The cover shows a snapshot from a direct numerical simulation of turbulent flow behind an obstacle; the flow is from left to right. The simulation has been carried out by the IWI research group Computational Mechanics and Numerical Mathematics; the visualization of the large amount of data involved has been performed by CWI.
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Research Institute for Mathematics and Computing Science (IWI)

Scientific director: Prof.dr.sc.tech. N. Petkov

Advisory council:
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(Emeritus, Professor of Theoretical Chemistry, RUG)
Prof.dr. F. Takens – vice chairman  
(Professor of Mathematics, RUG)
Prof.dr. G.R. Renardel de Lavalette  
(Professor of Computing Science, RUG)
Prof.dr. D.A. Wiersma  
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Scientific programmes and senior researchers

Mathematics

Programme 1 : Algebra and Geometry
Prof.dr. M. van der Put
Dr. J. Top

Programme 2 : Analysis
Prof.dr. B.L.J. Braaksma
Prof.dr.ir. A. Dijksma
Prof.dr.ir. H.S.V. de Snoo
Prof.dr. E.G.F. Thomas

Programme 3 : Dynamical Systems
Prof.dr. H.W. Broer
Prof.dr. F. Takens

Programme 4 : Systems and Control
Prof.dr. R.F. Curtain
Dr. H.L. Trentelman
Prof.dr.ir. J.C. Willems

Programme 5 : Probability and Mathematical Statistics
Prof.dr. H.G. Dehling
Dr. T. Mikosch
Prof.dr. W. Schaafsma

Programme 6 : Computational Mechanics and Numerical Mathematics
Dr. E.F.F. Botta
Prof.dr.ir. H.W. Hoogstraten
Prof.dr. A.E.P. Veldman
Dr.ir. R.W.C.P. Verstappen
Dr.ir. F.W. Wubs

Programme 7 : Teaching and History of Mathematics
Dr. J.A. van Maanen
Dr. A. van Streun
Computing Science

Programme 8 :  **Fundamental Computing Science**
Ir. E.J. Dijkstra
Prof.dr. W.H. Hesselink
Prof.dr. G.R. Renardel de Lavalette
Dr. R. Smedinga
Dr. J. Terlouw

Programme 9 :  **High Performance Computing and Imaging**
Dr. H. Bekker
Prof.dr.sc.tech. N. Petkov
Dr. J.B.T.M. Roerdink
Dr. G. Vegter

Programme 10 :  **Systems Technology**
Prof.dr.ir. L.J.M. Nieuwenhuis (extra-ordinarius)
Dr.ir. J.A.G. Nijhuis
Prof.dr.ir. L. Spaanenburg
Dr.ir. J.T. Udding
Research Schools

Researchers of the IWI participate in the following research schools:

1. **Mathematical Research Institute (MRI)**
   - Commissioner: University of Utrecht
   - Director: Prof.dr. J.J. Duistermaat
   - From 1 January 1999:
   - Commissioner: Universiteit van Nijmegen
   - Director: Prof.dr. J.H.M. Steenbrink

   Participating IWI programmes: 1, 2, 3, 5, and 7

2. **Dutch Institute of Systems and Control (DISC)**
   - Commissioner: Delft University of Technology
   - Director: Prof.dr.ir. H. Kwakernaak

   Participating IWI programme: 4

3. **The J.M. Burgers Centre for Fluid Dynamics**
   - Commissioner: Delft University of Technology
   - Director: Prof.dr.ir. G. Ooms

   Participating IWI programme: 6

4. **Dutch Graduate School in Logic (LOGICA)**
   - Commissioner: University of Amsterdam
   - Director: Prof.dr. D.J.N. van Eijck

   Participating IWI programme: 8

5. **Institute for Programming Research and Algorithmics (IPA)**
   - Commissioner: University of Eindhoven
   - Director: Prof.dr. J.C.M. Baeten

   Participating IWI programmes: 8 and 10

6. **Advanced School for Computing and Imaging (ASCI)**
   - Commissioner: Free University of Amsterdam
   - Director: Prof.dr. A.S. Tanenbaum

   Participating IWI programme: 9
Doctoral Dissertations 1998


1 Programme 1: Algebra and Geometry

1.1 Programme members

Prof.dr. M. van der Put
Dr. J. Top

1.2 Promovendi, postdocs and long-time visitors

Drs. W.R. Oudshoorn (Ph.D. student, supervisors: Van der Put, Top)
Drs. J. Scholten (Ph.D. student, supervisors: Top, Van der Put)
Drs. R. Vidunas (Ph.D. student, supervisor: Van der Put, jointly with Veger of programme 9)
Drs. K. Visser (promovendus, supervisor: Van der Put)

1.3 Research Program

The main subjects of research are:

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 subjects of study. Also, work is done on applications to Diophantine equations and arithmetic algebraic geometry.

2. *Langlands theory.* Calculations on representations are made, using advanced machinery from algebraic geometry.

3. *Rigid analytic geometry.* In this type of geometry, one works over non-archimedean valued base fields. The geometry has natural links with algebraic geometry and with complex analytic geometry. Symmetric spaces over local fields, which are special cases of rigid spaces, play an important role in number theory and the Langlands conjectures over function fields.

4. *Drinfeld modules.* This concerns a theory in positive characteristic which has similarities with the theory of elliptic curves and abelian varieties.
5. *Differential equations and Difference equations.* The differential (or difference) equations that are studied are ordinary linear (complex) differential equations. For linear and non-linear differential equations, the theory of Lie-symmetries is also studied. The methods are very often algebraic. The analytic part of the research concerns “multi-summation” and other types of liftings of formal solutions to actual solutions as functions on suitable sectors.

6. *Computeralgebra and Number theory.* One of the activities concerns the construction of algorithms for finding symbolic solutions of ordinary linear differential and difference equations. There is also interest in real-algebraic geometry, splines, robotica, Gröbner theory, LLL-algorithm, the number field sieve and the like.

Overview of scientific results:

ad (1). Some goals of the research in this area include the study of constructions and also limitations of methods that yield elliptic curves of high rank, and the construction of Galois representations associated with families of elliptic curves. Various papers on methods for calculating ranks and papers which use geometry of surfaces in the present context have been written and/or are still the topic of joint research. For example, during the summer of 1998, Top visited Chahal at BYU in Utah and they found methods to construct examples of elliptic K3 surfaces with maximal rank. Scholten finished a paper containing new results on a method of Mestre for constructing high rank curves over function fields. Further Scholten improved algorithms for computations on Galois representations, and found many examples in low dimensions of so-called non-selfdual ones.

ad (2). Top has continued joint work with Van Geemen, Van der Kallen and Verberkmoes, on algorithms for calculating automorphic representations of GL(3). In particular a better understanding of $L$-series of non-cuspidal representations was obtained. This led to an improved version of a preprint (accepted for publication in the sem. théorie des nombres Paris).

ad (3). The work on rigid analytic geometry and its relations with (arithmetic) algebraic geometry has been a major research subject of Van der Put over a long period. Let $K$ be a complete non-archimedean valued field. Any algebraic variety over $K$ have a natural structure as rigid space over $K$. The study of those rigid spaces, especially their uniformizations, can be used for a better understanding of those algebraic varieties. In particular there are
applications of rigid geometry to: curves and their reductions, abelian varieties, compactifications of moduli spaces, étale cohomology of rigid spaces and Drinfeld’s reciprocity theorem.

ad (4). Drinfeld modules are linked with the Langlands conjectures over a function field and with rigid spaces. Recent cooperation of Top and Van der Put on this subject concerned local-global obstructions in this setting. Also applications to factorization algorithms for polynomials were found. Top continued joint work with Schoen on applications to cycles on algebraic varieties over finite fields.

ad (5). Analytic aspects on differential and difference equations have been studied by Van der Put in cooperation with Braaksma, Immink and others, over a long period. The central theme is the Stokes phenomenon. Faber completed his Ph.D. thesis with Braaksma, Van der Put and Immink. The thesis was defended on February 6, 1998.

