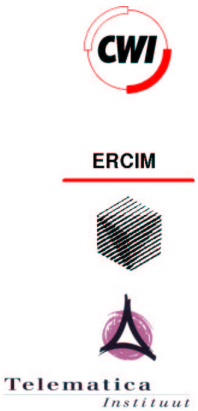
Overview Research Activities 1999



CWI is the National Research Institute for Mathematics and Computer Science. CWI is governed by the Stichting Mathematisch Centrum (SMC), the Dutch foundation for promotion of mathematics and computer science and their applications. SMC is sponsored by the Netherlands Organization for Scientific Research (NWO). CWI is a founding member of ERCIM, the European Research Consortium for Informatics and Mathematics. CWI participates in the Telematics Institute.

General Director

G. van Oortmerssen

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They can be ordered at CWI.
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PREFACE

This Overview is a supplement to CWI Annual Report 1999, which highlights CWI research in 1999. This overview reports extensively on the various activities in 1999 of CWI's four scientific clusters and their themes:

- **Probability, Networks and Algorithms – PNA**

  Themes:

  - Networks and Logic – Optimization and Programming – PNA1
  - Traffic and Communication – Performance and Control – PNA2
  - Stochastics – PNA3
  - Signals and Images – PNA4

- **Software Engineering – SEN**

  Themes:

  - Interactive Software Development and Renovation – SEN1
  - Specification and Analysis of Embedded Systems – SEN2
  - Coordination Languages – SEN3
  - Evolutionary Computation and Applied Algorithmics – SEN4

- **Modelling, Analysis and Simulation – MAS**

  Themes:

  - Environmental and Porous Media Applications – MAS1
  - Industrial Applications – MAS2
  - Mathematics of Finance – MAS3

- **Information Systems – INS**

  Themes:

  - Data Mining and Knowledge Discovery – INS1
  - Multimedia and Human/Computer Interaction – INS2
  - Interactive Information Engineering – INS3
  - Quantum Computing and Advanced Systems Research – INS4

Per cluster the following items are addressed:

- General overview;
- Staff survey;
- Survey of CWI reports published by cluster.

Per theme the following items are addressed:

- Staff (+ affiliation of seconded staff);
- Scientific report: General part + report per subtheme/project;
- PhD theses;
- Knowledge transfer;
- Organization of conferences, workshops, courses etc.,
- Visits to conferences, workshops, collquia, etc.; Working visits;
- Memberships of committees and other professional activities;
- Visitors;
- Software developed;
- Books;
- Papers in journals and proceedings;
- CWI reports (only the report numbers);
- Other publications.

PROBABILITY, NETWORKS, AND ALGORITHMS

General Overview

PNA focuses on discrete and probabilistic modelling, optimization and control (with control theory, discrete mathematics, logic, operations research, and stochastics as prime tools), and on their applications in technology and management, in particular (but not exclusively) in information technology and operations management.

The first and foremost research objective of PNA is to make fundamental and applied contributions to problems and techniques in these areas. Testing and implementing the new techniques for practical use and developing algorithms also belong to the objectives, as exemplified by participation in several externally funded application-oriented projects and a considerable number of consultancies.

As for consultancies, it is PNA's policy not to compete with other parties in the service sector, but rather to supplement them by developing innovative scientific techniques and implementing and testing them in practice. Results of PNA's research are being used in transportation (Dutch Rail, State Highways), information technology (IBM, Hewlett Packard, Philips, Microsoft), communication (KPN Research, AT&T, Bell Communications Research), public health (hospitals), environment (RIVM), seismology (Shell, KNMI), and finance (PricewaterhouseCoopers).

Much of PNA's research is on the borderline of mathematics and computer science. Examples are computational logic, computer-intensive methods in stochastics, computational complexity, fractal image coding and compression, wavelet transforms for signal analysis, morphological image processing, control of discrete-event systems and hybrid systems, performance and control of computer-communication networks, and the design of digital and VLSI circuits.

PNA maintains strong ties with academia and other research institutions. Six members hold a university professorship, while three others have other kinds of university associations. Members of PNA play an active role in several Dutch research schools, in graduate networks, and in research institutes like EURANDOM and the Telematics Institute. They present graduate courses and are involved in the organization of international conferences.

PNA receives financial support from NWO, STW, ERCIM, NATO, INTAS, and international programs with Indonesia and Hungary, for several research positions for PhD students and postdocs. In addition, the European Commission supports PNA through the Training and Mobility of Researchers (TMR) Program in the projects 'System Identification' (with CWI as coordinator) and 'Discrete Optimization Network', and through the Research Training Networks (RTN) Program in the projects 'Algorithmic Methods for Optimizing the Railways in Europe' and 'Statistical Methods for Dynamical Stochastic Models'.

Staff

- Networks and Logic – Optimization and Programming – PNA1

  - A.M.H. Gerards
  - K.R. Apt
  - M.A. Bezem
  - T. Dakic
  - T. Fleiner
  - J.H. Koolen
  - A. Kotlov
  - M. Laurent
  - J.K. Lenstra
  - E. Monfroy
  - F. van Raamsdonk
  - J.-H. Réty
  - R. Rizzi
  - A. Schrijver
  - A.G. Steenbeek

- Traffic and Communication – Performance and Control – PNA2

  - J.H. van Schuppen
  - J. van den Berg
  - S.C. Borst
  - R.J. Boucherie
  - O.J. Boxma
  - L.C.G.J.M. Habets

- B. Hanzon
- D. Jibetean
- R. Núñez Queija
- M.J.G. van Uitert

• Stochastics – PNA3

- J. van den Berg
- K.O. Dzhaparidze
- M.L. Eaton
- R. Helmers
- R. van der Horst
- M.S. Keane
- B. Lemmens
- A. Lukács
- I W. Mangku
- S. Rolles
- P.J.C. Spreij
- S.M. Verduyn Lunel
- M. Vervoort
- D. White
- J.H. van Zanten

• Signals and Images – PNA4

- H.J.A.M. Heijmans
- F.M. Dekking
- T.Q. Deng
- L. Kamstra
- M.S. Keane
- A.A.M. Kuijk
- A.J. Lenstra
- M.N.M. van Lieshout
- H.G. ter Morsche
- P.J. Oonincx
- E.J. Pauwels
- G. Piella
- B.A.M. Schouten
- A.G. Steenbeek
- N.M. Temme
- B.J. Whitcher
- P.M. de Zeeuw

