context of control as interconnection we have obtained the behavioral generalization of the classical problems of pole placement and stabilization. We have shown that, for a given full plant behavior, there exists an regularly implementable, stable behavior if and only if in the full plant behavior the variable to be controlled is detectable from the control variable and the manifest plant behavior is stabilizable. These results have been described in a paper that has appeared in the *IEEE Transactions on Automatic Control*.

In collaboration with P. Rapisarda, results have been obtained on Hamiltonian and variational systems. Different from classical approaches, the property of being a Hamiltonian system is not defined in terms of one of the system representations, but in terms of the interplay of the system behavior with a certain bilinear differential form (BDF) on that behavior. We have characterized the property of being Hamiltonian in terms of properties of the representation of the system. We have also given a formal proof of the statement that a system behavior is Hamiltonian if and only if there exists a Lagrangian functional of the system variables and its higher order derivatives such that the system behavior consists of the solutions of the (higher order) Euler-Lagrange equations associated with this Lagrangian functional. These results have been collected in a paper that has been submitted for publication in *SIAM journal of Control and Optimization*.

More recently, we have obtained preliminary results on the extension of our results on Hamiltonian and variational systems to systems described by linear partial dif-
ferential equations. These results have resulted in a paper that has been accepted for publication in *Mathematical and Computer Modelling of Dynamical Systems*.

**Infinite dimensional systems theory**

Progress has been made in all the research projects listed in §4.1.

The collaboration with O. Staffans and H. Logemann on absolute stability and tracking applications has resulted in two more publications and the project is now completed. We have obtained a complete generalization of the classic finite-dimensional results known as the “Popov criterion” and the “Circle criterion” that should be useful tools in the analysis of stability for nonlinear controlled partial differential equations.

The project with Demetriou and Ito is also completed with a paper submitted for publication.

The novel idea of reciprocal systems proved a very successful and fruitful approach. Three papers on the basic theory have been submitted for publication and so far two have been accepted. The approach has resulted in new more accessible formulas for the solutions of control problems for well-posed linear systems and new sufficient conditions for the existence of coprime factorizations. The advantage of these new formulas and conditions is that, unlike the previous ones, they can be readily verified. Moreover, they are suitable for algebraic and numerical computations. In fact it is the key tool used in the project on spectral factorization.

The optimal Hankel norm problem is equivalent to a J-spectral factorization problem and this has been solved for the large class of well-posed linear systems using a reciprocal approach. This paper has been accepted for publication in the journal Systems and Control Letters.

Preliminary numerical results on the LQG project have been obtained in the form of a masters’ thesis by Opmeer in July. He obtained a complete generalization of the existence of LQG-balanced realizations for infinite-dimensional discrete-time systems. He now has an OIO position and the thesis results have formed the basis for a paper that was submitted in October. He is now working on the continuous-time case. Numerical work on the feasibility of using truncated these LQG-balanced realizations for control design is being carried out as part of Ph.D. project by K. Camp at VPI, USA, under the supervision of B. King. Similar work is being carried out as a masters’ thesis in Groningen.

The preliminary results on the new topic on ordering of the solutions of Riccati
equations are promising.

The collaboration with G. Golo and A. van der Schaft on a mathematical formulation of Dirac structure in Hilbert spaces provided some promising preliminary results. With the participation of H. Zwart, some of the gaps were filled. Preliminary results on representation of Dirac structures in Banach spaces were also obtained.

4.3 Research subjects

M. N. Belur: control in a behavioral setting; pole placement and stabilization by interconnection; implementability of system behaviors; synthesis of dissipative systems.

M. K. Çamlıbel: linear complementarity systems; time varying system behaviors; dissipativity theory of non-controllable systems.

R. F. Curtain: stability problems and applications to tracking for well-posed linear systems, LQG-balanced realisations and truncations for distributed parameter systems with applications to robust control design, reciprocal systems for well-posed linear systems, spectral factorization problems for nonrational transfer functions, Riccati equations for infinite-dimensional systems.

O. V. Iftime: Riccati equations for infinite-dimensional systems, Port-Based Models: Interconnection Structures, $J$-spectral factorization in frequency domain with applications to control problems.

M. Opmeer: LQG-balancing and truncations for distributed parameter systems with applications to robust control design, reciprocal and discrete-time infinite-dimensional systems.

H. L. Trentelman: control in a behavioral setting; pole placement and stabilization by interconnection; implementability of system behaviors; synthesis of dissipative systems; Hamiltonian and variational systems; algorithmic issues in systems and control; spectral factorization problems; algebraic Riccati equations; systems described by linear PDE’s.

J. C. Willems: the behavioral approach to systems and control; modelling and representation questions; controllability and observability and their implications; $H_2$- and $H_\infty$-control; systems described by PDE’s; dissipative systems.

R. Zavala Yoe: stability criteria in a behavioral setting; robust stabilization by
interconnection; dissipative systems.

4.4 Publications

Contributions to books


Articles in scientific journals


**Articles in conference proceedings**


- P. Rapisarda and H.L. Trentelman, Linear Hamiltonian systems, In: D.S. Gilliam and J. Rosenthal (eds.), *Proc. 15th International Symposium on...
Mathematical Theory of Networks and Systems, Notre Dame University, USA, 2002, 12 pages.


Other publications


4.5 External funding and collaboration

External funding

R.F. Curtain obtained a four year grant from the NWO Open Competition program to finance the PhD-project *Model reduction for controller design for distributed parameter systems*. Drs. M. Opmeer has been appointed to carry out this research project.

External collaboration

Dissertation


The Systems and Control group of the RuG collaborates with the Dutch Institute for Systems and Control (DISC).

International experience for graduate students

Only one of our staff of three is Dutch and more than half of our graduate and post-doc students are from abroad. Ricardo Zaval Yoe from Mexico has been appointed as an Ubbo Emmius Ph.D. student. This means that English is the daily language. Moreover, our Ph.D. students follow national graduate course in Systems and Control organized by the research school DISC. These are given in English and about half of the students are Dutch. In addition, due to our research collaboration with colleagues abroad, we have many guests from abroad each year. This creates an international environment in Groningen. Our Ph.D. students will be funded to attend at least two international conferences during their study.

4.6 Further information

Prof. J. Willems has spent a sabatical year with the University of Leuven. He delivered a number of invited talks at several international conferences: Oberwolfach Tagung über Regelungstheorie, MTNS2002, Control0202, Conference on the occasion of the 60-th birthday of Anders Lindquist.

In May R. Curtain visited George Weiss at Imperial College in London and Hartmut Logemann at the University of Bath for the purpose of joint research. She gave
talks at both universities. She was an invited speaker at the farewell symposium of Professor Rien Kaashoek in November. In December she visited the University of Melbourne and the University of New South Wales where she gave invited talks.

In February, **H.L. Trentelman** participated in a Systems and Control theory workshop held in Oberwolfach in Germany.


Several members of the group, **M.N. Belur, M.K. Çalimbel, R.F. Curtain, O.V. Iftime, H.L. Trentelman** and **J.C. J. Willems**, participated in the MTNS 2002 meeting held in University of Notre Dame, South Bend, Indiana, USA, August 12-16, 2002.

A two day workshop was held in November 4 and 5 in Groningen on "Different perspectives on J-spectral factorization". The workshop was organized by **R.F. Curtain** and **O.V. Iftime**.
5. **Probability and Statistics**

**Group leader:** Prof.dr. W. Schaafsma

**Tenured staff (IWI members)**

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**PhD students**

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<td>C. Dechsiri, M.Sc.</td>
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<td>(supervisors: Dehling and A.C. Hoffman, Chemical Engineering RuG)</td>
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<td>Drs. A.W. Stegeman</td>
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**Guests**

Prof. Richard A. Davis, Colorado State University, Fort Collins, USA
Prof. M. Taqqu, Boston University, USA
Prof. T.M. Mikosch, University of Copenhagen, Denmark
5.1 Research Program

The group continued its research on foundations of statistical inference, on probability theory and stochastic processes in general, and was involved in applications. The research of the group centers around two themes:

- Applied probability theory and stochastic processes
- Foundations of statistical inference

**Applied probability theory and stochastic processes**

The main task of applied probability theory is modelling of random phenomena in Science, Technology, Economics and Life Sciences, and the subsequent mathematical analysis of the resulting models. Mostly, modelling is done with a concrete purpose in mind. This can range from the classical tasks of prediction and control of a stochastic process to modern applications in Financial Mathematics like assessment of financial risks, valuation of contingent claims and design of portfolio management schemes.