Algebraic aspects of differential equations have been studied as well. They include: differential Galois theory, the connection of the differential Galois theory with the “Stokes matrices” et cetera. The paper: “M. van der Put - Singular complex differential equations. An introduction - Nieuw Archief 1995” gives an impression of this research. This research is continued with Singer. The object is to write a book on the subject. Oudshoorn has been working on the algebraic foundation of the theory of Lie-symmetries. This topic has been known for a long time to physicists, but a good (algebraic) mathematical foundation was lacking.

ad (6). Theory and practice of symbolically solving linear differential (or difference) equations has resulted in papers and preprints. Another aspect is the behaviour of differential equations in characteristic $p$ and reductions modulo $p$ of differential equations. This resulted in two papers by Van der Put and a recent preprint. The research of Vidunas (Ph.D. student, since september 1995), has been in some aspects of differential equations. The second thesis advisor Vegter of Vidunas has stimulated his interest for real algebraic geometry, robotica, splines et cetera. The theory and practice of the number field sieve has been studied by Visser.
1.4 Research subjects


M. van der Put: rigid analytic geometry, Drinfeld modules, differential equations, difference equations, computer algebra.

J. Scholten: the arithmetic of elliptic curves and elliptic surfaces. Calculations on examples of Galois representations related to GL(3).

J. Top: arithmetical algebraic geometry in particular: elliptic curves, Galois representations, number theory, Drinfeld modules.


K. Visser: could unfortunately not combine his work as system manager of IWI with his interesting research on factorization and the number field sieve.

1.5 Publications

Articles in scientific journals


Contributions to books


1.6 Further information

Top and Van der Put have organized a succesful international AIDA-workshop on Computational aspects of Number theory. This meeting was held in Nunspeet, March 23–27, 1998.

Van der Put has been invited to give a lecture in Séminaire Bourbaki on June 20, 1998. The title of this talk is Recent work on differential Galois
theory. A pre-publication of this talk in the series of Séminaire Bourbaki will be followed by a publication in Progress in Mathematics.

He visited the university of Rennes from May 30 to June 21. He worked with Ulmer on the subject of differential equations and gave two talks with titles “Differential equations and Galois groups”, and “The inverse problem for complex linear differential equations”.

Van der Put was a member of the organizing committee of the MEGA conference at Saint Malo, June 22 through 27 and gave an invited talk with the title “Modular method for solving differential equations”.

He was an invited visitor at the MSRI, Berkeley from August 10 to December 23. He gave:

- one colloquium lecture for the department of Mathematics, Berkeley: “Progress on Differential equations”
- and one lecture at the seminar of Number theory, department of Mathematics Berkeley: “Differential equations and Number theory”.

Top has visited the BYU in Utah in August 1998. He worked with Chahal on the arithmetic of elliptic K3 surfaces. Also he was visited there by Schoen (Duke university) and they continued their collaboration on algebraic cycles.
2 Programme 2: Analysis

2.1 Programme members

Prof.dr. B.L.J. Braaksma
Prof.dr.ir. A. Dijksma
Prof.dr.ir. H.S.V. de Snoo
Prof.dr. E.G.F. Thomas

2.2 Promovendi, postdocs and long-time visitors

Drs. B.F. Faber (Ph.D. student, supervisors: Braaksma, Van der Put of programme 1)
Drs. R. Jofriet (Ph.D. student, supervisor: Thomas)
Drs. G.R. Kuik (Ph.D. student, supervisor: Braaksma, G.K. Immink (Econometrics, RUG))

*Long-time visitors*

T.Ya. Azizov (Voronezh State University)
Dr. Seppo Hassi (University of Helsinki)
Dr. Vladimir Derkach (State University of Donetsk)
Dr. Mark Malamud (State University of Donetsk)
Dr. Zoltan Sebestyen (University of Budapest)

*Promotions (Ph.D. defenses)*


2.3 Research Program

Mathematical Analysis is one of the oldest branches of mathematics and one that traditionally has the closest ties with applied mathematics and physics. It is a large area of which we can cover only small portions. At present our interest is mainly in topics within the global areas of:

A. Analysis in the Complex Domain,
B. Operator Theory,
C. Functional Analysis.

In the first named area attention remains focussed on analytic differential and difference equations with singularities. Together with Braaksma and Van der Put, Faber has worked on a formal theory of differential-translation equations. For a subclass of such equations he proved multisummability of formal solutions. On February 6, 1998, Faber has successfully defended his Ph.D. thesis entitled: “Summability theory for analytic difference and differential-difference equations”. On May 1, 1998, Professor Braaksma retired but he has agreed to continue the supervision of the Ph.D. work of Kuik, who has been formally appointed as Ph.D. student on September 1, 1998. Kuik’s project is entitled: “Exact asymptotics for a class of singular partial differential equations with applications to the analytic classification of nonlinear analytic ordinary differential equations and resonant vector fields”.

Dijksma and De Snoo continue their work in the area of operator theory. The research of Dijksma concerns in part interpolation and moment problems in an indefinite setting, in particular: extension theory, commutant lifting, reproducing kernel spaces theory, and the study of the defect of non-contractive operators in a Krein space. As an application an upper bound for the dimension of the space of solutions of certain elliptic problems could be derived. Much time this year has been spent in preparing and editing the anniversary volume for Prof. Heinz Langer (Technical University Vienna) on the occasion of his 60-th birthday and especially in studying his work. In the coming years the study of interpolation problems in an indefinite setting will be continued. In addition it is planned to study non-stationary analogs of the representation formulas for Schur and Herglotz functions as transfer functions of certain systems.

De Snoo is interested in a classification of (generalized) Nevanlinna functions according to integrability properties. This also leads to work on finite rank perturbations, generalized Friedrichs and Krein-von Neumann extensions, and spectral theory for canonical systems. Closely related is the realization theory for a class of operator valued Nevanlinna functions, and a description of extensions in exit spaces.

In the field of functional analysis Thomas continues work on his theory of path distributions. The main aim is to give a correct mathematical description of the Feynman ‘path integral’ which, introduced heuristically in 1948, and in spite of numerous efforts, still does not have a satisfactory math-
Jofriet (who’s appointment terminated this year) and Thomas have worked on the extension of the finite path integral to the case of countable discrete state space, and on the analogue of the classical action functional. Besides Thomas has worked on the theory of path distributions for the case time is discrete, but space is continuous, defining Fresnel distributions on appropriate sequence spaces. Dorlas (University College Swansea), has visited to initiate collaborative work on this topic. On a different topic Thomas has continued work with Faraut (Paris VI) involving a new application of the nuclear integral representation theorem to Harmonic Analysis on complex manifolds.

2.4 Research subjects

B.L.J. Braaksma: Exact asymptotics for a class of singular partial differential equations with applications to the analytic classification of nonlinear analytic ordinary differential equations and resonant vector fields.

A. Dijksma: problems in an indefinite setting such as related to differential operators with applications to quantum mechanics; commutant lifting; interpolation problems in various classes and nonstationary representations of generalized Stieltjes functions.

B.F. Faber: summability theory for analytical difference and differential-difference equations.

R. Jofriet: discrete path-integrals.

G.R. Kuik: exact asymptotics for a class of singular partial differential equations with applications to the analytic classification of nonlinear analytic ordinary differential equations and resonant vector fields.

H.S.V. de Snoo: classification of (generalized) Nevanlinna functions; realization theory for a class of operator valued functions; spectral theory for canonical systems.