• Secretaries:

- W.J.B. van Ojik
- L.M. Schultze

CWI Reports

PNA-R9901. R. Núñez Queija. *Sojourn times in non-homogeneous QBD processes with processor sharing.*

PNA-R9902. Z. Kato. *Bayesian color image segmentation using reversible jump Markov chain Monte Carlo.*

PNA-R9903. R. Núñez Queija, J.L. van den Berg, M.R.H. Mandjes. *Performance evaluation of strategies for integration of elastic and stream traffic.*

PNA-R9904. M.L. Eaton. *Markov chain conditions for admissibility in estimation problems with quadratic loss.*

PNA-R9905. H.J.A.M. Heijmans, J. Goutsias. *Multiresolution signal decomposition schemes. Part 2: Morphological wavelets.*

PNA-R9906. M.N.M. van Lieshout. *A note on the superposition of Markov point processes.*

PNA-R9907. M.A. Bezem. *Extensionality of simply typed logic programs.*

PNA-R9908. R.A. Zuidwijk, P.M. de Zeeuw. *The fast Wavelet X-Ray Transform.*

PNA-R9909. J.H. van Zanten. *On the uniform convergence of local time and the uniform consistency of density estimators for ergodic diffusions.*

PNA-R9910. A. Bedekar, S.C. Borst, K. Ramanan, P.A. Whiting, E.M. Yeh. *Downlink scheduling in CDMA data networks.*

PNA-R9911. M.R.H. Mandjes, S.C. Borst. *Overflow behavior in queues with many long-tailed inputs.*

PNA-R9912. K.O. Dzhaparidze, J.H. van Zanten. *A note on Bernstein-type inequalities for martingales.*

PNA-R9913. R. Helmers, I W. Mangku. *Statistical estimation of Poisson intensity functions.*

PNA-R9914. I W. Mangku. *Nearest Neighbor estimation of the intensity function of a cyclic Poisson process.*

PNA-R9915. R. Helmers, I W. Mangku, R. Zitikis. *Consistent estimation of the intensity function of a cyclic Poisson process.*

PNA-R9916. S.C. Borst, O.J. Boxma, P.R. Jelenković. *Asymptotic behavior of Generalized Processor Sharing with long-tailed traffic sources.*

PNA-R9917. J. van den Berg, R. Brouwer. *Random sampling for the monomer-dimer model on a lattice.*

PNA-R9918. J. van den Berg, J. Kahn. *A correlation inequality for connection events in percolation.*

PNA-R9919. P.J. Oonincx, H.G. ter Morsche. *Integral representations of affine transformations in phase space with an application to energy localization Problems.*

Networks and Logic – Optimization and Programming – PNA1

Staff

- Prof. dr. ir. A.M.H. Gerards, theme leader (until February 28: 1.0; as of March 1: 0.8 PNA1, 0.2 Eindhoven University of Technology)
- Prof. dr. K.R. Apt, senior researcher (0.8 PNA1, 0.2 University of Amsterdam)
- Dr. M.A. Bezem, (Utrecht University), senior researcher (0.6, until February 28)
- T. Dakic, PhD student (seconded by Simon Fraser University, Vancouver, Canada), September 1–December 31,
- T. Fleiner, MSc. (NWO), PhD student
- Dr. ir. J.H. Koolen, postdoc researcher (until September 15)
- Dr. A. Kotlov, (NWO), postdoc researcher
- Dr. M. Laurent (also Ecole Normale Supérieure, Paris), senior researcher
- Prof. dr. J.K. Lenstra, (Eindhoven University of Technology), senior researcher (0.2)
- Dr. E. Monfroy, postdoc researcher
- Dr. F. van Raamsdonk, (Free University, Amsterdam), senior researcher (0.2)
- Dr. J.-H. Réty, ERCIM-fellow (until July 1)
- Dr. R. Rizzi, postdoc researcher (from April to June and from November to December)
- Prof. dr. A. Schrijver, senior researcher (0.4 PNA1, 0.4 PNA, 0.2 University of Amsterdam)
- A.G. Steenbeek, programmer (0.9 PNA1, 0.1 PNA4)

Scientific Report

PNA1 focuses on fundamental and applied research in the areas of mathematical logic, combinatorics (in particular networks), optimization, algorithmics, complexity, and transportation. The problems studied originate from fields like networks, combinatorial optimization, computational logic and computational complexity, and from practice, in particular from production and transportation planning, routing, scheduling, and timetabling, and the design of VLSI-circuits.

The techniques developed make use of models and methods coming from mathematics (mathematical logic, geometry, topology, graph theory), operations research (linear and integer programming), and computer science (logic and constraint programming and complexity theory).

In 1999, the theme has started to investigate computational and combinatorial problems arising in molecular biology. The objective being to build up knowledge and to orient in this new field rich in potential applications of techniques from discrete mathematics and combinatorial optimization. M. Laurent has given a series of lectures on this topic. In 2000, L. Stougie (Eindhoven University of Technology) will join PNA1 for one day per week, in order to further strengthen the group in this research direction.

Networks & Optimization – PNA1.1

Submodular function minimization. A. Schrijver designed a new, combinatorial algorithm to find the minimum value of a submodular function.

Touching number of convex bodies and equilateral sets. The following is joint work of J. Koolen, M. Laurent and A. Schrijver. The touching number of a convex body K is defined as the maximum number of translates of K that are pairwise touching; two convex bodies being touching if they meet but their relative interiors are disjoint. For K centrally symmetric, the touching number is equal to the maximum number of equidistant points in the associated normed space having K as unit ball. Kusner (1983) conjectured that the touching number of the k-dimensional cross-polytope (the unit ball of ℓ_1-space) is equal to $2k$. Bandelt, Chepoi and Laurent (1998) have shown that the conjecture holds for $k \leq 3$ and we now settle the case $k = 4$. This conjecture is also related to determining the touching number of the simplex and to finding large antichains in designs.

l_1-embeddibility. T. Fleiner provided new insights on the l_1-embeddibility problem based on a relation with Fleiner's theorem on symmetric chain covers.

Branch width of graphs and matroids. Broadly speaking, a graph or matroid has 'small width' if it decomposes across noncrossing separations into small parts. Together with J. Geelen (University of Waterloo) and G. Whittle (Victoria University, Wellington), A.M.H. Gerards proved that a class of matroids representable over a fixed finite field and with bounded branch width is well-quasi-ordered under taking minors. This generalizes Robertson and Seymour's result that graphs with bounded tree width (or equivalently, bounded branch width) are well-quasi-ordered under taking minors.