A major portion of the research activities in Groningen is directed towards the modelling of time series. During the past decade there has been increasing awareness of shortcomings of traditional linear Gaussian time series. Models incorporating nonlinearity, heavy-tailedness and long-range dependence have subsequently been proposed as alternatives. The Groningen research on time series mainly focusses on the analysis of these nonstandard models. Issues like model identification, prediction and spectral analysis were studied until Stegeman completed his PhD studies (May 2002).

The mathematical analysis of stochastic models often requires asymptotic techniques, like various types of limit theorems. In most cases the underlying random variables are either not independent or have infinite variance, and thus often new techniques have to be developed. This fundamental research has a strong history in the work of the Groningen group. It turns out that various, seemingly unrelated, applications require the same type of mathematical tools. It is one of the aims of the group to find probabilistic structures which allow one to solve different problems from a unifying point of view. In particular, methods and techniques from empirical process theory were used successfully.

In addition to time series analysis, the Groningen group was involved in several other projects. One of them is the attempt to provide a rigorous analysis of neural
network learning algorithms, which leads to questions of stochastic approximation theory. Another project is the stochastic modelling of transport phenomena in chemical reactors, done in cooperation with a group in the Chemical Engineering Department.

Both teamleaders decided to leave Groningen because the Faculty did not provide the ‘niche’ they deserved. Dehling became C4 Professor in Bochum, Mikosch became Professor and leader of a team in Copenhagen. Ph.D. work of Stegeman and Dechsiri was continued in Groningen under the supervision of Dehling (Dechsiri) and Mikosch (Stegeman who completed his study in May 2002). Gao moved to the research group of Wim Hesselink (programme 8). Research will be continued by new staff members.

*Foundations of Statistical Inference*

Concrete applications to areas like physical anthropology (human growth, craniofacial growth, human evolution), biology, cytology, clinical decision making, diagnosis and prognosis, experimental neurology, etc., provided the motivation for the more fundamental research in statistical inference carried out in Groningen.

The work done in hypothesis testing during the sixties resulted in a deadlock: the Neyman-Pearson-Wald approach is not satisfactorily conclusive if more than 2 hypotheses have to be considered. One would like to assign ‘probabilities’ to these hypotheses but, at that time, such concepts were not allowed. The physical–anthropological problem of making sex diagnoses on the basis of skeletal material provided the motivation to concentrate the attention on the less controversial problem of estimating (reasonably) well-defined posterior probabilities. The POSCON project thus initiated had its own foundational crisis. Work done by meteorologists and Bayesian statisticians generated the idea that the properness of loss functions is essential in extending the Neyman-Pearson-Wald approach such that the ‘forbidden’ probabilities become ‘respectable’. This led to (relatively) new theories of hypothesis testing ($q$-values instead of $p$-values) and of distributional inference. This work is still in progress. Meanwhile other work was initiated. The research project of the physical anthropologist Williams about human evolution generated a new definition of size and shape which will be applied to human growth, craniofacial growth in particular (by De Bruin), and human evolution (by Williams and Van Vark). The project is entitled ‘Size and Shape of Man and Ape’.

The work of this group will be reported in two preprints of books. One co-authored by O.J.W.F. Kardaun about ’Distributional Inference’ (a book of about 300 pages containing many innovations of great interest for Statistics at large) and the other
one by De Bruin (with Schaafsma as co-author) with the title ‘Size and Shape of Man and Ape’ already indicated. Definitions of ‘size’ and ‘shape’ are of considerable interest in morphometrics. Albers completes his studies on March 7, 2003 with a thesis entitled ‘Distributional Inference: The Limits of Reason’. Papers about this subject will be published in 2003.

5.2 Overview of scientific results

5.3 Research Subjects


C. Dechsiri: stochastic modelling of transport phenomena in gas-solid fluidized beds, experimental aspects included.

W. Schaafsma: distributional inference, applied statistics, combination of opinions.

A.W. Stegeman: teletraffic workload processes and long-range dependence in teletraffic.

5.4 Publications

Dissertations


Articles in scientific journals


Other publications


5.5 External funding and collaboration

Schaafsma supervises the thesis work of R. de Bruin (Computer Center RuG): definitions of size and (components of) shape, applications to human growth and evolution. There is an intense cooperation with various research workers, Otto Kardaun (Max Planck Institut für Plasmaphysik) in particular.

External funding

Alwin Stegeman’s PhD study was funded by NWO (Dutch Science Organization). He completed his study in May 2002.

External collaboration

The group continued its collaboration with Dehling and Mikosch and via them, with Sid Resnick and Gennady Samorodnitsky (Cornell University), Richard A. Davis (Colorado State University), Michael Braverman (University of Ber Sheva), Olim Sharipov (Uzbek Academy of Science), Paul Embrechts (ETH Zürich), Claudia Klüppelberg (TU München), Catalin Starica (Chalmers University Gothenburg and Universite Libre de Bruxelles), Andre Dabrowski (Ottawa University). The group participated in the research training network DynStoch under the programme Improving Human Potential financed by the Fifth Framework Programme of the European Commission (Statistical Methods for Dynamical Stochastic Models, 2000-2004, see www.math.ku.dk/~michael/dynstoch).

5.6 Further information

Schaafsma retired on May 1. The chair for Stochastics and Statistics will be continued.
6. **Computational Mechanics and Numerical Mathematics**

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

**Tenured staff (IWI members)**

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<td>Dr.ir. R.W.C.P Verstappen</td>
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<td>Dr.ir. F.W. Wubs</td>
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**Tenured staff (other)**

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**Technical staff**

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**PhD students**

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<td>Ir.drs. M.T. Dröge</td>
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<td>Ir. G. Fekken</td>
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<td>Ir. K.M.T. Helmholt–Kleefsman</td>
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<td>Ir. A.J.A. Kort</td>
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<td>Ir.drs. G.E. Loots</td>
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<td>Ir. A.C. de Niet</td>
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**Collaborative PhD supervision**

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<tr>
<td>Ir. H. Scherpenkate</td>
<td>Chemical Engineering (RUG)</td>
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<td>(with Veldman)</td>
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6.1 Research Program

With the continuing progress in numerical mathematics and computer technology, the impact of computer simulation on society is rapidly increasing. Our group is an active part of this dynamic scientific computing scene: we specialize 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.

Turbulent flow: A main area of research concerns turbulent flow. Industrial simulation methods make use of turbulence models to keep the required computational effort within reasonable limits, but a price is paid in terms of accuracy. Thus research into direct numerical simulation (DNS) methods which resolve all length and time scales (i.e. no modelling errors) is essential. Our group concentrates on improving numerical techniques (space discretization and time integration) with which the price of DNS reduces significantly.

Free-surface flow: Another main research area concerns the numerical simulation of free-surface flow in terrestrial and extra-terrestrial conditions. In cooperation with NLR and international space agencies, an experiment is being prepared with a free flying spacecraft to study the influence of on-board liquid on spacecraft dynamics. A fast-growing application area is maritime technology. Our group is involved in projects on ship slamming (funded by MARIN) and on wave loading on offshore platforms (funded by EU). Also (smaller) free-surface flow projects with academia and industry are supported. Basic tool is the in-house developed simulation method ComFlo.