2.5 Publications

Dissertations

Edited books


Articles in scientific journals


Contributions to books


Articles in conference proceedings


Other publications

2.6 Further information

Dijksma organized the International Workshop on Operator Theory and Applications, IWOTA 98, Groningen, June 30 – July 3, 1998 (100 participants from 18 countries) and is the managing editor of the Proceedings (with refereed articles) to be published in the series Operator Theory: Advances and Applications published by Birkhäuser Verlag in Basel. He visited Vienna (invited lecture, member Habilitationskommission).

De Snoo made several visits abroad:
Helsinki (4 weeks working visit, invited lecture), January 1998.
Nice (1 week), May 1998.
Timisoara (1 week conference, lecture), June 1998.
Warschau (Banach Center, 2 weeks workshop, invited lecture), August 1998.
Winnipeg (1 week, conferentie, invited lecture), October 1998.

Thomas gave an invited lecture at the Séminaire Choquet, Initiation à l’Analyse, Paris VI, 5-3-98.
3 Programme 3: Dynamical Systems

3.1 Programme members

Prof.dr. H.W. Broer
Prof.dr. F. Takens

3.2 Promovendi, postdocs and long-time visitors

Drs. H.H. de Jong (Ph.D. student, FOM/SWON; supervisor: Broer, in collaboration with Prof. M. Winnink and A.C.D. van Enter, Theoretical Physics, RUG)
Drs. G.A. Lunter (Ph.D. student, jointly with group 9; supervisors: Broer, and Vegter of programme 9)
Drs. M. van Noort (Ph.D. student, FOM/SWON; supervisor: Broer, jointly with Vegter of programme 9, and Hoveijn)
Drs. E.A. Verbitski (Ph.D. student, SWON; supervisor: Takens)
Drs. R. Vitolo (Ph.D. student; supervisors Broer, Simó (University of Barcelona), and Hoveijn)
Dr. A.L. Hagen (postdoc of programme 9: joint project with programme 3)

Collaborative Ph.D. projects: Drs. K.A. Blom (with Van Maanen and Van Streun of programme 7); R. Bakker (Chemical Engineering, TUD, collaboration with Takens).

Promotions (Ph.D. defenses)


3.3 Research program

In this program we investigate mathematical models describing time evolution of deterministic systems. As a very simple example one may think of an oscillator (or a pendulum). Already the slightly more complicated example
of two oscillators with (weak) interaction gives an illustration of most of the questions on which the present research concentrates:

– will each oscillator still keep its own (independent) frequency (in this case we speak of multiperiodic dynamics), or;

– will the combined system assume one globally periodic state so that the frequency of the apparent motions of the individual oscillators is a multiple of this global frequency (here one speaks of resonance);

– it turns out that there is a third possible dynamical state: there may be a continuous range of frequencies present in the dynamics (in this case the motion is called chaotic).

It is the occurrence of, and transitions between, these states (multiperiodic, resonant, and chaotic) which is the central theme of research in this program — not only for a few coupled oscillators but for a wide class of systems.

These questions are studies on three different levels:

– on the most general level on considers all possible systems (where we restrict ourselves to deterministic systems with finite dimensional state space) — one is interested in what is logically possible or impossible;

– for specific systems, e.g. systems proposed as mathematical model by some scientist, it is often important to obtain information about the dynamical states which can occur — here we are interested in the development of algorithms which will help in such an analysis;

– interpretation of measured data: recorded data of the time evolution of a system can often be used to determine the dynamical state of the system, or they can provide an indication that there are (partially) random effects involved.

It is clear that the different levels interact strongly: in order to know where to look for in a special case, one has to know what one can expect and what is logical possible or impossible.

There is cooperation with groups in other sciences on the analysis of specific systems (physics (VUA), meteorology (KNMI)) and on interpretation of experimental data (chemistry (TUD) on neural networks and fluid bed
reactors, and physiology (RUL)). The theoretical work is internationally ori-
eted and involves intensive cooperation with a.o. the universities of Dijon,
Barcelona, and with IMPA in Rio de Janeiro.

3.4 Research subjects

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

**A.L. Hagen**: see programme 9.

**I. Hoveijn**: Non-integrability, complicated dynamics, bifurcational aspects
of systems with structure, resonances and singular reduction.

**H.H. de Jong**: Application of KAM-theory to study ergodicity of a large
system; adaptation of the theory for the case with strong normal resonance.

**G.A. Lunter**: Resonance phenomena, application of singularity theory and
Groebner basis techniques. Elaboration of various methods.

**M. van Noort**: Resonance phenomena with inverted pendulum as a case
study, combination of analytical and both formal and numerical methods,
bifurcations ‘at infinity’.

**F. Takens**: Analysis of time series, in particular the extension of meth-
ods for deterministic systems to situations with (weak) stochastic noise;
extension of thermodynamical formalism for the dimension spectrum to the
entropy spectrum.

**E.A. Verbitski**: Ergodic theory of differentiable dynamical systems, in
particular different types of entropy and entropy and multifractal spectra.

**R. Vitolo**: The Lorenz–84 climate model with seasonal forcing: a dynamic
exploration.

3.5 Publications

**Dissertations**


- M.J. van der Heijden, *Non-linear analysis of continuous and discrete
  physiological time sequences*. Promotores: prof.dr. F. Takens en
**Articles in scientific journals**


**Articles in conference proceedings**


3.6 Further information

*F. Takens*: editor Springer Lecture Notes in Mathematics, member of the Royal Academy of Sciences (KNAW) and chairman of the ‘Akademie Raad Wiskunde’.
4 Programme 4: Systems and Control

4.1 Programme members

Prof.dr. R.F. Curtain
Dr. H.L. Trentelman
Prof.dr.ir. J.C. Willems

4.2 Promovendi, postdocs and long-time visitors

T. Cotroneo (Ph.D. student, SWON; supervisor: J.C. Willems)
Ir. J. Daams (NLR, promovendus; supervisor: J.C. Willems)
Ir. J.C. Oostveen (Ph.D. student; supervisor: R.F. Curtain)
Dr. H.K. Pillai (postdoc, NWO; supervisor: J.C. Willems)
P. Rapisarda (University of Trieste, promovendus; supervisors: J.C. Willems, H.L. Trentelman)
A. Sasane (Ubbo Emmius Ph.D. student; supervisor: R.F. Curtain)

Promotions (Ph.D. defenses)


4.3 Research Program

The aim of the research in the program Systems and Control is the development of mathematical tools for the modelling of open dynamical systems and of algorithms for their control. The emphasis is on two lines of research:

- The behavioral approach to systems and control (Willems, Trentelman, Pillai, Rapisarda, Cotroneo, Daams)
- Infinite-dimensional systems theory (Curtain, Oostveen, Sasane)

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 modelling 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 presupposed 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 modelling systems as interconnection of standard components, as is common practice in computer-assisted object-oriented modelling tools, one invariably encounters (auxiliary) latent variables in addition to the manifest variables that the model aims at. Our approach is based on this trypitich: 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 $H_\infty$-control. Most of the work aims at linear differential systems, but systems with inequality constraints and nonlinear differential algebraic systems are studied as well.

*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 abstract linear systems, robust control for dissipative systems and to adaptive control and observation.

4.4 Research subjects

**T. Cotroneo**: Nonlinear systems in a differential algebraic setting; controllability and flat systems. State space representations; controllability and observability of nonlinear and linear time varying systems.

**R.F. Curtain**: Infinite-dimensional linear systems; robust control for dissipative systems; abstract linear systems; adaptive observers and compensators.

**J. Daams**: Tradeoff in system identification and filtering between misfit, latency and complexity; modelling the human operator.

**J.C. Oostveen**: Systems and control theory for strongly stabilizable systems, dissipative systems, flexible structures.