Stability. T. Fleiner extended the stable matching theorem of Gale and Shapley to par-

tially orders and matroids. It turns out that these results, including Gale and Shapley's, follow from a fixed point theorem of Tarski. It also turned out that a theorem of Sands et al. on monochromatic paths and Pym's linking theorem can easily be derived from Tarski's theorem. Fleiner also extended the linear description of the stable matching polytope as given by Vande Vate and by Rothblum to the matroid-kernel case. T. Fleiner and R. Aharoni observed a connection between a lemma of Scarf and the topological fixed point theorem of Brouwer.

Stable sets. With M. Conforti (University of Padova), A.M.H. Gerards derived a polynomial time algorithm for the stable set problem in cap-free graphs without even holes. The algorithm is based on a decomposition theorem for these graphs by Conforti, Cornuéjols, Kapoor, and Vušković and uses novel decompositions techniques.

Hypercubes. A. Kotlov proved that every collection of $2^{d-1}+1$ nodes in the d-dimensional hypercube contains a subcollection that meets every facet of the hypercube and induces a connected subgraph in the skeleton of the hypercube. This was conjectured by Alon, Seymour, and Thomas in 1990. Further, such a subcollection can be chosen of size $O(1.5^d)$.

Using a simple construction, A. Kotlov proves that for every bipartite G the strong product of G and K_2 is a minor of the Cartesian product of G and K_2. In particular, the d-dimensional hypercube has a complete minor on $2^{(d+1)/2}$ vertices if d is odd, and on $3 \cdot 2^{(d-2)/2}$ vertices if d is even.

It was conjectured by I. Havel in 1984 and proved by L. Nebeský in 1988 that a subdivision of a star, i.e. a tree with exactly one vertex of degree greater than two, is a spanning tree of the d-dimensional hypercube if and only if some trivially-necessary conditions are satisfied. Recently, Kobeissi and Mollard made a similar conjecture for more complicated trees. A. Kotlov settled their conjecture.

Graph colouring. Kotlov proved that the complement of minimal counterexample to Hadwiger's conjecture has a matching of size $\lfloor n/2 \rfloor$ (with n the number of vertices). This implies the result of T. Gallai (1963), that the chromatic number of such a counterexample is at most $\lceil n/2 \rceil$. Further, the forementioned complement is homeomorphic to a three-connected graph and has tree width at least four. The same holds for minimal counterexamples to Colin de Verdière's conjecture. The proofs of these results use the Gallai-Edmonds structure theorem. A. Kotlov also provided a short proof of that result.

Triangluations of spheres and balls. A. Kotlov proved the conjecture of Aharoni and Chudnovsky that every triangulation of the $(d-1)$-sphere can be extended to a triangulation of the d-dimensional ball by a (possibly empty) sequence of adding a vertex of degree at most $2d$. (The special case $d = 3$ was settled by A. Kotlov and Aharoni.) Kotlov also proved that a triangulation T of the $(d-1)$-sphere is can be extended to a triangulation of the d-dimensional ball by adding vertices of degree at most $2d-1$ if and only if it is contained in a triangulation of d-dimensional ball whose one-skeleton is equal to that of T.

Random walks. Using a mixture of linear algebra and statics, A. Kotlov derives for the context of mechanical systems a generalization of the Coppersmith-Tetali-Winkler identity $H(i,j) + H(j,k) + H(k,i) = H(j,i) + H(k,j) + H(i,k)$ for hitting times of a random walk.

Cuts in graphs. R. Rizzi strengthened and generalized results of Nagamochi, Ono and Ibaraki concerning the efficient implementation of legal ordering algorithms for minimum cut problem based on multiple node-identifications in legal order computations.

Constraint and Integer Programming – PNA1.2

K.R. Apt worked on a number of aspects of constraint programming. In particular, he generalized his previous work on uniform approach to constraint propagation to deal with more specialized algorithms. To this end he extended the previously proposed framework by considering the notions commutativity and semi-commutativity of the scheduled functions. This allowed him to show how the well-known AC-3, PC-2, DAC and DPC (directed) arc and (directed) path consistency algorithms are instances of a single generic algorithm. He presented these results in an invited talk during the Fifth International Conference on Principles and Practice of Constraint Programming. A full version of the paper was submitted for publication.

K.R. Apt and *E. Monfroy* studied constraint satisfaction problems that are based on predefined, explicitly given finite constraints. To solve them they proposed a notion of rule consistency that can be expressed in terms of rules derived

from the explicit representation of the initial constraints. They illustrated the usefulness of this approach to constraint propagation by discussing the implementations of both algorithms and their use on various examples, including Boolean constraints, three valued logic of Kleene, constraints dealing with Waltz's language for describing polyhedral scenes, and Allen's qualitative approach to temporal logic. A paper on this subject was presented during the Fifth International Conference on Principles and Practice of Constraint Programming

ALMA-0 is a small programming language that provides a support for declarative programming within the imperative programming framework. It is obtained by extending a subset of Modula-2 by a limited number of features inspired by the logic programming paradigm. It was introduced in the 1998 paper that appeared in the ACM TOPLAS. In a joint paper with A. Schaerf, the co-designer of the language, Apt discussed the rationale for the design of Alma-0, the benefits of the resulting hybrid programming framework, and the current work on adding constraint processing capabilities to the language. A paper on this subject appeared in a volume entitled 'Correct System Design'.

E. Monfroy studied several aspects of constraint propagation. He realized a solver for numeric constraints based on chaotic iteration and interval arithmetic. The idea is to improve performances by applying functions that are gradually more and more stronger, till enforcing box consistency, a local consistency for numeric constraints.

E. Monfroy and *J.-H. Réty* worked on distributed and parallel aspects of propagation. A mathematical framework, asynchronous iterations, was designed in order to adapt chaotic iterations to parallel computation. Two algorithms devoted to specific hardware architectures were realized. E. Monfroy also developed a coordination-based algorithm for chaotic iterations. This algorithm overcomes problems that are inherent to the two above mentioned algorithms: it is more flexible, scalable, dynamic, and it provides a kernel in which strategies and new features can be integrated. C. Ringeissen (INRIA-Lorraine) and E. Monfroy also worked on rule-based constraint solving to extend the syntax of rules used for propagation and to perform rule-based solver extensions. With Carlos Castro (LORIA Nancy), E. Monfroy designed a framework for writing solvers and solver collaborations with a reduced control language based on filters, sorters, separators and strategy operators.