Sparse-matrix solvers: The repeated solution of one or more systems of equations is part of any CFD method. Therefore the quest for improved matrix solvers is another major research area. A method (MRILU) is being developed which can cover a broad class of matrices: symmetric or non-symmetric, structured or unstructured. A major application area is the investigation of flow patterns in global ocean circulation (with UU-IMAU).
Engineering applications: A large number of CFD applications is supported. In addition to the ones already mentioned, we report scientific projects in the areas of anatomy (arterial blood flow; with UU and AZG), biophysics and biomedical engineering (artificial organs), and chemical engineering (extruder flow). Again, ComFlo is the basic simulation tool. Further, extensive collaboration with the Dutch technological institutes is going on. In particular, with NLR a long-term cooperation exists covering a large variety of flow problems (ranging from aerodynamic design to spacecraft dynamics). As mentioned above, also with MARIN several projects are going on concerning hydrodynamic wave loading. Finally, various cooperations with industry can be mentioned (see below).

6.2 Overview of scientific results

In 2002, the DNS project has focussed on two themes. Firstly, the symmetry-preserving discretization of boundary conditions at non-grid-aligned boundaries (cut-cell method) has been refined. A second-order implementation has been completed and is ready to be validated with available benchmarks. Secondly, the discretization near (local) refinement boundaries has obtained much attention.

The free-surface projects (ComFlo development) have made considerable progress in 2002. The MARIN-funded project on ship slamming has concentrated on the implementation of moving objects; a start has been made with modeling the interaction between body motion and wave dynamics. Further, in the EU-funded SafeFLOW project on wave loading in off-shore applications, generation and propagation of non-linear waves has been implemented. Considerable attention had to be paid to the design of non-reflecting outflow conditions. Experimental validation support is being provided by the University of Glasgow and by MARIN. The ‘maiden’ application is wave loading on a so-called SPAR platform. Also, TU Delft and BlueWater have been supported in a small project on ship roll stabilization by means of kim keels.

The sparse-matrix project is closely cooperating with the Institute for Marine and Atmospheric Studies (IMAU) in Utrecht. The MRILU solver is being used to study stability and bifurcation patterns in ocean circulation. In 2002 a PhD project has been awarded by NWO (Wiskunde Toegepast) to reconstruct the time-mean ocean circulation pattern. Further, the MRILU solver has been implemented in one of the reservoir engineering codes at Shell (Rijswijk).
In the *hemodynamics project* the modelling and implementation of elastic vessel walls has obtained much attention. Another interesting study concerns the influence of secondary flow patterns in the embryonal heart development. The cooperation with AZG on modelling atherosclerosis has provided measurement data to validate the simulations (carried out with ComFlo).

*Industrial engineering projects* in 2002 involved cooperation with Biddle B.V. (indoor climate control), DASA Aerospace (liquid management in space) and a consortium consisting of Kvaerner-Buss, Shell SRTC, DSM and AKZO (venturi loop reactors). Also, the cooperation with ECN-NRG on free-surface flow problems was continued.

### 6.3 Research subjects

**E.F.F. Botta**: development of effective solution methods (algebraic multi-level ILU preconditioners) for sparse systems of equations in structured and unstructured problems.

**M.T. Dröge**: cartesian grid methods for direct numerical simulation of turbulent flow.

**G. Fekken**: numerical simulation of ship slamming (with MARIN).

**K.M.T. Helmholt–Kleefsman**: numerical simulation of hydrodynamic loading of offshore platforms (EU Safe-FLOW project, with MARIN).

**A.J.A. Kort**: algorithms for direct numerical simulation of turbulent flow.

**G.E. Loots**: fluid-structure interaction in viscous flows, with application in hemodynamics (with University of Utrecht).

**A.C. de Niet**: reconstruction of the time-mean velocity field of the ocean circulation (with IMAU).


**R.W.C.P. Verstappen**: development of simulation methods for turbulent flow (direct numerical simulation DNS).

**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.
6.4 Publications

Articles in books


Articles in scientific journals


Articles in conference proceedings


### 6.5 External funding and collaboration

Our research policy focusses on strengthening the link between fundamental developments in mathematics and the scientific and technical needs from society; in-house developed software plays an essential role here.

**External funding**

Five out of our six IWI PhD projects and our joint PhD project with Chemical Engineering are being funded by either the national science foundation (NWO), by industry or by other external funding (e.g. a donation from Computational Mechanics). In 2002, the NWO programme ‘Wiskunde Toegepast’ awarded a PhD project (in cooperation with IMAU) on reconstructing the time-mean velocity field of the ocean circulation. Also, an NCF grant has been awarded to parallelize our MRILU code (25 kEuro). Finally, some small contracts have been carried out for industry (Shell, Biddle BV, Coberco).
Societal relevance

As indicated above most of our PhD research is carried out in physical or technological applications (for details see above). Moreover, about 90% of our Masters’ projects are part of a cooperation with groups outside mathematics. In 2002 the latter projects involved RuG Biomedical Engineering (3 projects), AZG (2 projects), NLR (2 projects), UU IMAU (2 projects), RuG Computing Science, University of Bremen, MARIN, Biddle BV and SasTech.

International collaboration

Various bilateral contacts exist with research groups outside the Netherlands, leading to e.g. traineeships for our Masters’ students and/or to joint publications. On a multilateral scale, a major project is the cooperation with MARIN and about two dozen off-shore companies throughout Europe, Northern America and Asia on hydrodynamic wave loading (EU-funded Safe-FLOW project). Another project is the cooperation with NLR, ESTEC, NASA (and some European companies) on the design and exploitation of an experiment satellite: SloshSat FLEVO. Furthermore, our group takes part in the EU-funded networks ‘Eureka’ on artificial speech (coordinated by RuG Biomedical Engineering) and ‘Liquid management in space’ (coordinated by the University of Bremen), and we are involved in the 5th-framework project ‘ASICA’ on aircraft-cabin climate (coordinator Cerfacs, Toulouse).

6.6 Further information

Veldman is a member of the Scientific Committee NIVR-NLR, appointed by the Netherlands Agency for Aerospace Programs (NIVR), where he is involved in the Subcommittees on Aerodynamics and on Applied Mathematics and Information Technology. Further he is a scientific consultant of the ICT division at the National Aerospace Laboratory NLR (Amsterdam). He is on the editorial board of Computers and Fluids and Journal of Engineering Mathematics, and he is a member of the NWO ‘Beoordelingscommissie Wiskunde’.

During the annual JM Burgerssymposium in Delft (10 January 2002), Loots has been awarded a prize for the best poster presentation.

In 2002, group members (co-)presented a total of 14 lectures (of which 7 invited) at national and international meetings, amongst which: Offshore Mechanics and Arc-
tic Engineering (Oslo, Norway), Finite Volumes for Complex Applications (Porquerolles, France), European Turbulence Conference (Southampton, UK), Bluff Body Wakes and Vortex Induced Vibration (Port Douglas, Australia), Preconditioning Methods for Optimal Control and Constrained Optimization (Nijmegen), Preconditioning of Indefinite Systems (Eindhoven), and Dutch National Visualisation Days (Groningen).

An animated impression of the group’s research can be found at the website http://www.math.rug.nl/~veldman/cfd-gallery.html.
7. Software Engineering

Group leader: Prof.dr.ir. J. Bosch

**Tenured staff (IWI members)**  

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**Post-docs**  

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**Guests**  

- A. Maccari (focus area manager), Nokia Research Center (NRC), Finland  
- Prof.dr. K. Koskimies, Tampere University of Technology, Finland  
- A. Purhonen, VTT Electronics, Finland  
- Prof.dr. B. Neumann, Universität Hamburg, Germany  
- Dr. L. Hotz, Universität Hamburg, Germany  
- T. Krebs, Universität Hamburg, Germany  
- A. Hein, Robert Bosch GmbH, Germany  
- J. MacGregor, Robert Bosch GmbH, Germany  
- P. Burghardt, Thales Naval, the Netherlands
T. van der Weij, Thales Naval, the Netherlands
H. Obbink, Philips Research, the Netherlands
J. Schekkerman, Cap Gemini Ernst & Young, the Netherlands
R. van den Biggelaar, Refactive Software Re-engineering b.v., the Netherlands
G. Bakker, Refactive Software Re-engineering b.v., the Netherlands
E. Kesseler, Nationaal Lucht- en Ruimtevaartlaboratorium Amsterdam, the Netherlands
7.1 Research Program

The software engineering research group at the department of mathematics and computing science at the University of Groningen is a recently (September 2000) established group currently consisting of a full professor, one assistant professor, one post-doc, six Ph.D. students and five externally Ph.D. candidates. Within the field of software engineering, focus of the research group is on software architecture and software product families. The group employs an empirical research approach and extensive cooperates with the national and European software industry.