**H. Pillai**: Behavioral approach to n-D linear systems; controllability, observability of systems on constant coefficient PDE’s; dissipative distributed parameter systems.

**P. Rapisarda**: Linear differential systems; state algorithms; algorithms for polynomial J-spectral factorization; balancing and model reduction.

**A. Sasane**: Infinite-dimensional systems.

**H.L. Trentelman**: Control in a behavioral setting; $H_\infty$ control theory in a behavioral setting; algorithms for polynomial J-spectral factorization; theory of dissipative systems.

**J.C. Willems**: The behavioral approach to systems and control; modelling and representation questions; controllability and observability and their implications; LQ- and $H_\infty$-control; identification.

4.5 Publications

**Dissertations**

Books


Edited books


Articles in scientific journals


Contributions to books

– I. Mareels and J.C. Willems, Elimination of latent variables in real
differential algebraic systems. In: V.D. Blondel, E.D. Sontag, M.
Vidyasagar, and J.C. Willems (eds), Open Problems in Mathematical

– J. Rosenthal and J.C. Willems, Open Problems in the area of pole
placement. In: V.D. Blondel, E.D. Sontag, M. Vidyasagar, and J.C.
Willems (eds), Open Problems in Mathematical Systems and Control

– H.L. Trentelman, When does the algebraic Riccati equation have a
negative semi-definite solution? In: V.D. Blondel, E.D. Sontag, M.
Vidyasagar, and J.C. Willems (eds), Open problems in Mathematical

– J.C. Willems, Lyapunov theory for high order differential systems. In:
V.D. Blondel, E.D. Sontag, M. Vidyasagar, and J.C. Willems (eds), Open
problems in Mathematical Systems and Control Theory, Springer Verlag,

– J.C. Willems, Path integrals and stability. In: J. Baillieul and J.C.
Willems (eds), Mathematical Control Theory, Festschrift at the occa-
sion of the 60-th birthday of R.W. Brockett, Springer Verlag, 1998,
1–32.

– J.C. Willems, State and storage. In: D. Normand-Cyrot (ed), Per-
spectives in Control, Festschrift at the occasion of the 60-th birthday

Articles in conference proceedings

– R.F. Curtain and J.C. Oostveen, Absolute stability for collocated sys-
tems, Optimization Techniques and Applications, Proceedings of the

– M. Demetriou, R.F. Curtain, and K. Ito, Adaptive observers for struc-
turally perturbed positive real delay systems, Optimization Techniques
and Applications, Proceedings of the ICOTA’98, Curtin University of

– M. Demetriou and R.F. Curtain, Adaptive observers for slowly time
varying infinite dimensional systems, Proceedings of the 37th IEEE


4.6 Further information

The Systems and Control group of the RUG collaborates with the Dutch Institute for Systems and Control (DISC). Willems is chair-person of the board of DISC.

Trentelman and Willems collaborate on the NWO ‘Groot Project’: *Modeling and Control of Open Dynamical Systems* (coordinator: A.J. van der Schaft, UT). Cotroneo (OIO) and Pillai (postdoc) are funded by this project.

Sasane is a Ubbo Emmius bursaal (started in 1997).

Members of the group are part of several networks sponsored by the EU Science program or by the ESF (European Science Foundation).

The visit of Trentelman to Bombay was sponsored by NUFFIC and continues our collaboration with the control group of the Indian Institute of Technology in Bombay, India.

*Other Facts*

Trentelman spent the month of November at the Indian Institute of Technology in Bombay, India, to lecture in the Advanced Lecture Series of IIT Bombay. He is an associate editor for the *SIAM Journal on Control and Optimization*.

Willems spent September to December 1998 on study leave at Harvard University. He is on the editorial board of a number of journals and one book-series.

Willems was an invited speaker at the International Congress of Mathematicians, Berlin, August, 1998.
Sussmann and Willems received the 1998 outstanding paper award of the
IEEE Control Systems Magazine for their paper: “300 years of optimal
control: From brachystochrone to the maximum principle”, CSM, Volume

Willems received the 1998 IEEE Control Systems Award for “seminal con-
tributions to control theory and systems research”.
5 Programme 5: Probability and Statistics

5.1 Programme members

Prof.dr. H.G. Dehling
Dr. T. Mikosch
Prof.dr. W. Schaafsma

5.2 Promovendi, postdocs and long-time visitors

Drs. C. Albers (Ph.D. student, supervisor: Schaafsma)
Drs. S. Borovkova (Ph.D. student, NWO, supervisor: Dehling, jointly with programme 3)
Drs. B. Basrak (Ph.D. student, NWO, supervisor: Mikosch)
Dr. R. de Bruin (FWN, promovendus, supervisor: Schaafsma)
Drs. D. Salomé (Ph.D. student, supervisor: Schaafsma)
Dr. D. M. Salopek (NWO, postdoc, supervisors: Dehling, Mikosch)
Drs. A. Stegeman (Ph.D. student, NWO/SWON, supervisor: Mikosch)

Long-time visitors

Prof.dr. U. Rössler (Christian-Albrechts-Universität Kiel)
Dr. C. Stărică (Wharton Schools of Economics, Philadelphia, and Chalmers University, Gothenburg)

Promotions (Ph.D. defenses)


5.3 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

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 are being studied.

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, application 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 have been used successfully.

In addition to time series analysis, the Groningen group is 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.
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'.

5.4 Research Subjects

- **C. Albers**: Distributional inference, a ‘new’ approach.
- **B. Basrak**: Sample autocorrelations of non-linear processes.
- **S. Borovkova**: Dynamical systems, estimation and prediction of time series generated by such systems.
- **T. Mikosch**: Analysis of financial time series, modelling of heavy-tailed phenomena.
- **D. Salomé**: Distributional inference, fuzzy logic, density estimation, applied statistics.
D.M. Salopek: Mathematical finance.
W. Schaafsma: Distributional inference, applied statistics, human growth (with R. de Bruin), human evolution (with Williams and Van Vark).
A.W. Stegeman: Shot noise processes, teletraffic workload process.

5.5 Publications

Dissertations


Books


Articles in scientific journals


Contributions to books


Articles in conference proceedings


Further publications


5.6 Further information

Dehling spent a 6 month sabbatical as SOKRATES fellow at the University of Göttingen. He gave colloquium talks at the universities of Eindhoven, Bochum, Hannover, Karlsruhe, Kaiserslautern and Göttingen. Moreover, Dehling was invited to the Oberwolfach conference ‘Mathematische Stochastik’ and to the workshop ‘Dynamical Systems’ at Göttingen university.

Dehling is associate editor of Statistica Neerlandica.

*Dehling and Mikosch* organised a Section on Financial Mathematics at the Dutch Mathematical Congress in Twente.

*Mikosch* and Samorodnitsky (Cornell University) were awarded a NATO Research Grant for 1998.

*Mikosch* gave a course on stochastic calculus in Leuven for the Belgian Numerical Mathematics Network. He was invited speaker at several conferences, workshops and meetings (Oberwolfach, Zürich, Amsterdam, Gothenburg, Cambridge, Groningen), had longer research visits in Aarhus, Cornell, Fort Collins, Gothenburg, Liverpool and gave talks at various institutions.

*Mikosch* became an advisor for financial stochastics in the newly founded research institute on random phenomena (EURANDOM) in Eindhoven and works part time there. He is Associate Editor of the journals “Probability Theory and Mathematical Statistics” and “Communications in Statistics - Stochastic Models”.

*Salopek* gave invited talks at an International Conference on Stochastic Models and at the 50th Anniversary of the Economics Faculty, University of Groningen.

On December 10 a mini-conference was held about Distributional Inference and Related Topics with Eaton (University of Minnesota), Zabell (Northwestern University) and Van Zwet (Leiden and EURANDOM) as main invited speakers.