Logic programming. F. van Raamsdonk and S. Etalle (Maastricht University) propose an extension of logic programming where the user can specify, together with the initial query, the information he is interested in by means of a request. This allows one to extract a result from an incomplete computation, such as the prefix of an infinite derivation. The classical property of independence of the selection rule does not hold anymore. It is shown that under mild conditions a class of selection rules can be identified for which independence holds.

Lambda calculus and type theory. The Calculus of Inductive Constructions (CIC) is a powerful type system, featuring dependent types and inductive definitions, that forms the basis of proof-assistant systems such as Coq and Lego. F. van Raamsdonk extended CIC with constructor subtyping a basic form of subtyping in which an inductive type A is viewed as a subtype of another inductive type B if B has more elements than A. F. van Raamsdonk and G. Barthe (INRIA Sophia-Antipolis) show that the calculus is well-behaved and provides a suitable basis for formalizing natural semantics in proof-development systems.

Term-rewriting. F. van Raamsdonk, J.W. Klop (SEN2), and R.C. de Vrijer (Free University, Amsterdam) work on coinduction and infinitary rewriting.

Work on books

- K.R. Apt co-edited the book *The Logic Programming Paradigm: a 25 Years Perspective*, see page 13 for the complete title.
- A. Schrijver continued finishing his book *Polyhedral Combinatorics*. A.M.H. Gerards and M. Laurent continued working on a book on binary spaces and optimization.

Knowledge Transfer

- Cooperation between CWI and LCN Planning/Scheduling BV: E. Monfroy.
- Graduate course 'Combinatorial Optimization I', Landelijk Netwerk Mathematische Besliskunde, Fall: M. Laurent.
- Minicourse 'Introduction to Combinatorial Optimization' at Ecole d'hiver sur les telecommu-

nications, Antibes, France, December 6–10: M. Laurent.

- K.R. Apt and A. Schrijver are part-time Professor at the University of Amsterdam.
- A.M.H. Gerards is part-time Professor at the Eindhoven University of Technology.

Organization of Conferences, Workshops, Courses, etc.

- Twenty-Fourth Conference on the Mathematics of Operations Research, Lunteren, The Netherlands, January 12–15: A.M.H. Gerards, member Organizing Committee.
- 7th European Symposium on Algorithms, Prague, Czech Republic, June 9–11: J.K. Lenstra, member Programming Committee.
- 4th Workshop on Models and Algorithms for Planning and Scheduling Problems, Renesse, The Netherlands, June 14–18: J.-K. Lenstra chair Program and Organizing Committee.
- 4th Joint ERCIM/Compulog Workshop on Constraints, Paphos, Cyprus, September 25–27: K.R. Apt, E. Monfroy.
- Workshop on Polyhedral and Semidefinite Programming Methods, The Fields Institute for Research in Mathematical Sciences, Toronto, Canada, November 1–6: A. Schrijver.
- 11th Benelog, Annual Benelux Meeting on Logic Programming, Maastricht, The Neterlands, November 5: K.R. Apt, F. van Raamsdonk.
- Workshop on verification of logic programs, Las Cruces, New Mexico, USA, December 1: F. van Raamsdonk.
- Twenty-Fifth Conference on the Mathematics of Operations Research, Lunteren, The Netherlands, January 11–14, 2000: A.M.H. Gerards, member Organizing Committee.
- SODA 2000, Eleventh Annual ACM-SIAM Symposium on Discrete Algorithms, January 9–11, 2000: A.M.H. Gerards, member Programming Committee.
- The 2000 CIRM-DONET Workshop on Graph Theory, Levico, Italy, May 7–12, 2000: A.M.H. Gerards, member Organizing Committee.
- IPCO 2001, Utrecht, The Netherlands, June 2001: A.M.H. Gerards, member Organizing Committee, chair Program Committee.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- Tagung 'Combinatorial Optimization', Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, January 10–16: A.M.H. Gerards, M. Laurent, J.K. Lenstra, A. Schrijver.
- Twenty-Fourth Conference on the Mathematics of Operations Research, Lunteren, The Netherlands, January 12–15: T. Fleiner, A.M.H. Gerards, J.K. Lenstra.
- DeduGIS Kick-off meeting, Venice, Italy, January 14–15: E. Monfroy.
- University of Ljubljana, Slovenia, January 21–February 7: J.H. Koolen.
- BETA Unit Management Dag, Eindhoven, The Netherlands, January 21: J.K. Lenstra.
- Technische Universität Berlin, Berlin, Germany, February 1–2: J.K. Lenstra (lecture: *Newspapers, timetables, and whizzkids*).
- Eidma minicourse 'Randomized algorithms' by N. Alon, Eindhoven University of Technology, Eindhoven, The Netherlands, February 8–12: T. Fleiner, A.M.H. Gerards, J.H. Koolen.
- Workshop on Combinatorial Optimization, Aussois, France, March 8–12: J.K. Lenstra.
- SAC99, San Antonio, Texas, USA, February 28–March 2: E. Monfroy.
- Réunion de Travail Groupe Collaboration de Solveurs, Paris, France, March 16: E. Monfroy.
- Mid Sweden University, Sundsvall, Sweden, March 22–April 5: J.H. Koolen.
- 34ste Nederlands Mathematisch Congres, Utrecht, The Netherlands, April 8–9: J.K. Lenstra.
- Tagung 'Geometrical and Topological Combinatorics', Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, April 11–17: A. Schrijver.
- School in Logic and Computation, H. Watt University, Edinburgh, Scotland, April 10–14: F. van Raamsdonk (lecture: *Higher-order rewriting*).
- University of Padova, Italy, April 14–20: A.M.H. Gerards.
- Working visit University Warsaw, Poland, May 6–17: K.R. Apt (lecture May 11: *The Alma project, or how logic can help us in imperative programming*).
- Hebrew University, Technion, University of Tel Aviv, Israel, May 9–31: A. Kotlov.