Software Architecture
Over the last decade, the software engineering community has come to the understanding that the challenging task of the development of software systems no longer is to provide the required functionality, but rather to fulfil the quality requirements of the system. Quality requirements, e.g. modifiability and usability, typically require explicit attention during development in order to achieve the required levels. Unfortunately, software engineers have few techniques available for predicting the quality attributes of a software system before the system itself is available and, consequently, to explicitly design for quality attributes.

Within the domain of software architecture, our research addresses two activities, i.e. assessment of quality attributes and the design of software architectures. The research towards assessment activities focusses particularly on assessment of usability and modifiability, but also other quality attributes, e.g. scalability, are considered. Quality attribute assessment starts with the precise, scenario-based specification of the quality requirement, i.e. a scenario profile. The architecture of the software system is consequently systematically assessed using the specified profile. The results of the assessment are quantified and exploited during the iterative design and evolution of the software architecture.

The research on software architecture design is concerned with the relation between quality attributes and design decisions and the difficulty of replacing or changing architecture design decisions once these have been taken. As an example of the first aspect: what is the effect of using a blackboard style for a software system on its performance and modifiability characteristics? In the context of the EU project STATUS, we investigate the relation between usability and software architecture. With respect to the second aspect, we have identified an increasing concern with the lack of flexibility of software architecture design decisions. Although this has long been accepted as a fact of life and has driven the attention towards ex-
explicit, up-front design of software architectures, during evolution also the software architecture typically has to evolve. In our research, we investigate approaches that allow for the first-class representation of architectural design decisions, during the architecture design phase, but also during later phases in the lifecycle. Finally, we study the notion of design erosion. As software evolves over time, it also ’ages’, i.e. its suitability for its intended purpose decreases. In our research, among others in cooperation with Baan and Philips, we study the identification, repair and avoidance of design erosion.

The second main area of research within the group is software reuse, in particular in the context of software product families. A software product family consists of a product line architecture, a set of components and a set of products. Each product derives a software architecture from the product line architecture, instantiates and configures a subset of the product line components and contains some product specific code. The group studies, among others, the evolution and maturity of product families, scoping and organizational aspects, but our primary focus is on software variability management. Software variability refers to all locations in software artefacts where the behaviour of an artefact can be changed, adapted or extended. In our research, we develop a conceptual framework for variability management, approaches to visualize variability and representation, assessment and configuration approaches for variability management.

7.2 Overview of scientific results

As discussed in the description of the research program, the main topics of the research group are in software architecture and software product families. In the overview of the scientific results, we present our contributions according to the following topics: software variability management, software architecture assessment and design, software product families and design erosion.

Software Variability Engineering
Promoting software reuse is probably the most promising approach to the cost-effective development and evolution of quality software. A successful example of reuse is the adoption of software product families in industry. In a product family context, software architects anticipate product variation and design architectures that support variants in both time (e.g., successive products) and space (e.g., co-existing products). Product variation is based on the concept of variability: a single architecture and a set of components support a family of products. It is im-
important to anticipate where variability has to be planned and the options possible in particular situations. Adding variations in an ad hoc manner typically erodes the original design, meaning that it becomes harder to modify the system (e.g., due to tangled dependencies) and often compromises performance (e.g., memory leakage). Supporting variability requires a well-defined architecture and insight into the consequences of adapting a software system, but useful tools and techniques to engineer for variability are not available or do not scale up to real-world systems. In our research, we have introduced a model to visualize and classify variability in software systems (VME: Variability Modeling and Engineering) and applied this model in several case studies. The model is not a manual explaining how to deal with variability, but instead a means to collect variability information on the system for improving the software reuse process, e.g., to gain insight into the consequences of selecting a particular variant. With VME, a software system can be classified in one out of five maturity levels by pinpointing its variability in the software lifecycle. A maturity level is where a software system has its predominant variation point binding times (e.g., during compilation or run-time).

Development in software product families is separated in a process for the analysis, design and implementation of shared artefacts (domain engineering) and a process for the development of individual products using those artefacts (application engineering). The process of constructing products from shared product family artefacts is often referred to as product derivation. In the experience of many companies, product derivation is still a rather expensive activity. In this context, the EU-project CONIPF studies and develops methodologies to improve the existing product derivation strategies. Prior to defining suitable product derivation methodologies, we investigated what aspects are responsible for the high costs associated with product derivation, in particular with respect to variability management. To this extent, we studied the product derivation processes at two industrial partners that produce software in large quantities and size respectively, i.e. Robert Bosch GmbH (Germany) and Thales Nederland B.V. (The Netherlands). Based on the study, we identified several problems and issues related to product derivation that, in our opinion, have a wider relevance than the specific companies.

**Software Architecture Assessment and Design**

Quality requirements such as performance, maintainability and usability are, in our experience, generally specified rather weakly in industrial requirement specifications. To address this, one common denominator of most quality attribute specification techniques is that some form of scenario profile is used as part of the specification. A scenario profile is a set of scenarios, generally with some relative
importance associated with each scenario. Typical examples of profiles include the usage profile (for performance and usability), hazard profile (for safety) and maintenance profile (for maintainability).

In our research, we have assessed maintainability of software architectures by evaluating the impact of the maintenance profile on the architecture. Using the profile, we perform an impact analysis that in turns is used to state a quality attribute prediction. As a result during 2002, we have documented the experiences of using our method for modifiability assessment, ALMA-Architecture Level Modifiability Analysis

The aim of the STATUS project is to study and determine the connections between software architecture and the usability of the resultant software system. The project will investigate the characteristics of software architectures that improve software usability. Usability is a key quality attribute in software products. Usability benefits are patent from the viewpoint of both the user organization (for example, the benefits due to more efficient use of information technologies) and the developer organization (for example, the extent to which its applications are used).

In our research the relationship between usability and software has been studied. A framework has been developed which illustrates the relation between usability and software architecture, by relating usability attributes (a decomposition of usability into measurable components) to usability patterns (captured design knowledge that has an effect on usability and is architecture sensitive). This framework provides the basis for developing assessment techniques that allow us to assess an architecture for usability. The framework also provides usability requirements and design solutions (in the form of usability patterns) that can be used during architectural design.

The ever growing size and complexity of software systems is making it increasingly harder to built systems that both meet current and future requirements. During architecture design, the predominant design decisions are taken. We have created an architecture design notation based on UML’s activity diagrams. The notation allows for the specification of architecture fragments and supports composition of these fragments as well as superimposition of the fragments on each other. This notation allows us to make dynamic compositions of architecture fragments (reflecting design decision alternatives) to adapt the architecture to new requirements.
We have found that our notation is very suitable for modelling separate concerns at the architectural level.

**Software Product Families**

Software product families have received considerable adoption in the software industry and prove to be a very successful approach to intra-organizational software reuse. Existing literature, however, often assumes a singular transition from independent product development to a software product family approach. One of our contributions in this domain during 2002 is that we have developed a taxonomy of different approaches to architecture-centric, intra-organizational reuse of software artefacts that organizes these in maturity levels. The maturity levels include standardized infrastructure, platform, software product family and configurable product base. In addition, we relate these maturity levels to the maturity of the product family artefacts, i.e. architecture, component and product, and to different organizational models. This taxonomy allows organizations to adopt architecture-centric software engineering in an evolutionary fashion. Finally, we studied the role of variability and composition in software product families and concluded that moving from variability to composition-based product derivation allows for a considerably wider scope of products to be covered by a product family.