Former Statistics student Arjen Hussem (now with PGGM pensionfunds, Zeist) was awarded the annual price of the Society of Pensionfunds (VB) for his Master’s thesis ‘Grondslagen toetsen - de Statistiek achter ABP-sterftetafels’. His advisors were Dehling and Schaafsma.
6 Programme 6: Computational Mechanics and Numerical Mathematics

6.1 Programme members

Dr. E.F.F. Botta
Prof.dr.ir. H.W. Hoogstraten
**Prof.dr. A.E.P. Veldman**
Dr.ir. R.W.C.P Verstappen
Dr.ir. F.W. Wubs

6.2 Promovendi, postdocs and long-time visitors

Ir.drs. J. Gerrits (Ph.D. student, SRON; supervisor: A.E.P. Veldman)
Ir.drs. G.E. Loots (Ph.D. student); supervisors: H.W. Hoogstraten, A.E.P. Veldman) Ir. E. Tiesinga (Ph.D. student, NWO; supervisors: A.E.P. Veldman, F.W. Wubs)

Collaborative Ph.D. supervision:
Ir.drs. N.M. Maurits (Biophysical Chemistry, RUG; with Veldman);
Ir. H. Scherpenkate (Chemical Engineering, RuG; with Veldman);
Ir. P.F. Rozendal (Chemical Engineering, RUG; with Hoogstraten);
Drs. M.P. de Vries (Biomedical Technology, RUG; with Veldman);
Ir. D.J. van der Wal (Chemical Engineering, RUG; with Hoogstraten).

Joint post-doc projects within RUG:
Dr. M. Hencka (Chemical Engineering, RUG; with Veldman)

*Long-time visitors*

Dr. C.-H. Lai (University of Greenwich, UK)

Promotions (Ph.D. defenses)


D.J. van der Wal, *Improving the properties of polymer blends by reactive compounding*. Promotores: prof.dr.ir. L.P.B.M. Janssen (Chemical Engi-

6.3 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 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.

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 methods (DNS) 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 (several orders of magnitude). Recent workshops in 1996-98 have revealed that, for moderate Reynolds numbers, our newly developed DNS methods can compete with current industrial flow solvers, yet yielding more accurate results. For the visualization of the large amounts of data involved we cooperate with CWI.

Another main research area concerns research into the dynamics of sloshing liquids, including the interaction between liquid and container. In cooperation with NLR and international space agencies, an experiment is being prepared with a free flying spacecraft; our group will give theoretical support. This research has already led to a spin-off in other projects featuring moving liquid boundaries, such as the study of green-water loading on ships (with MARIN) and a recently started Ph.D. project on fluid-structure interaction in arterial blood flow (with UU). Basic knowledge carrier is the in-house developed simulation method ComFlo.

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 pursued which can cover a
broad class of matrices: symmetric or non-symmetric, structured or unstructured. Current applications imply the investigation of stability (bifurcation analysis) of flow patterns in global ocean circulation (with UU-IMAU) and in laminar-turbulent flow transition.

A large number of CFD applications is supported. Next to the ones already mentioned, we report scientific projects in the areas of anatomy (arterial blood flow; with UU), chemical engineering (fluidized beds, extruder flow), biophysics (cupular and cochlear mechanics) and biophysical chemistry (self-organizing fluids). Further, in 1998 industrial projects with Wärtsilä NSD (flow problems in diesel engines), Biddle B.V. (indoor climate control), Gasunie (turbulent heat transfer) and a consortium consisting of Kvaerner-Buss, SRTC, DSM and AKZO (venturi loop reactors) deserve mentioning. Cooperation with technological institutes is strengthened through our participation in HPCN-NICE (Netherlands Initiative for CFD in Engineering). With NLR a long-year cooperation exists covering a large variety of flow problems. Cooperation with MARIN began in 1998 (roll-damping of ships, ‘green water’ loading), and has led to the funding of a Ph.D. research project on slamming to be started in 1999.

6.4 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.

J. Gerrits: Theoretical and experimental investigation of coupled liquid/solid-body dynamics of spacecraft (SloshSat experiment in cooperation with NLR, ESA and NASA).

H.W. Hoogstraten: Application of CFD techniques to problems from anatomy (arterial blood flow), chemical engineering (fluidized beds, extruder flow) and biophysics (cupular and cochlear mechanics).

G.E. Loots: Fluid-structure interaction in viscous flows, with application in hemodynamics (with UU).

E. Tiesinga: Sparse matrix solvers for continuation methods; application to bifurcation analysis of global ocean circulation (with RUU-IMAU) and laminar-turbulent flow transition.

R.W.C.P. Verstappen: Development of simulation methods for turbulent flow (direct numerical simulation DNS), analysis of DNS data.

F.W. Wubs: Development of a multi-level ILU preconditioner for sparse systems; application to eigenvalue and continuation problems.

6.5 Publications

Dissertations


Articles in scientific journals


**Articles in conference proceedings**


**6.6 Research - specific aspects**

Our research policy focuses 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 in knowledge transfer. In 1998, two out of three IWI Ph.D. projects and all five joint Ph.D. projects are being funded by either the national science foundation (NWO) or by industry. All of these projects involve cooperation
with research groups outside the discipline of mathematics. In 1999 another industry-funded IWI Ph.D. project will start (with MARIN). Other external grants awarded in 1998 (and to be carried out in 1999) are from NWO-NCF (kf 45 for parallelization of MRILU, and for making it publicly available) and from the Ministry of Economic Affairs (kf 100 for the design of air curtains, with Biddle BV).

Further, over the last four years 90\% of our Masters’ projects have been carried out in cooperation with groups outside mathematics. Half of them (about four projects per year) are sponsored by industry.

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 we have joined an EC funded network on ‘Liquid management in space’ (coordinated by the University of Bremen).

### 6.7 Further information

*Veldman* has been appointed by the Netherlands Agency for Aerospace Programs (NIVR) as a member of the Scientific Committee NIVR-NLR. Further he is a scientific consultant at the National Aerospace Laboratory NLR (Amsterdam). He has been a sub-organizer of the 11th Domain-Decomposition Conference, held July 1998 in Greenwich (UK). Also he is editor of a number of journals.

*Hoogstraten* is editor of the Journal of Engineering Mathematics.

In 1998, group members presented a total of 15 lectures on national and international conferences and workshops.
7 Programme 7: Teaching and History of Mathematics

7.1 Programme members

Dr. A. van Streun
Dr. J.A. van Maanen

7.2 Promovendi, postdocs and long-time visitors

Drs. K.A. Blom (Ph.D. student; supervisors: Van Streun and Van Maanen jointly with Broer of programme 3)

Collaborative Ph.D. projects:
J.F. Deinum (Dept. of Educational Studies, RUG; with Van Streun),
B. Zwaneveld (Dept. of Mathematics, Dutch Open University; with Van Streun),
E. Welling (TU Twente; with Van Streun),
B. van Amerom (Dept. of Mathematics, Utrecht; with Van Maanen),
S. la Bastide-van Gemert (Dept. of History, RUG; with Van Maanen)

7.3 Research Program

The programme ‘Teaching and History of Mathematics’ studies the overlap of the fields ‘Teaching’ and ‘History’ as well as both fields separately.