- EIDMA minicourse 'Low-Rank Approximation' by Ravindran Kannan, CWI, Amsterdam, The Netherlands, May 31–June 4: T. Fleiner, J.H. Koolen, R. Rizzi.
- Workshop on Logic-Based Artificial Intelligence, Washington D.C., USA, June 14–16: K.R. Apt. Lecture: *Formulas as Programs: a Computational Interpretation of First-Order Logic*.
- 4th Workshop on Models and Algorithms for Planning and Scheduling Problems, Renesse, The Netherlands, June 14–18: J.K. Lenstra.
- Fourth Workshop on Models and Algorithms for Planning and Scheduling Problems, Renesse, The Netherlands, June 14–18: A. Schrijver.
- Bielefeld University, Bielefeld, Germany, June 14–24: J.H. Koolen.
- JFPLC'99, Lyon, France, June 2–4: E. Monfroy.
- ECOOP'99, Lisbon, Portugal, June 14–18: E. Monfroy.
- COTIC'99, Lisbon, Portugal, June 13: E. Monfroy.
- Conference on rewriting techniques and applications (RTA), July 2–4: F. van Raamsdonk (invited tutorial: *Higher-order rewriting*).
- Fourth International Conference on Industrial and Applied Mathematics Edinburgh, Scotland, July 4–7: J.K. Lenstra (lecture: *Whizzkids: two exercises in computational discrete optimization*).
- Eidma minicourse 'Quaternary Codes and Sequences' by P.V. Kumar, Eindhoven University of Technology, Eindhoven, The Netherlands, June 7–11: J.H. Koolen.
- University of Ljubljana, Slovenia, June 19–July 2: J.H. Koolen.
- Fourth Slovene International Conference in Graph Theory, Bled, Slovenia, June 28–July 2: T. Fleiner, J.H. Koolen, A. Kotlov, R. Rizzi.
- Paul Erdős and his mathematics, Budapest, Hungary, July 4–11: T. Fleiner, A. Kotlov.
- PSI'99, Novosibirsk, Akademgorodok, Russia, July 6–9: E. Monfroy.
- Working visit to the University of Victoria, Canada, August 4–28: K.R. Apt.
- Algebraic and Geometric Combinatorics Conference, Oisterwijk, The Netherlands, August 12–16: J.H. Koolen, A. Kotlov.
- University of Padova, Italy, August 16–September 3: A.M.H. Gerards.
- High Performance Methods in Optimization, Eindhoven University of Technology, The Netherlands, September 1: M. Laurent.
- DMV-Jahrestagung, Mainz, Germany, September 6–9: A. Schrijver.
- Troelstra Symposium, Noordwijkerhout, The Netherlands, September 16–18: K.R. Apt.
- Workshop on Spation-Temporal Models and Languages (STDML'99) Florence, Italy, August 30–31: E. Monfroy.
- DEXA'99, Florence, Italy, August 30–September 3: E. Monfroy.
- DeduGIS meeting, Florence, Italy, September 1: E. Monfroy.
- Workshop 'Wiskundige methoden voor het ontwerpen van dienstregelingen', TRAIL Research School, Delft, The Netherlands, October 4: A. Schrijver.
- EIDMA-Lustrumcongres, Mierlo, The Netherlands, October 7–8: A.M.H. Gerards, A. Schrijver.
- Fifth International Conference on Principles and Practice of Constraint Programming, Alexandria, Virginia, USA, October 11–15: K.R. Apt (invited lecture: *The rough guide to constraint propagation*), E. Monfroy.
- Tagung 'Graph Theory', Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, October 17–23: A.M.H. Gerards, A. Koltov, A. Schrijver.
- 4th ERCIM/COMPULOG Workshop on Constraints, Paphos, Cyprus, October 25–27: K.R. Apt, E. Monfroy.
- Workshop on Scheduling in Computer and Manufacturing Systems, Schloss Dagstuhl, Germany, October 25–29: J.K. Lenstra.
- ERCIM 10th Anniversary Celebration Meeting, Amsterdam, The Netherlands, November 4: K.R. Apt.
- 'AMORE'-meeting, University of Konstanz, Konstanz, Germany, October 31–November 2: A.M.H. Gerards.
- The Fields Institute for Research in Mathematical Sciences, Toronto, Canada, October 30–November 26: T. Fleiner.
- Workshop on Polyhedral and Semidefinite Programming Methods, The Fields Institute for Research in Mathematical Sciences, Toronto, Canada, November 1–6: T. Fleiner, A. Schrijver.
- INFORMS Conference, Philadelphia, USA, November 7–10: J.K. Lenstra.
- The Fields Institute for Research in Mathematical Sciences, Toronto, Canada, November 10–21: A.M.H. Gerards.

- University of Waterloo, November 22–December 5: A.M.H. Gerards.
- Informatica Instituut, Universiteit Utrecht, November 25: J.K. Lenstra (lecture: *De strijd tegen de complexiteit*).
- 11th Benelog, Annual Benelux Meeting on Logic Programming, Maastricht, The Netherlands, November 5: K.R. Apt, E. Monfroy, F. van Raamsdonk.
- Tagung 'Transport and Traffic Optimization', Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, November 7–13: A. Schrijver.
- Sixteenth International Conference on Logic Programming (ICLP 99), Las Cruces, New Mexico, USA, November 29–December 4: K.R. Apt (lecture: *The Alma Project, or how first-order logica can help us in imperative programming*), F. van Raamsdonk.
- Workshop 'Matchings, Matroids and Extensions', University of Waterloo, Canada, December 6–11: A.M.H. Gerards.
- Philips Workshop on Scheduling and Resource Management SCHARM'99, Eindhoven, The Netherlands, December 7–8: J.K. Lenstra (lecture: *Deterministic scheduling: The mystical power of twoness*).
- Workshop on Parity and Connectivity, Bonn, June 18–24: T. Fleiner, R. Rizzi.
- Working visit in Grenoble, at IMAG, Laboratoire Leibniz, August 22–September 5: T. Fleiner.

Memberships of Committees and Other Professional Activities

PhD Committees

- W.H.M. Raaymakers (September 10, Eindhoven University of Technology): J.K. Lenstra.
- J.P. Warners (September 14, Eindhoven University of Technology): J.K. Lenstra.
- A.M.C.A. de Koster (November 4, Maastricht University): J.K. Lenstra.
- E. de Kock (December 15, Eindhoven University of Technology): J.K. Lenstra.
- S.R. Tiourine (September 21, Eindhoven University of Technology): A.M.H. Gerards, J.K. Lenstra (thesis advisor).