**Design Erosion**

Design erosion is a common problem in software engineering. We have found that invariably, no matter how ambitious the intentions of the designers were, software designs tend to erode over time to the point that redesigning from scratch becomes a viable alternative compared to prolonging the life of the existing design. We have illustrated the mechanisms fundamental to design erosion by presenting the evolution of the design of a small software system. In our analysis of this example, we show how design decisions accumulate and become invalid because of new requirements. Also, it is argued that even an optimal strategy for designing the system (i.e. no compromises with respect to e.g. cost are made) does not lead to an optimal design because of unforeseen requirement changes that invalidate design decisions that were once optimal.

### 7.3 Research subjects

**J. Bosch:** software variability management, software architecture assessment and design, software product families, design erosion.

**S. Deelstra:** software product families and software variability evolution
E. Folmer: software architecture and usability.
J. van Gurp: quality attributes, software architecture design, design erosion.
A. Jansen: modelling software, architecture design decisions.
M. Jaring: variability engineering in software product families.
T.D. Meijler: concepts for realizing for software variability management
M. Sinnema: software product families and variability representation
R. Smedinga: software families architecture design decision representation.

7.4 Publications

Edited books


Articles in scientific journals


Articles in conference proceedings


**Other publications**


### 7.5 External funding and collaboration

**External funding**


**External collaboration**

Five industrial Ph.D. students are connected with the group:
R. van Ommering (Philips Research): product populations and the Koala component model.
A. Maccari (Nokia Research): architecture centric software development and evolution.
S. Stuurman (Open Universiteit): Software architecture representation and design decisions.
7.6 Further information

During 2002 Bosch was reviewer/technical expert EU IST projects, article reviewer for numerous journals and member of the program committee of the Dutch Jacquard research programme on software engineering.

He was member of, among others, the following programme committees:


In addition, Bosch is member of the following steering committees: Working IFIP/IEEE Conferences on Software Architecture, since 2001, Generative and Component-based Software Engineering Conferences, since 2001.

Also, Bosch (co-)organized the Seventh Workshop on Component-Oriented Programming Workshop associated with the 15th European Conference on Object-Oriented Programming. Organisers: Jan Bosch, Clemens Szyperski (researcher, Microsoft Research), Wolfgang Weck (Oberon Systems). June 2002.

He gave, among others, the following tutorials and invited talks: Software Architecture Theory and Practice: Status and Challenges, Landelijk Architectuur Congres, Golden Tulip Figi, Zeist; Architecture-centric Software Engineering, seminar by VTT Electronics, Oulu (Finland), October 2002; Jacquard Research Programme Software Architecture, ICT Kenniscongres, September 2002; Managing Variability in Architecture-centric Software Systems, University of Alberta at Edmonton (Canada), August 2002; Transition to Software Product Lines: Guidelines and Experiences, Nokia Software Architecture Seminar (Finland), May 2002.
8. Fundamental Computing Science

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

Tenured staff (IWI members)

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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. The following themes are studied: equational reasoning, multi-agent systems, programming methodology, decision support systems.

Equational reasoning is a well-known kind of mathematical reasoning that is practised e.g. in algebra and in many correctness proofs. Its standard formalisation is equational logic, a simple but very general reasoning system that is often used in computing science, e.g. in algebraic specification and rewrite systems (Mathematica is a well-known example). Proof theory for this logic, addressing structural properties of equational proofs, hardly exists, and the group tries to fill in the gap.

Multi-agent systems (MAS, also known as Agent Computing or just Agency) 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. As an example, think of a travel agency trying to compose a holiday trip that best fits the client’s wishes: this requires collaboration between the agents that perform subtasks such as hotel booking and airplane reservation. MAS is inspired by process theory and concurrency on the one hand, and logic and formal specification on the other hand. Process theory and concurrency provide the notion of concurrent and communicating processes; logic and formal specification provide high-level languages for description of and reasoning about agents and their intentions.

Some years ago, the group started to study some topics on the logical side of MAS: dynamic logic, epistemic logic, knowledge game theory. Recently, the group decided to investigate MAS also from the perspective of (concurrent) programming.

For programming methodology, the group aims to contribute to the design, specification, and verification of sequential, parallel and distributed algorithms, programs, and systems, possibly with assistance of a mechanical theorem prover.

The research in decision support systems focuses on medical realtime support systems (e.g. monitoring and warning systems for anesthesia and intensive care). For a smooth interaction with the user, such systems must have some kind of user awareness, i.e. they must know about the cognitive activities and the mental state of the user. This research subject combines two disciplines: human-computer interaction and artificial intelligence.
8.2 Overview scientific results

Le Feber and Pott performed an international survey on the improvement of real time medical support systems, and are working out the results. They performed experiments with alarms that code information about the cause of the problem. Moreover, they are developing a knowledge system that estimates probability and plausibility of diagnoses, given a collection of symptoms.

De Haan worked on knowledge based asynchronous programming, inspired by a hardware leader election problem: how should agents determine who is the leader, when they have only restricted means of communication via a number of wires? When solving this and related problems, one is inclined to think in terms of information and knowledge, and the aim is to make these notions formally explicit.

Gao has mechanically verified an algorithm for extendable efficient wait-free parallel accessible hash tables; the algorithm itself is due to Groote and Hesselink. Reports about the algorithm and its correctness proof have yet to be written.

Hesselink has finished the correctness proof of a serializable database interface based on the new technique of eternity variables. For the sake of this proof, the concept of invariance had to be generalized and new proof rules for invariance had to be invented. The proof has been verified with the mechanical theorem prover NQTHM to give additional confidence in the result and in the feasibility of the approach. In the field of artificial intelligence, Hesselink has characterized preference ranking policies induced by a utility function via the minimax principle.

Kooi extended dynamic epistemic logic with probabilities, and investigated optimal strategies for knowledge games. With Albers and Schaafsma, he finalised a paper on the Two Envelopes Paradox in probability theory. With Van Ditmarsch and Van der Hoek, he obtained a completeness proof for concurrent dynamic epistemic logic.

Renardel obtained (in collaboration with Kooi and Verbrugge) an elegant proof for a general result on the strong completeness of modal logics with infinitary rules (including dynamic logic, and epistemic logic with common knowledge operators). He also discovered a somewhat surprising counterexample for program harmony in these logics. Moreover, he continued his investigation on abstract derivations for equational logic.
8.3 Research subjects

**Le Feber**: development of a knowledge and classification system for diagnoses.
**Gao**: application of mechanical theorem provers to the verification of concurrent algorithms.
**De Haan**: concurrency, agent computing, knowledge-based programming.
**Hesselink**: design of concurrent algorithms.
**Kooi**: logical analysis of reasoning with uncertain and incomplete knowledge, the extension of epistemic logic with probabilities.
**Pott**: analysis of the survey results, design of a anesthesia monitor based on the survey results.
**Renardel**: proof theory of equational logic; modal and dynamic logic.

8.4 Publications

**Articles in scientific journals**


**Articles in conference proceedings**


Other publications


8.5 External funding, collaboration and internationalization

Le Feber and Pott work in the project *Requirements Engineering for Medical Realtime Advice Systems*, led by Renardel de Lavalette and funded by NWO. There is close collaboration with Ballast (Academic Hospital Groningen) and other anesthesiologists.

Kooi and Renardel collaborate with Verbrugge (Artificial Intelligence, Groningen), Van Ditmarsch (University of Otago, New Zealand) and Van der Hoek (University of Liverpool) on several subjects in (dynamic) modal logic and game theory.

Hesselink and Gao collaborate with Groote (Eindhoven University).

Kooi visited the University of Otago (New Zealand) during October 2002 - January 2003 where he collaborated with Van Ditmarsch and Van der Hoek (Liverpool) and
from where he attended the Annual Conference of the Australasian Association for Logic (Canberra Australia). He obtained a grant from NWO for the visit. Pott attended the Doctoral Symposium of the IEEE Joint International Requirements Engineering Conference in Essen, and the Conference of the European Society for Computing and Technology in Anaesthesia and Intensive Care in Zürich. De Haan attended the Summer School on - Specification, Refinement and Verification in Turku (Finland). He also visited the First International Symposium on Formal Methods for Components and Objects in Leiden.