In the overlap the central topic is the integration of the history of mathematics in mathematics teaching. Currently research is done and set out for the next few years about the question whether introducing historical elements in the teaching of the standard curriculum at secondary school may improve this teaching. Blom focusses on this question with respect to the domain of geometry, and Van Amerom at Utrecht, who is in the pre-final stage of the research, with respect to algebra. This topic is of great international concern, since the 4-years Study of the International Commission on Mathematics Instruction (ICMI) is devoted to the “Role of the History of Mathematics in the Teaching and Learning of Mathematics”. Van Maanen is co-chairing this large project, which will report in a state-of-the-art book to the International Congress on Mathematical Education (ICME-9,
As to the separate field of ‘Teaching’ the present changes in Dutch secondary education require substantiation and critical evaluation from the side of educational research. Our programme contributes considerably to this process, as can be seen in the various topics that have been researched, and that will be continued:

– ‘Teaching plane geometry’. The report by Jacolien van Dijk and Iris Gulikers, two former students of Van Streun, has had a major influence on the development of the new national vwo-curriculum. Also Van Streun has implemented results of research done in our programme in the widely used series of secondary school books *Moderne Wiskunde*.

– The effects of graphic and symbolic calculators and software (including Cabri and Derive) in secondary education and the development of computer aided instruction (joint work with GION, the Institute of Research in Education, University of Groningen).

– Development and research of Instructional Design Models to improve the concept of the “Studiehuis” in havo-vwo (the ‘Study-house’ involves a lot of independent seat work and self-reliant learning next to classroom teaching, and is introduced in the three final years of Dutch secondary schools as of 1998).

– ‘Optional subjects’. The curriculum change in the upper secondary school (vwo) re-introduces optional subjects. The research topics involved are: “What subjects are suitable for the stream preparing for academic studies in the domain of Nature and Health?” and “What type of resource material should be available?”

The separate field of ‘History’ is continued at a slightly lower pace, because of the increasing attention for the overlap with ‘Teaching’. The themes that were researched in recent years (the Bernoulli family, the pre-history of the calculus, mathematics in the Netherlands in the 17th and 18th century), have been of continued interest. A substantial chapter in the second area will appear early 1999, another chapter in the third area is in press.

### 7.4 Research subjects

**K.A. Blom**: Re-invention of geometry; the effect of introducing historical
elements in the teaching of geometry; themes from the history of geometry, design and evaluation of classroom materials in which geometry is taught with the use of historical elements.

**J.A. van Maanen**: “Role of the History of Mathematics in the Teaching and Learning of Mathematics”; (ICMI study); history of probability theory; history and mathematics teaching.

**A. van Streun**: implementation of a new mathematics curriculum in Dutch secondary schools; self-reliance of the learner and the use of new classroom organisation and new media.

### 7.5 Publications

**Articles in scientific journals**


**Other publications**


### 7.6 Research - specific aspects

The project ‘Reinvention of geometry’, started this year, is financed for 50% by a NWO-grant.

A proposal for a grant to study the ‘Reinvention of Probability Theory and Statistics’ was submitted again this year, after rejection on formal grounds in 1997.

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The research related to the improvement of mathematics teaching has considerable impact within society, which is acknowledged by the involvement of the researchers in the design of school books, the discussions about the mathematics curriculum, and the national mathematics examinations.

7.7 Further information

Van Maanen is member of the International Commission on the History of Mathematics (Dutch representative), chair of the International Study Group on the Relations between History and Pedagogy of Mathematics, co-chair of the ICMI-Study on the 'Role of the History of Mathematics in the Teaching and Learning of Mathematics', member of the board of Gewina (the Dutch Society for the History of Medicine, Mathematics, Natural Sciences and Technical Sciences), member of the Programme Committee of the ‘Nationale Wiskundedagen’, member of the Programme Committee of the annual ‘CWI-Vakantiecursus’, and chair of the governemental committee that approves of the national Dutch mathematics examinations (havo-B and vwo-B).

Van Streun continues to work at the Department of Mathematics and Computing Science for 0.6 fte (full-time-equivalent), and is appointed for 0.4 fte at the Groningen UCLO (central institute of teacher education and training). He will therefore contribute with 0.2 fte to the research programme of the IWI.
8 Programme 8: Fundamental Computing Science

8.1 Programme members

Ir. E.J. Dijkstra (until October 1, 1998)
Prof.dr. W.H. Hesselink
Prof.dr. G.R. Renardel de Lavalette
Dr. R. Smedinga
Dr. J. Terlouw

8.2 Promovendi, postdocs and long-time visitors

Drs. H.P. van Ditmarsch (Ph.D. student; supervisor: G.R. Renardel)
Dipl.-Math. R.M. Dijkstra (Ph.D. student; supervisor: W.H. Hesselink)
Drs. J.E. Jonker (promovendus; supervisor: W.H. Hesselink)
Drs. I. Polak (Ph.D. student; supervisors: G.R. Renardel, J.T. Udding)
Drs. E.H. Saaman (Ph.D. student; supervisor: G.R. Renardel)
Dr. S. Lifsches (TCM-postdoc; supervisor: R. Smedinga)

8.3 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.

In the foundational research of this programme, the following themes are studied: lambda calculus, dynamic logic, equational reasoning, fixpoint semantics.

Lambda calculus is an abstract theory of computation: our research focuses on specific behavioural properties of computations, e.g. involving termination.

Dynamic logic is an extension of traditional predicate logic so as to reason over the effect of change (e.g. by executing a computer programme or by adding information to a knowledge base); we try to unify different proposals for such a logic.

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 we try to fill in the gap.

Fixpoint semantics is the elegant and powerful approach of defining the meaning of computer programs in mathematical terms. Dealing with recursion is the difficult part, and this involves the use of fixpoints of certain functions, i.e. values $x$ satisfying $f(x) = x$. Our work investigates the (by no means trivial) generalisation of existing methods to infinite cases.

The following research projects have a stronger focus on applicability: mechanical theorem proving, formal specification, semantics of programming languages, compiler construction, hybrid systems.

For programming methodology, we aim to contribute to the development of an effective design methodology for computer programs (sequential, parallel, and distributed). The methodology should result in a rational adaptable design with complete arguments for its correctness; when the requirements and specification change afterwards (as is often the case), the design must allow modification accordingly.

Formal specification is part of the upcoming formal methods approach in software engineering: we develop a compact and general formal specification language and software tools for developing and checking formal specifications, and apply it in case studies.

The semantics of a (programming) language is the mathematical definition of the meaning of its programs. For programming languages, there are several kinds of semantics, emphasising the operational, declarative or logical aspect of the programs. Our work focuses on the parallel programming language UNITY.

Compilers are programs that translate programs into executable machine code. With Philips Research Laboratories Eindhoven we do research on re-targetable code generation, aiming at the development of a compiler from a programming language (e.g. C or Java) to a whole variety of machines, where a compact, high-level description of the specific machine (e.g. a Pentium) acts as a parameter.

Hybrid systems are dynamical systems that combine discrete and continuous aspects, which are often studied apart. In the TMR-project ALAPEDES (The ALgebraic Approach to Performance Evaluation of Discrete Event Systems) we started research on the mathematical description of these systems.
and their control.

8.4 Research subjects

H.P. van Ditmarsch: Analysis of games using epistemic logic.
E.J. Dijkstra: Instruction selection by tree and DAG matching, an approach to the problem of re-targetable code generation.
R. Dijkstra: Computation calculus: a kind of interval temporal logic that can be used for the analysis of the parallel programming formalism UNITY.
W.H. Hesselink: Design methodology for parallel or distributed algorithms; application of programming methodology to problems in image processing; semantics of fixpoint equations.
J.E. Jonker: Knaster-Tarski’s fixpoint theorem.
S. Lifsches: Hybrid systems and related control problems using standard mathematical structures (trees, graphs) and monadic second-order logic.
I. Polak: Application of theorem provers to reasoning about DI-algebra; the use of normal forms of expressions to decide equality.
G.R. Renardel: Quantified dynamic logic; novel approach to proof theory, with a first application in equational logic.
E.H. Saaman: Specification language AFSL, including tool development and case studies.
R. Smedinga: (Logical) discrete event dynamical systems and hybrid systems; object-oriented modelling and programming.
J. Terlouw: Lambda calculus and type theories, proofs for strong normalisation; normalization for generalized labelled β-reduction by means of the successor relation method; applications in the area of functional and imperative programming.