Organizational Activities

- Association for Logic Programming: K.R. Apt, President.
- BETA, Onderzoekschool voor Business Engineering & Technology Applications: J.K. Lenstra, member Management Team.
- European Association of Computer Science Logic: M.A. Bezem, President.
- Member ESPRIT working group TYPES (21900): M.A. Bezem.
- EIDMA – Euler Institute for Discrete Mathematics and Its Applications: A. Schrijver, member Board.
- ERCIM Working Group on Constraints: K.R. Apt, chairman; E. Monfroy, secretary.
- Institute for Operations Research and the Management Sciences: J.K. Lenstra, director.
- INFORMS Journal on Computing: J.K. Lenstra, chair Review and Search Committee.
- KNAW Akademie Raad voor de Wiskunde: J.K. Lenstra, member Board, A. Schrijver, member.
- KNAW Akademie Raad voor de Wiskunde-Commissie Toekomst Wiskunde onderzoek in Nederland: A.M.H. Gerards.
- Koninklijke Nederlandse Akademie van Wetenschappen: A. Schrijver, member.
- Landelijk Netwerk Mathematische Besliskunde: A.M.H. Gerards, J.K. Lenstra, A. Schrijver, member Governing Board.
- Mathematical Programming Society: J.K. Lenstra, chair Nomination Committee; A. Schrijver, member Symposium Advisory Committee.
- NWO, Gebiedsbestuur Exacte Wetenschappen, Adviescommissie Wiskunde: J.K. Lenstra.
- Society for Industrial and Applied Mathematics: J.K. Lenstra, jury SIAM Activity Group on Optimization Prize.
- SOM, Onderzoekschool voor Systemen, Organisatie en Management (Groningen University): J.K. Lenstra, member Science Council.
- Stieltjes Instituut voor Wiskunde: A. Schrijver, member Science Council.
- STW-SWON Programma Wiskunde Toegepast: J.K. Lenstra, member Programme Committee.
- ERCIM Working Group on Constraints: E. Monfroy, secretary.
- Webmaster of the ALP webpage: E. Monfroy.
- Wiskundig Genootschap: J.K. Lenstra, chair.

Editorial Activities

- *ACM Transaction on Computational Logic*: K.R. Apt, editor-in-chief and founding editor.
- *ACM Journal of Experimental Algorithmics*: J.K. Lenstra, member Advisory Board.
- *Combinatorica*: A. Schrijver, editor-in-chief.
- *CWI Tracts, CWI Syllabi*: K.R. Apt, editor, A.M.H. Gerards, managing editor, J.K. Lenstra, editor.

- *Discrete Applied Mathematics*: A. Schrijver, editor.
- *Discrete Mathematics and Theoretical Computer Science*: A.M.H. Gerards, editor.
- *Excerpta Informatica*: J.K. Lenstra, member Advisory Board.
- *Fundamenta Informaticae*: K.R. Apt.
- *Handbooks in Operations Research and Management Science*, North-Holland: J.K. Lenstra, editor.
- *Information and Computation*: K.R. Apt.
- *INFORMS Journal on Computing*: J.K. Lenstra, Area Editor for Design & Analysis of Algorithms.
- *International Journal of Foundations of Computer Science*: J.K. Lenstra, associate editor.
- *Journal of Combinatorial Optimization*: A. Schrijver, advisory editor.
- *Journal of Combinatorial Theory*, Series B: A. Schrijver, editor.
- *Journal of Combinatorics, Information and System Sciences*: A. Schrijver, editor.
- *Journal of Logic and Computation*: K.R. Apt.
- *Journal of Logic Programming*: K.R. Apt.
- *Journal of Scheduling*: J.K. Lenstra, member editorial board.
- *Kluwer Series in Operations Research/Computer Science Interface*: J.K. Lenstra, member editorial Advisory Board.
- *Mathematical Programming, Series A*: A.M.H. Gerards, associate editor.
- *Mathematics of Operations Research*: J.K. Lenstra, advisory editor, A. Schrijver, associate editor.
- *MPS-SIAM Series in Optimization*: J.K. Lenstra, member Advisory Board.
- *North-Holland Mathematical Library*: A. Schrijver, advisory editor.
- *Operations Research Letters*: J.K. Lenstra, area editor for optimization.
- *SCIMA Special Series*: J.K. Lenstra, member Advisory Board.
- *SIAM Journal on Discrete Mathematics*: A.M.H. Gerards, editor, A. Schrijver, editor.
- *SIAM Monographs on Discrete Mathematics and Applications*: A. Schrijver, member editorial board.
- *Science of Computer Programming*: K.R. Apt, editor.
- *Wiley/Interscience Series in Discrete Mathematics and Optimization*: J.K. Lenstra, advisory editor.
- *Wiley/Teubner Series in Computer Science*: K.R. Apt.

Visitors

- Brian Curtin, Zürich, Switzerland, May 11–18.
- Andrea Schaerf, University of Udine, Italy, July 20–August 10.
- Jeanette Janssen, Dalhousie University, Halifax, Canada, May 1–June 30 (lecture: *List colorings and orientations*).
- Aleksandar Jurisic, Ljubljana, Slovenia, August 7–21.
- Lisa Fleischer, Columbia University, New York, USA, April 15, (lecture: *Approximating fractional multicommodity flows independent of the number of commodities*).
- B.A. Reed, Université de Paris, Paris, France, May 27.
- C.H.C. Little, Massey University, Palmerston North, New Zealand, May 25–28, (lecture: *Towards a characterisation of Pfaffian graphs*).
- Dima Pasechnik, Utrecht University, October 16, (lecture: *Bounding the size of bicliques in bipartite graphs and tensor products of semidefinite programs*).
- L. Lovász, Microsoft Research, Seattle, USA, October 14–15, (lecture: *Covering time of random walks*).

Software Developed

- CADANS, Software for timetabling, for Railned: A. Schrijver and A. Steenbeek.
- Software for scheduling of trainee posts for medical students, for Free University, Amsterdam: A. Steenbeek.

Book

The Logic Programming Paradigm: A 25 Years Perspective, K.R. Apt, V. Marek, M. Truszcynski, D.S. Warren (eds.). Springer-Verlag, Artificial Intelligence Series.

Papers in Journals and Proceedings

K.R. Apt (1999). The essence of constraint propagation. *Theoretical Computer Science* **221**(1–2), 179–210.

K.R. Apt (1999). The rough guide to constraint propagation. *Proceedings of the 5th International Conference on Principles and Practice*

of Constraint Programming (CP'99), Springer-Verlag, Lecture Notes in Computer Science **1713**, 1–23 (invited lecture).