8.6 Further information

*Renardel* is chairman of the board of the Dutch Research School in Logic, and member of the Board of the Dutch Society for Theoretical Computer Science.

*Le Feber* obtained the 2nd prize in the Best Paper Award of the Conference of the European Society for Computing and Technology in Anaesthesia and Intensive Care in Zürich, for his joint paper Encoded alarms in anaesthesiology (with A. Eikelboom, to appear).
9. *Computing and Imaging*

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

**Tenured staff (IWI members)**

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| Dr. M.A. Westenberg        | RuG           | 0.5 |
  (supervisor: Petkov)      |

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| A. Ghosh                    | RuG        | 1.0 |
  (supervisor: Petkov)      |
| C. Grigorescu               | RuG        | 1.0 |
  (supervisor: Petkov)      |
| S.E. Grigorescu             | RuG        | 1.0 |
  (supervisor: Petkov)      |
| A. Jalba                    | EU & RuG   | 1.0 |
  (supervisor: Roerdink and Wilkinson) |
| Ir. D.J. Kamerman           | RuG        | 1.0 |
  (supervisor: Wilkinson)    |
| N.G.H. Kruithof             | EU         | 1.0 |
  (supervisor: G. Vegter)    |
| L. Muresan                  | RuG        | 1.0 |
  (supervisor: Roerdink)     |
| S. Plantinga                | NWO        | 1.0 |
  (supervisor: Vegter)       |
| K. de Raedt                 | RuG        | 1.0 |
  (supervisor: Petkov)       |
PhD students (cont.)
E.R. Urbach RuG 1.0
(supervisor: Wilkinson)
A.M. Wink NWO 1.0
(supervisor: Roerdink)

Guests
prof.dr. R. Klette, University of Auckland, Australia
9.1 Research Program

The research program includes topics from computer vision, scientific computing and visualization.

In the areas of image processing, computer vision and scientific computing, models of the visual cortex are developed. The purpose of this research is to understand how man sees and eventually employ principles of natural vision in artificial vision systems.

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. 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.

Other projects involving image processing and pattern recognition concern automatic identification of diatoms (single-cell algae with silica shells), and quantitative shape description.

Visualization and exploration of large three-dimensional digital data volumes is becoming increasingly popular. Volume rendering is prominent among the techniques which have been developed for this purpose. The desire to exchange volume data through the internet has created a need for fast and efficient methods of transfer and display. For this purpose multiresolution models are studied, in particular wavelet methods and, more recently, methods from morphological image processing. Wavelets are also applied in functional neuroimaging, where 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 new project was initiated on graph visualization in the context of bioinformatics research on gene expression networks.
Research in the area of geometric computing is focused on the design of algorithms for representation, manipulation and visualization of curves, surfaces and general manifolds. Algorithms are being developed for fast rendering of implicit surfaces, both with static camera positions and under continuous camera motion. Especially the evolution of visible contours of various types of surfaces under camera motion is one of the central topics. This work has been continued and extended in the direction of implicit surfaces and evolving geometric objects (morphing). Furthermore, evolving curves and surfaces require special representations, that make their time-dependent shape easy to maintain and manipulate. Methods have been developed for constructing approximations of general geometric curves and surfaces with such dedicated representations.

The aim of computer simulation of the intestinal microflora (part of scientific computing) is to provide a flexible means of modelling and simulating those ecological processes which have consequences for the host. It will provide a platform for medical researchers to test hypotheses in silico before commencing with (costly) in vitro or in vivo experiments. The research in this field focusses on computational strategies which may be applied to other fields of biomedical simulation.

9.2 Overview scientific results

Image processing and computer vision

In the area of texture analysis, features based on the local power spectrum obtained by a bank of Gabor filters were compared. The following features were considered: Gabor energy, complex moments, and grating cell operator features. The capability of the corresponding operators to produce distinct feature vector clusters for different textures was compared using two methods: the Fisher criterion and the classification result comparison. Both methods gave consistent results. The grating cell operator gave the best discrimination and segmentation results, Fig.1. This operator was the only one that selectively responded only to texture and did not give false response to non-texture features such as object contours.

A computational model of nonclassical receptive field (non-CRF) inhibition was proposed. In general, an orientation selective neuron with non-CRF inhibition responds most strongly to a single bar, line, or edge in its receptive field, and shows reduced response when other such stimuli are present in the surroundings. In an extreme case, the cell responds only to an isolated bar or line. Two contour detection operators inspired by this mechanism were proposed: one based on the Gabor energy operator (C. Grigorescu et al. 2002a, Biologically Motivated Computer Vi-
Figure 1: Segmentation results obtained with the fuzzy c-means classification algorithm for texture images containing two, five, and nine oriented textures (S.E. Grigoescu et al., *IEEE Trans. on Image Processing*, 11 (10), 2002, 1160–1167.).
tion, Tübingen) and another based on the Canny edge detector (C. Grigorescu et al. 2002b, *Computer Vision and Graphics*, Zakopane). These operators were tested on natural images, and the performance was compared with ground truth contour maps (Fig. 2). The results show that contour detection performance is improved substantially for images that contain an object of interest on a cluttered or textured background.

![Figure 2: Image processing operators inspired by nonclassical receptive field inhibition were proposed. (a) Input image. (d) Ground truth contour image drawn by an observer. (b,c,e,f) Edge maps obtained with (b) traditional Canny operator, (c) traditional Gabor energy operator, (e) Canny operator augmented with surround inhibition, (f) Gabor energy operator augmented with surround inhibition. The images (e) and (f) show a great reduction of spurious edge responses that arise in texture areas.](image)

In the area of functional neuroimaging, research concentrated on data pre- and postprocessing. Motion correction in functional magnetic resonance imaging was studied, in particular the so-called spin-history effect. This effect is due to the fact that the fMRI signal is a function of both the current object position and the spin excitation history which depends on the position in all previous scans. A fMRI spin history simulator was developed which is able to predict and visualize the spin history artifacts generated by a change in position, and an automated algorithm was designed for reduction of these artifacts. This is joint work with the Biomedical Technology group (RuG). Also, wavelet denoising of functional neuroimages
was studied as an alternative to Gaussian smoothing, the most common denoising method. It was found that Gaussian smoothing, especially for large filter kernels, introduces deformations of active brain regions, whereas wavelet denoising better preserves the shapes and statistical activation patterns of these regions. In the area of volume rendering, an extension of the multiresolution representation for maximum intensity projection based on morphological pyramids was developed, by using morphological analysis filters which retain more of the fine details in higher levels of the pyramid.

A multi-scale method based on mathematical morphology was developed which can be successfully used in pattern classification tasks. The method is based on morphological hat-transform scale spaces and makes use of connected operators. The most important features are extracted from the scale spaces by unsupervised cluster analysis, and the resulting pattern vectors provide the input of a decision tree classifier.

Experiments were performed with a Minkowski-sum based method to compute the similarity of convex polyhedra. Tuzikov’s conjecture was shown to be false.

A review of methods for computing connected filters was published this year, including a discussion of a union-find based algorithm developed here. The theory of shape filters, which provide single-step, multi-scale morphological filters, was developed further. The speed of our shape-filter-based vessel-enhancement filters was increased further and now attains interactive filtering speeds. Furthermore, spatial pattern spectra which retain information on the locations of objects of different size classes were developed, along with efficient algorithms for their computation.