8.5 Publications

Edited books

Articles in scientific journals


Articles in conference proceedings


Other publications


8.6 Research - specific aspects

In the Requirements Engineering programme of NWO, a tender with the title *RE for medical realtime advice systems* has been submitted by Renardel
together with dr. B. Ballast (RUG, Anesthesia) and dr. G.A.W. Vreeswijk (RUG, Cognitive Engineering). It has been accepted and will be worked out in 1999.

8.7 Further information

Hesselink was member of the Programme Committee of the conference Mathematics of Program Correctness 1998 (MPC98) in Marstrand, Sweden.

Renardel is programme leader of the HCM-project DeStijl (Design and Specification through Interfacing and Joining Languages), chairman of the board of the Dutch Research School in Logic. He was member of the Program Committee of the conference Fundamental Approaches to Software Engineering (FASE98) in Lisbon, Portugal.

Smedinga is member of the TMR-project ALAPEDES (ALgebraic Approach to Performance Evaluation of Discrete Event Systems). He was co-organizer of the Workshop on Discrete Event Systems (WODES98) in Cagliari, Italy.
9 Programme 9: High Performance Computing and Imaging

9.1 Programme members

Dr. H. Bekker (0.2 fte)
Prof.dr.sc.tech. N. Petkov
Dr. J.B.T.M. Roerdink
Dr. G. Vegter

9.2 Promovendi, postdocs and long-time visitors

P. Kruizinga (researcher, NWO, supervisor Petkov)
C. Grigorescu (Ubbo Emmius Ph.D. student, supervisor Petkov)
S.E. Grigorescu (Ubbo Emmius Ph.D. student, supervisor Petkov)
Dr. A.L. Hagen (postdoc, NWO; supervisor Vegter jointly with Broer)
Th. Lippert (Univ. of Wuppertal, external promovendus; supervisor: Petkov)
T. Lourens (Ph.D. student; supervisor Roerdink; promotor G.R. Renardel de Lavalette)
A. Meijster (Ph.D. student, supervisor Roerdink)
F. Schnorrenberg (Univ. of Cyprus, external promovendus; supervisors Petkov and Ch. Shizas)
M.A. Westenberg (Ph.D. student, supervisor Roerdink)
M. Wilkinson (postdoc, European Commission, supervisor Roerdink)

Collaborative Ph.D. projects: G. Lunter and M. van Noort of programme 3 and R. Vidunas of programme 1 (all with Vegter)

Promotions (Ph.D. defenses)


T.A. Lippert, Hyper-Systolic Parallel Computing. Promotor: prof.dr. N.
9.3 Research Program

Part of the research activities concerns the development of computer models of the visual cortex. The purpose of this research is to understand how men see and to employ principles of natural vision in artificial vision systems. The properties of grating cell operators for texture processing were studied and compared with the properties of widely used texture operators. A new quantitative comparison method, which is based on Fisher’s criterion, has been proposed for this purpose. Further research in this area focussed on the development of parallel sparse coding algorithms in analogy with the inhibition mechanisms in the primary visual cortex. A parallel version of the matching pursuit algorithm was developed. The concept of receptive fields was systematically applied in the design of an image processing system for the detection and classification of breast cancer cells, work which led to the thesis of F. Schnorrenberg that was defended in May 1998. An important contribution to the theory of parallel algorithms was done by Th. Lippert in this thesis on hypersystolic algorithms which was defended in May 1998.

In the area of image reconstruction the research concentrates on tomographic techniques, with special emphasis on efficient (parallel) computation. For the visualization of 3D data sets by direct volume rendering techniques, wavelets are being investigated. A comparison of the use of wavelets in two volume rendering methods, i.e. splatting and Fourier reconstruction, was carried out. In the area of morphological image processing, parallel algorithms for computing connected components, distance transforms and the watershed transform were studied and implemented on a shared memory computer (Cray 920). Also, theoretical problems related to similarity measures based on Minkowski addition were studied. A project was started (ADIAC, 7 European partners, funded by the European Commission) on automatic identification of diatoms (unicellular algae) using morphological image analysis schemes. A new project was initiated on pattern detection and estimation in functional neuroimaging, within the context of GNIP (Groningen NeuroImaging Project) and in collaboration with the Academic Hospital (AZG) and the local research school BCN (Behavioural, Cognitive and Neurosciences).

Recent 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, in the tradition of Computer Aided Geometric Design. On the theoretical side progress has been made in the study of spline spaces. A general framework has been developed, generalizing and simplifying several of the classical results and algorithms of, e.g., De Casteljau and De Boor in CAGD. This research is applied in the project on computation and visualization of invariant manifolds in dynamical systems (cooperation with H.W. Broer, M. van der Put and co-workers), and in ongoing research with groups in France (J.-D. Boissonnat, M. Pocchiola).

9.4 Research subjects

H. Bekker: problems related to similarity measures based on methods from mathematical morphology (Minkowski addition).

C. Grigorescu: sparse coding of natural images using the matching pursuit algorithm; graph-based approaches.

S.E. Grigorescu: applying a new method for the comparison of texture operators and features to a broader class of texture operators.

A.L. Hagen: algorithms for invariant manifolds, numerical and computational issues; general applicability and visualization.

P. Kruizinga: texture analysis properties of grating cells.

Th. Lippert: design of hypersystolic parallel algorithms.

T. Lourens: biologically plausible system for corner-based object recognition from color images.

A. Meijster: parallel implementation of morphological image operators on shared memory computers.

N. Petkov: parallel algorithms for sparse image coding; design of hypersystolic parallel algorithms; non-linear texture operators.

J.B.T.M. Roerdink: mathematical morphology; parallel watershed algorithms; wavelet based volume rendering; medical image processing.

F. Schnorrenberg: image processing system for detection and classification of breast cancer cells.

M.A. Westenberg: scientific visualization (direct volume rendering) using wavelets.

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

9.5 Publications

Dissertations


Edited books


Articles in scientific journals


Contribution to books


Articles in conference proceedings


9.6 Research - specific aspects

Foundation National Computing Facilities granted kf 60 to a project of Petkov for the parallelisation of scientific software. The grant has been used to support the work of Kruizinga.

A project for the Internet implementation of texture processing operators has been started (Kruizinga, S.E. Grigorescu, Petkov). The aim is to implement a bank of texture processing algorithms and a method for their comparison on specific image material. This will enable researchers and
practitioners elsewhere to test, evaluate and select algorithms for their particular needs via Internet.

Vegter is *external collaborator* of the joint project *Geometrica* with INRIA-Sofia Antipolis (project Prisme), INRIA-Lorraine (project ISA) and the Ecole Normale Supérieure of Paris (équipe Géocal).

The European Commission, MAST3 programme, granted 115 kECU to Roerdink for the project ADIAC - Automatic Diatom Identification and Classification, involving seven European partners (Faro, Bern, Groningen, Madrid, Edinburgh, Newcastle-upon-Tyne, Strasbourg).


### 9.7 Further information

The organizing committee of the European Signal Processing Conference 1998 awarded the best young author paper award for EUSIPCO-98 to Arnold Meijster, for the paper ‘A disjoint set algorithm for the watershed transform’ by A. Meijster and J.B.T.M. Roerdink.