K.R. Apt, M. Bezem (1999). Formulas as programs. K.R. Apt, V. Marek, M. Truszcynski, D.S. Warren (eds.). *The Logic Programming Paradigm: A 25 Years Perspective*, Springer-Verlag, Artificial Intelligence Series, 75–107.

K.R. Apt, E. Monfroy (1999). Automatic generation of constraint propagation algorithms for small finite domains. *Proceedings of Fifth International Conference on Principles and Practice of Constraint Programming*, CP'99 Alexandria, Virginia, USA, Lecture Notes in Computer Science **1713**, 58–72.

K.R. Apt, A. Schaerf (1999). The Alma Project, or how first-order logic can help us in imperative programming. E.-R. Olderog, B. Steffen (eds.). *Correct System Design*, Springer-Verlag, Lecture Notes in Computer Science **1710**, 89–113.

R. Battiti, A.A. Bertossi, R. Rizzi (1999). Randomized greedy algorithms for the hypergraph partitioning problem. P. Pardalos, S. Rajasekaran, J. Rolim (eds.). *Proceedings of the DIMACS Workshop on Randomization Methods in Algorithm Design* (Princeton, NJ, 1997), DIMACS Series on Discrete Mathematics and Theoretical Computer Science 43, American Mathematical Society, Providence, RI, 21–35.

M.A. Bezem (1999). Extensionality of simply typed logic programs. *Proceedings of the 1999 International Conference on Logic Programming (ICLP '99)*, Las Cruces, USA, MIT Press, 395–410.

A.E. Brouwer, J.H. Koolen (1999). The distance-regular graphs of valency four. *J. Algebraic Combin.* **10**, 5–24.

M. Desrochers, C.V. Jones, J.K. Lenstra, M.W.P. Savelsbergh, L. Stougie (1999). Towards a model and algorithm management system for vehicle routing and scheduling problems. *Decision Support Systems* **25**, 109–133.

S. Etalle, F. van Raamsdonk (1999). Logic programming with requests. *Proceedings of the 1999 International Conference on Logic Programming (ICLP '99)*, Las Cruces, USA, MIT Press, 558–572.

T. Fleiner, W. Hochstättler, M. Laurent, M. Loebl (1999). Cycle bases for lattices of binary matroids with no Fano dual minor and their one-element extensions. *Journal of Combinatorial Theory B* **77**, 25–38.

T. Fleiner, T. Jordan (1999). Coverings and structure of crossing families. *Connectivity augmentation of networks: structures and algorithms* (Budapest, 1994), *Mathematical Programming Series B* **84**, 505–518.

H. van der Holst, L. Lovász, A. Schrijver. The Colin de Verdière graph parameter. L. Lovász, A. Gyárfás, G. Katona, A. Recksi, L. Székely (eds.). *Graph Theory and Combinatorial Biology*, János Bolyai Mathematical Society, Budapest, 29–85.

S. Klavzar, J. Koolen, H. Mulder (1999). Graphs which locally mirror the hypercube structure. *Inform. Process. Lett.* **71**, 87–90.

L. Lovász, A. Schrijver (1999). On the null space of a Colin de Verdière matrix. *Annales de l'Institut Fourier* **49**, 1017–1026.

E. Monfroy, C. Ringeissen (1999). An open automated framework for constraint solver extension: the SoleX approach. *Fundamenta Informatica* **39**(1–2), 167–187. Special Issue: Symbolic Computation and Artificial Intelligence.

E. Monfroy (1999). Using 'weaker' functions for constraint propagation over real numbers. *Proceedings of the 14th ACM Symposium on Computing*, SAC'99, Scientific Computing Track, San Antonio, Texas, USA, March, ACM Press, 553–559.

E. Monfroy, J.-H. Réty (1999). Chaotic iteration for distributed constraint propagation. *Proceedings of the 14th ACM Symposium on Applied Computing*, SAC'99, Artificial Intelligence and Computational Logic Track, San Antonio, Texas, USA, March 1999, ACM Press, 19–24.

E. Monfroy, J.-H. Réty (1999). Itérations asynchrones: un cadre uniforme pour la propagation de constraintes parallèle et répartie. *Proceedings of Journées Francophones de Programmation Logique et Contrainte*, Hermès, 123–137.

F. van Raamsdonk (1999). Higher-order rewriting. *Proceedings of the 10th International Conference on Rewriting Techniques and Applications (RTA '99), Trento, Italy*, Springer-Verlag, Lecture Notes in Computer Science **1631**, 220–239.

F. van Raamsdonk, P. Severi, M.H. Sorensen, H. Xi (1999). Perpetual reductions in lambda calculus. *Information and Computation* **149**(2), 173–225.

J.-H. Réty (1999). Structure analysis for hypertext with conditional linkage. *Proceedings of Hypertext '99 on Hypertext and Hypermedia (Hypertext)*, ACM digital Library, ACM, 135–136.

Romeo Rizzi (1999). Indecomposable r-graphs and some other counterexamples. *Journal of Graph Theory* **32**, 1–15.

A. Schrijver (1999). Bipartite edge-colouring in $O(\Delta m)$ time. *SIAM Journal on Computing* **28**, 841–846.

A. Schrijver, P. Seymour, P. Winkler (1999). The ring loading problem. *SIAM Review* **41**, 777–791.

CWI Reports

The following CWI report was published by a member of theme PNA1. See page 6 for the complete title of the report.

PNA-R9907

Other Publications

K. Aardal, J.K. Lenstra, F. Maffioli, D.B. Shmoys (eds.) (1999). *Selected Papers of Eugene L. Lawler.* CWI Tract 126, CWI, Amsterdam.

K.R. Apt (1999). A logical analysis of boolean constraints. *JFAK Essays Dedicated to Johan van Benthem on the Occasion of his 50th Birthday*, Amsterdam University Press, Vossiuspers (cd-rom).

K.R. Apt (1998). Book review of *Programming With Constraints: An Introduction.* K. Marriott, P.J. Stuckey (eds.). The MIT Press, *Artificial Intelligence in Medicine*, **16**, 315–319.

S. van Vlijmen, S. Klusener, A. Schrijver (1999). The compact dynamic bus station. *Electronic Notes in Theoretical Computer Science* **21**, 7, Elsevier, Amsterdam.