Scientific visualization and geometric modelling

In the context of Fourier-wavelet volume rendering, which is a Fourier domain implementation of the wavelet X-ray transform, an extension was developed similar to a technique called view interpolation in computer graphics. It was shown that the speed of rendering low resolution images is increased by interpolation of precomputed sets of wavelet approximation coefficients in the Fourier domain, resulting in improved user interaction. We also proposed a multiresolution representation for maximum intensity projection volume rendering based on morphological pyramids, which allows progressive refinement and perfect reconstruction. The structure of the multiresolution representation is very similar to wavelet splatting, the main differences being that linear summation of voxel values is replaced by maximum computation, and linear wavelet filters are replaced by (nonlinear) morphological filters.
Evolution of geometric objects (morphing) is an other central theme. Especially discontinuities in their topology, shape, or visibility properties are topics of active research. Fast rendering methods for surfaces under evolving parallel projection are based on fast methods for computing contours. The contour separates regions on a surface with front facing normals from regions with back facing normals, relative to the parallel or perspective projection. When the direction or center of projection change over time, the contour of the surface generally evolves continuously, with discontinuities occurring at isolated moments. We extended our earlier work by designing a robust implementation of a contour-tracing algorithm, based on interval arithmetic. In this way the output is guaranteed to be topologically correct, even in the neighborhood of (generic) singularities of the contour generator. Figure 3 shows the output of our algorithm for a specific class of implicit surfaces.

We also extended our work on approximation of curves in the plane to the context of surfaces in three space. In particular, we designed an algorithm to approximate a smooth surface by a skin surface, which has a very simple representation, that lends itself to easy manipulation, visualization, and morphing. Our method guarantees that the approximating surface has the same topology as the original surface, and comes with an error bound.

**Computer simulation and parallel computing**

The addition of adhesion to the simulator for the intestinal wall has increased its flexibility greatly. Besides interactions based on secretion of toxins have been
included. Both additions allow modelling of new classes of interactions, including combinations which cannot be treated analytically.

9.3 Research subjects

**H. Bekker**: aligning vector triples for similarity measure evaluation; calculating dense lattice packings of non-convex polyhedra for fast M.D. simulations.


**C. Ghosh**: bioinformatics, analysis of cDNA microarray data.

**C. Grigorescu**: shape recognition, contour detection.

**S.E. Grigorescu**: image segmentation, texture.

**A. Jalba**: automatic diatom identification and classification.

**D.J. Kamerman**: computer simulation of the intestinal microflora.

**N. Kruithof**: computational geometry of evolving curves and surfaces.

**L. Muresan**: pattern detection and estimation in functional neuroimaging.

**P. Ogao**: visualization of regulatory gene networks.

**N. Petkov**: texture, shape recognition, contour detection, psychophysics.

**S. Plantinga**: visibility amidst smooth obstacles in the plane.

**K. de Raedt**: visual memory, categorization.

**J.B.T.M. Roerdink**: morphological image analysis; scientific visualization; wavelets; neuroimaging; bioinformatics.

**E.R. Urbach**: morphological analogues of visual cortex models for texture operators.

**G. Vegter**: geometric computing and modelling; algorithms and schemes for curves, surfaces and manifolds; symbolic and numerical methods; visualization.

**M.A. Westenberg**: scientific visualization; automatic diatom identification and classification; contour detection, psychophysics.

**M.H.F. Wilkinson**: morphological image analysis, connected operators, biomedical modelling.

**A.M. Wink**: functional neuroimaging using wavelets.

9.4 Publications

**Contributions to books**

- M.A. Westenberg and J.B.T.M. Roerdink, Mixed-method identifications, Ch. 12 In: J.M.H. du Buf and M.M. Bayer (eds.) *Automatic Diatom Identifi-


Articles in scientific journals


Articles in conference proceedings


Other publications


9.5 External funding and collaboration

*External funding*

Wilkinson (in collaboration with M. Oudkerk, Radiology, and M.C.J.M. de Jong, Dermatology) obtained funding for a PhD student for the project Generalized Connected Morphological Operators for Robust Shape Extraction within the NWO Open Competition.

*Vegter* is site-manager of the joint European project on *Effective Computational Geometry of Curves and Surfaces* (Information Society Technologies Programme), a joint project of INRIA - Sophia Antipolis, ETH Zürich, FU Berlin, Groningen University, Max-Planck-Institut für Informatik - Saarbrücken, and Tel Aviv University. A three-year PhD-position has been awarded to Groningen.

*External collaboration*

In November the group hosted a meeting of the European graduate school on Neurosensorics (Groningen - Oldenburg).

*Petkov* participates in the European graduate school on Neurosensorics (Groningen - Oldenburg). He collaborates with Ch. Buys (RuG, medical genetics) in bioinformatics research.

*Roerdink* has an ongoing collaboration in the context of the Groningen Center for Functional Brain Research and the local research school BCN (Behavioural, Cognitive and Neurosciences) with the department of Biophysics, the Faculty of Medical Sciences (RUG) and the Academic Hospital Groningen (AZG) on functional neuroimaging (two PhD projects). He also collaborates, within the context of a larger NWO-BMI project, with the Department of Molecular Genetics (RUG) on Bioinformatics research, in particular modelling, identification, simulation and visualization of gene expression networks.

*Vegter* visited the site of INRIA (Institut Nationale d’Informatique et d’Automatique) at Sophia Antipolis, France, from February 1 to April 1.
Wilkinson conducts the project on simulation of the human intestine in collaboration with the International Study Group on New Antimicrobial Strategies (ISGNAS: http://www.isgnas.org/). He collaborates with the Radiology and Dermatology departments of the Academic Hospital in Groningen in the aforementioned NWO-project. He will also contribute to the collaboration on genomics analysis.

9.6 Further information

Petkov is member of the editorial boards of Journal of Neural, Parallel and Scientific Computations (Dynamic Publ.), Parallel Algorithms and Applications (Gordon and Breach) and Real-Time Imaging (Academic Press). He started his work as general chair of the Int. Conf. on Analysis of Images and Patterns (CAIP’2003, August 2003, Groningen). He is member of the scientific-technical council of foundation SURF and the commission Scientific use of supercomputers of Foundation National Computing Facilities. In 2002 he attended the following conferences: Texture workshop of ECCV (June, Copenhagen), Workshop on High performance Computing (June, Cetraro), Summer school on Cognitive Science (July, Sofia), European Conference on Visual Perception (August, Glasgow), Computer Vision and Graphics (September, Zakopane), Biologically Motivated Computer Vision (Tubingen, November). In November he took part in the study trip of the scientific-technical council of Foundation SURF, visiting major ICT companies in the USA.


Vegter was a member of the Program Committees of the International Workshop Automatic Deduction in Geometry (ADG’2002), Linz, Austria, September 2002, the Nineteenth Annual ACM Symposium on Computational Geometry, San Diego, USA, June 2003, and the Int. Conf. on Shape Modeling 2003 (SMI’03), Seoul, Korea, May 12–16, 2003. He presented an invited main lecture at the at the 18th European Workshop on Computational Geometry (Warszaw, April 10–12) and gave invited talks at the Séminaire Prisme (INRIA, Sophia Antipolis, France, April 23, 2002), at the Fifth International Conference on Curves and Surfaces (Saint Malo, France, June 27–July 3, 2002), and three invited lectures at the ECG workshop on
Computational Topology (Sophia Antipolis, October 2002). He also was on the Research Evaluation Committee of INRIA (Paris, March 14–15, 2002). He was a member of the reading committees of the PhD thesis of P. Angelier (École Normale Supérieure, Paris) and of the PhD thesis of R. Lindenbergh (University of Utrecht).

*Wilkinson* is member of the CAIP2003 programme and local organizing committees. Since 1999 he is a member of the ISGNAS, and the steering committee of the Old Herborn University Seminars.
10. *System Technology*

**Group leader:** Prof.dr.ir. L. Spaanenburg

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10.1 Research Program

Microelectronic developments make information-processing systems hard to design, test and maintain. This is accelerated in future systems, that feature distributed computing either in a network of regular computers or of embedded computers (EmNets). Such networks will be based on chips that are highly configurable in a plethora of programming opportunities and house a rich repertoire of on-chip test functions. The processed data source from widely differing devices, ranging from sensors to multi-media systems, and are supported by intelligent services actively/passively distributed over the system parts.