After ICPR in Brisbane Petkov visited the University of Auckland and the University of Dunedin and gave seminars.
10 Programme 10: Systems Technology

10.1 Programme members

Prof.dr.ir. L.J.M. Nieuwenhuis (Extraordinarius, full time at KPN Research)  
Dr.ir. J.A.G. Nijhuis  
Prof.dr.ir. L. Spaanenburg  
Dr.ir. J.T. Udding

10.2 Promovendi, postdocs and long-time visitors

Ir. S. Achterop (promovendus; supervisor: Spaanenburg)  
E.I. Barakova Msc. (AIO; supervisor: Spaanenburg)  
Drs. M.H. ter Brugge (Ph.D. student; supervisors: Nijhuis, Spaanenburg)  
Drs. M. Diepenhorst (Ph.D. student; supervisors: Nijhuis, Spaanenburg)  
Ir. W.J. Jansen (IMPACTs, promovendus; supervisors: Nijhuis, Spaanenburg)  
Drs. W.C. Mallon (Ph.D. student; supervisors: Udding, Spaanenburg)  
Drs. J.H. Stevens (Holec, promovendus; supervisors: Spaanenburg, Nijhuis)  
Drs. M. van Veelen (Ph.D. student; supervisors: Nijhuis, Spaanenburg)  
Drs. R.S. Venema (Ph.D. student; supervisors: Spaanenburg and Dehling)  
Ir. W.P. de Waard (KPN Research) (external promovendus, supervisor: Spaanenburg)  
Collaborative Ph.D. project: Dipl.-Ing. S. Hafner (Bosch) (promovendus; supervisor: Kistner, collaboration with Spaanenburg).

Dr. H.M. Groenboom (postdoc, HSA; supervisor: Udding)

Long-time visitors

W. Peng Msc. (Zhengzhou Institute, TCC; supervisor: Nijhuis)

Promotions (Ph.D. defenses)

10.3 Research Program

The accelerated pace of microelectronic developments makes information-processing systems increasingly hard to design, test and maintain. Such systems will be based on distributed computing, either in a network of computers or in an ensemble of computing elements. The processed data range from sensors to multi-media systems and are distributed over the system parts. The programme aims to research tools, methods and standards that allow to raise the quality of such designs.

In the section “Intelligent modeling” the structured design of intelligent systems, based on neural networks and fuzzy logic, is researched. The main thrust is currently in the on-line handling of information from a variety of knowledge sources for natural processes. The nature of learning problems is identified by Barakova, while the concepts for the underlying object-orientation are specified by Jansen. Venema will apply these theoretical advances for use in time-series prediction, while Diepenhorst focusses on their hardware relevance. This line of research has spawned a patent application on fuzzy/neural knowledge merging.

Another and related direction in the research on “Intelligent modelling” aims to extract knowledge from images through the use of fuzzy logic and neural networks. It has been shown that images specified by morphological expressions can be transformed to cellular neural networks. Ter Brugge is investigating a further automation of this kind of technology mapping, while Achterop is rather oriented towards formalizing the hardware/software trade-off. Meanwhile, Stevens is looking at annealing de-fuzzification techniques to handle poor quality images, as are often resulting from non-obtrusive medical monitoring. Two patent application on annealing de-fuzzification have been filed.

Where sofar system complexity was viewed as a problem in intelligent information processing, the section “Embedded systems” aims to exploit process algebras for the formalisation of inter-process communication. Mallon has designed an operational semantic for DI-algebra and is currently extending this work towards the symmetrical DI-model of Verhoeff. Part of this work is in cooperation with SUN Microsystems and offers a growing set of automated design & verification tools. Groenboom is formalising an asynchronous software- architecture for embedded systems (SPLICE) in cooperation with HSA.
In the long run, the formal and the intelligent approach are meant to become ingredients in the design of complex multi-media and/or data-mining systems. Such a complex assembly will occur in the maturization of Electronic Commerce. The coming years will therefore show an in-flow of the theoretical developments in formal communication and local intelligence to the benefit of managing process interaction in distributed computing.

10.4 Research subjects

S. Achterop: functional languages for the CoDesign of microelectronic systems.
M.H. ter Brugge license-plate recognition system; structured mapping of morphological specifications on CNN functions.
H.M. Groenboom: formalization of an asynchronous software-architecture for embedded systems (SPLICE) using a process algebra.
W.C. Mallon: designed an operational semantic for DI-algebra; symmetrical DI-model of Verhoeff.
L.J.M. Nieuwenhuis: Distributed Computing.
W. Peng: DSP code generation for intelligent software.
L. Spaanenburg: intelligent software agents for network computing, such as large-scale data-mining in Electronic Commerce.
J.H. Stevens intelligent systems for the 3-D diagnosis of scoliosis patients; dynamic optimisation of geometrical objects with fuzzy relations.
J.T. Udding: Embedded systems, process algebras for flexible factory automation.
M. van Veelen: on-line training of neural networks.
W.P. de Waard: intelligent functions for printed (and lately also cursive) word recognition.
10.5 Publications

Dissertations


Articles in scientific journals


Articles in conference proceedings


**Other publications**


### 10.6 Research - specific aspects

*Externally funded research*

In 1997 the Research & Consultancy Center IMPACTs was founded with support of the regional EEC stimulation fund ISP. In 1998 IMPACTs has been active in the ADAPT-project STIBT for the dissemination of technological knowledge to regional SME’s. Within and independent from this project a number of small-scale feasibility studies have been performed, notably in the area of telemetry and of intelligent control.

Meanwhile the larger research programs with HSA and HOLEC Projects have been continued. The system for real-time license-plate recognition has been re-engineered and field-tested. Current performance widely exceeds
the 85% recognition rate at 0.001% error rate as demanded by the Dutch government. Today this VIPUR system is one of the four systems actually tested for public acceptance.

The basic clustering and classification technology has been extended for fuzzy structure descriptions in a project for 3D-diagnosis of scoliosis. Further a proposal for document management has been a finalist in the New Venture’98 competition. STW has granted funds to organize expert workshops in new neural technologies.

**External contacts**

In 1998 the contacts with the universities in Bremen (Germany), Rostock (Germany), Iasi (Rumenia) and Budapest (Hungary) / Berkeley (USA) have been intensified to create a more formal cooperation in Ph.D. student and staff exchange in 1999.

From the EEC we received funds out of the ADAPT and the regional stimulation programs. Further W. Peng has received a scholarship to finance the continuation of his scientific work at Groningen University till 2001.

### 10.7 Further information


*Spaanenburg* is on the Executive Committee of MicroNeuro, Granada (Spain); Institute for Programming and Algorithmics (IPA); Vereniging Artificiële Neurale Netwerken (VANN, president); KIVI-Noord; and RuG Lustrum 1999 Committee (Scientific Track).

He was on the Programme Committee of Umweltinformatik UI’98, Bremen (Germany); and Nederlandse AI Conferentie NAIC’98, Amsterdam.

He is on the Editorial Board of VLSI Design Journal, Gordon and Breach Publishers; and (past) Integration, Elsevier Science Publishers.

He is also member of KIVI Raad voor Wetenschap en Techniek; VDI/GMA Fachausschuss 4.5 “Neuronale Netze”; ITG Fachgruppe 8.4.9 ”Mikroelektrotechnik neuronaler Netze”; Colleghie Ubbo Emmius; and IEEE TC on
CNN.
And finally, he is reviewer of: Design Automation Conference; Workshop on Real-Time Systems; Journal of Systems Architecture; and IEEE Transactions on Circuits and Systems I.

Udding was on the Programme Committee of International Symposium on Advanced Research in Asynchronous Circuits & Systems. He is reviewer of Information Processing Letters; Formal Methods in System Design; Journal of the ACM; Distributed Computing; and Science of Computer Programming.

Nijhuis is on the Editorial Board of Embedded Systems (Uitgeverij Stam); he is member of “Begeleidingscommissie ICT sectordoorklikting Noord”; he is RUG representative at TCN and finally he is reviewer of IEEE Transactions on Neural Networks; and of Neural Networks.