The programme aims to research tools, methods and standards that are fundamental for such designs, focussing on in-situ adaptivity of design, product and test. It is structured around four themes:

(a) Modular Net Composition
(b) Knowledge specification by nets
(c) Net Implementation and
(d) System Integration

It is endeavored to find solutions primarily in the exploitation of Computational Intelligence by multi-nets. Such networks appear often in nature, but artificial nets have long been confined to monolithic ones. We have developed basic concepts for the function-preserving merging of pre-defined modules that brings benefits in precision, accuracy, transparency and flexibility into reach of a variety of future EmNets and mean to extend the theoretical foundation towards a further computer-aided design automation.

The overall programme seeks to find a transparent relevance for “knowledge from data”. Most natural processes can be modeled before they are mathematically understood. Large-scale networks need a model-free fault diagnosis and isolation (FDI) or event-driven reconfiguration to provide for autonomous self-healing. Though this research area has been around for some time, little progress has been made. Recent technology forecasts indicate, that breakthroughs will be needed to maintain Quality of Service in the coming (wireless) networks.

10.2 Overview scientific results

Alternative ways are addressed to describe modular learning systems. Modules seem to be related to functions. Hence functional programming may be a more
designer-friendly way to present the knowledge structure in a multi-net. Since Minsky has forcefully shown, that a linear neural transfer does not always bring adequate learning, the world community has adopted non-linear means only. Ten Berg has illustrated, that piece-wise linear neural transfer is not only a viable alternative but also sometimes a necessity. This opens the door to automate the neural technology mapping by means of transformation rules. The use of such rules and the metrics that may guide the control of such transformations are studied.

Work in neural implementations is centered on the development environment InterAct. Massive experimentation is applied to substantiate probable sources of knowledge. From such experimental evidence Van Veelen has concluded that the ensemble behavior of synaptic weights enables the early detection of fundamental changes in the modeled process. Some alternative detection methods are researched in collaboration with Venema from BSU. Further research together with Astron will be directed towards the potential for in-line SW/HW self-test. This merges neural technology with the earlier GALS concept of Spaanenburg.

Further progress has been made by Nijhuis in the area of character recognition. This combines neural network theory with the practice of multiple classifiers in the area of pattern recognition. A further improvement was found possible by the appropriate handling of occluded characters. Though such characters are rare to appear, they bring the overall performance down by percentages. Extension of the modular system structure with a separate recognizer for occluded characters nullifies this effect.

10.3 Research subjects

J.A.G. Nijhuis: Structured design methodologies for high performance classification systems.
L. Spaanenburg: Intelligent and networked embedded systems.
10.4 Publications

Articles in conference proceedings


10.5 External funding and collaboration

10.6 Further information

Spaanenburg is on the Board of the Research School for Programming and Algorithms (IPA). He was also on the Program Committee of the Belgisch/Nederlandse AI Conferentie (BNAIC) and the 7th Fuzzy Days in Dortmund. He is on the Editorial Board of VLSI Design Journal (Gordon and Breach Publishers) and of Journal of Intelligent and Fuzzy Systems (IOS Press). Spaanenburg is issue manager on the KIVI Raad voor Wetenschap, Techniek en Maatschappij (RWTM), external reviewer on the ITEA-project ”Digital Head-End”, core-team member for the Progress Embedded Systems RoadMap and serves on the IEEE Technical Committee on CNN. He is also member of the KIVI committee for the 2001 Speurwerkprijs. From September 1 he is appointed as professor at the University of Lund, Sweden.

Nijhuis is member of the editorial board of PT Embedded Systems (ten Hagen & Stam).
11. **BioInformatics**

**Group leader:** Prof.dr. R.C. Jansen

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11.1 Research Program

Research Programme Groningen Bioinformatics Centre (GBIC) was established in 2002. The following goals and mission were formulated for research, teaching and collaboration:

- **Research**: to carry out internationally competitive research in bioinformatics, with emphasis on subjects relevant to existing areas of life sciences research and computer science in the University of Groningen and University Medical Centre Groningen;

- **Teaching**: to organise and give courses in bioinformatics for students in life sciences, mathematics, informatics and related disciplines at all levels of their career;

- **Collaboration**: to form multidisciplinary teams with experimental groups requiring bioinformatics software, hardware, and know-how for their research.

To reach the goals several initiatives have been started in 2002:

- **Research**: In its research GBIC follows a ‘systems biology’ approach aiming at integrative analysis of large amounts of heterogeneous genetic and genomic information. An approach, that is indispensable for translating the vast amount of genomic information into biologically meaningful results. Complex phenotypic characters of interest (e.g. sensitivity to disease; risk factors; enzyme activity) will be assessed at various biomolecular levels simultaneously (e.g. polymorphisms; mutations; mRNA, protein and metabolite expression profiles; sequence patterns; 3D structure). The research program of the GBIC concentrates on the development of novel analytical concepts, methods and models for the purpose of unravelling complex characters, fully exploiting GBIC’s strength in statistical and mathematical modeling and modern informatics. Its research is carried out in close collaboration with research institutes from both the Faculty of Medical Sciences and the Faculty of Mathematics and Natural Sciences. In September the BioGRID project started, funded by the EU, with specific tasks on information analysis and systems for GBIC, in collaboration with the faculty of Management Sciences.

- **Education and Training**: GBIC actively participates in the development of the new Life Sciences curriculum, chairing the development team for the
‘hoofdstroom’ (mean stream) Genomics, Proteomics & Bioinformatics. Lectures on bioinformatics topics were given as part of a new GUIDE PhD course on Modern Analytical techniques and in Biology courses. GBIC also actively collaborates with the bioinformatics development team at Hanzehogeschool (HBO); together an education plan was submitted to the national BioASP initiative.

- **Collaboration**: GBIC is actively seeking collaboration within IWI and with research groups at University of Groningen, University Medical Centre Groningen, and other universities, institutes and companies. Job vacancies and proposed projects at various training levels (master student, PhD student and postdoc) are available, e.g. on stem cell biology in the mouse or on correlated gene expression in bacteria with other groups in Groningen, and on expression profiling of populations with groups in Wageningen and Utrecht. Several joint project proposals were written and submitted. A Bioinformatics working group was started within IWI, with participation of staff from Petkov’s and Roerdink’s groups.

### 11.2 Overview of scientific results

**Genetic mapping**: development of novel models, methods and software for mapping quantitative trait loci (QTL) underlying complex multigenic traits in segregating populations (plant and animal populations resulting from inbred-line crosses, complex plant, animal and human pedigrees). Recently, we developed methods for detection of epistasis (gene-by-gene interaction).

**Genetical genomics**: recently we proposed the concept of ‘genetical genomics’. This involves expression profiling and marker-based fingerprinting of each individual of a segregating population, and exploits the statistical tools developed for QTL analysis. Genetical genomics will combine the power of two different worlds in a way that is likely to become instrumental in the further unravelling of metabolic, regulatory and developmental pathways. This has internationally been recognised as a new strategy of high potential (e.g. Nature Reviews Genetics 3:43-52, 2002; and News and Views article in Nature 422:269-270, 2003).
11.3 Research subjects

R.C. Jansen: unravelling of complex (quantitative or multigenic or multifactorial) traits, statistical, mathematical and (bio)informatic issues concerning systems biology, biomolecular methodologies (genetic mapping, genetical genomics, transcriptome and proteome analysis, transgene expression) and use of modern data management and analysis tools.

11.4 Publications

Articles in scientific journals


11.5 **External funding and collaboration**

*External funding*

The Dutch 'Regieorgaan' Genomics coordinated calls for a concerted action in the Netherlands on bioinformatics to be funded by a ICS/KIS grant. Groningen co-ordinated workpackages on information systems (de Brock), biostatistics (Jansen) and visualization (Roerdink).

Jansen obtained funding from the EU for a PhD student for the BioGRID project.

11.6 **Further information**

*Jansen* is interested in statistically designing, modelling and analysing quantitative expression experiments on populations, using strategies that combine the merits of genetics with the power of genomics.

Invited lectures