Traffic and Communication – Performance and Control – PNA2

Staff

- Prof. dr. ir. J.H. van Schuppen (program leader and senior researcher; part time 0.8; at TUE part time 0.2)
- Dr. J. van den Berg (researcher)
- Prof. dr. ir. S.C. Borst, (researcher, part time 0.6; part time 0.2 at TUE and 0.2 with Lucent Technologies)
- Dr. R.J. Boucherie (researcher, part time 0.4, funded by STW and affiliated with UvA)
- Prof. dr. ir. O.J. Boxma (researcher, part time 0.2 from TUE)
- Prof. dr. ir. J.W. Cohen (advisor)
- Dr. ir. L.C.G.J.M. Habets (researcher, part time 0.2 from TUE, since December 1)
- Dr. B. Hanzon (advisor, Free University, Amsterdam)
- Ms. D. Jibetean (PhD student, since April 16)
- Drs. R. Núñez Queija (PhD student)
- Drs. M.J.G. van Uitert (PhD student, since May 1)

Scientific Report

General report

The research effort of the theme is directed to fundamental and applied research in performance of queueing systems and in control and system theory. Most of the research is motivated by various forms of traffic, communication, and other engineering problems.

Traffic and communication are undergoing rapid technological changes because of the demands of modern industrial societies and because of the availability and low cost of computers and communication hardware. The high performance standards motivate research on performance analysis and control synthesis. Motivating engineering problems include: Communication and computer networks (ATM, B-ISDN, IP, LANs, wireless); freeway traffic (ramp-metering, routing, network management); railway traffic; transportation of goods; manufacturing systems.

The research effort of 1999 in performance focused on various issues in integrated-services networks, such as queueing models with heavy tails, the delay analysis for best-effort services, and the queueing analysis of Generalized Processor Sharing mechanisms. The research effort of 1999 in control was directed to hybrid systems, to decentralized control of discrete-event systems, divergence approximation of Gaussian systems, and the stochastic realization problem for σ-algebra families.

Communication and computer networks – PNA2.1

Project LT

Spurred by recent developments in communications, there is presently much interest in the occurrence of long-range dependence, self-similarity, and heavy-tailed distributions in queueing theory. This is the central topic in project LT.

O.J. Boxma. Boxma and various co-authors have analyzed the effect of heavy-tailed input distributions on the performance of queueing systems. With Deng, he has investigated the asymptotic behaviour of a tandem queue; with Deng and Resing, a polling model has been studied; with Deng and Zwart, the waiting time distribution of an M/G/2 queue with two heterogeneous servers has been analyzed. If one server is exponential and the other has a heavy-tailed service time distribution, then the asymptotic behaviour of the waiting time distribution is completely different, depending on whether the exponential server is able to handle all offered traffic on its own or not. Boxma and Kurkova have demonstrated that a similar phenomenon occurs in the M/G/1 queue with two speeds when the service request and low-speed period distributions are heavy-tailed.

S.C. Borst, O.J. Boxma, & P.R. Jelenković. Borst, Boxma, & Jelenković (Columbia University, New York, USA) have continued the queueing analysis of long-tailed traffic sources under the Generalized Processor Sharing (GPS) discipline. GPS-based scheduling algorithms, such as Weighted Fair Queueing, have emerged as important mechanisms for accommodating heterogeneous quality-of-service requirements in integrated-services networks.

The results show a sharp dichotomy in qualitative behaviour, depending on the relative setting of the weight parameters. In certain cases, an individual source with long-tailed traffic characteristics is effectively served at a *constant* rate, which may be interpreted as the maximum feasible average rate for that source to be stable. Asymptotically, the source is then only affected by the traffic characteristics of the other sources through their average rate. In particular, the source is essentially immune from excessive activity of sources with 'heavier'-tailed traffic characteristics.

In other scenarios, however, a flow may be strongly affected by the activity of 'heavier'-tailed flows, and may inherit their traffic characteristics, causing induced burstiness. The stark contrast in qualitative behaviour illustrates the crucial importance of the setting of the weight parameters in protecting individual flows.

O.J. Boxma & D. Perry. Boxma and Perry have continued their study of fluid queueing models in which the buffer content varies linearly during periods that are governed by a semi-Markov process. In addition, they are analyzing a class of queueing models in which the workload is 'cleared' at random times that may be determined by the workload value.

Project BEST

R. Núñez Queija. The research on the performance analysis of data transfers in modern telecommunication systems has been carried on, resulting in a PhD thesis. The results are of interest not only for the ABR (Available Bit Rate) service, which was designed to accommodate data transfers in ATM (Asynchronous Transfer Mode) networks, but also for data transfers (or, more generally, *elastic* traffic services) in other network types such as the Internet. The integration of elastic traffic with other services (including *real-time* services such as telephony and interactive video applications) is studied through *processor-sharing* models with varying service capacity. With processor sharing, individual elastic traffic flows get equal portions of the total available capacity.

A first detailed study of sojourn times of customers in a processor-sharing queue subject to service interruptions was accepted by the journal *Queueing Systems* for publication in 2000. A continuation of the research on sojourn times when the service fluctuations have a more general structure was presented in a CWI report (PNA-R9901) and was submitted for publication. Numerical experiments for a communication system with integrated elastic and real-time services (joint work with Dr. J.L. van den Berg and Dr. M.R.H. Mandjes of KPN Research) were presented at the 16th International Teletraffic Congress.

An important issue in the modelling of modern telecommunications is the fact that service requirements tend to have a heavy-tailed distribution (see also the project *LT* above). For the processor-sharing model with service interruptions and a heavy-tailed service requirement distribution, Núñez Queija showed that the tail

of the sojourn time distribution is as heavy as the tail of the service requirement distribution. This extends Zwart and Boxma's result for the processor-sharing model with constant service capacity. The existing analytic methods seem inappropriate to tackle the case with service interruptions, therefore a new probabilistic method was developed. The new approach proved to be a powerful alternative for the case with constant service capacity. It could be used to prove the 'tail equivalence' of the sojourn time and service requirement distributions not only for the processor-sharing discipline, but also for the *Foreground Background Processor Sharing* (FBPS) and the *Shortest Remaining Processing Time First* (SRPT) disciplines. Papers with these results will be submitted for publication in a journal.

Project QoS

M.J.G. van Uitert. Van Uitert carried out research at CWI from May 1. The main research topic is the analysis of scheduling mechanisms in integrated-services networks. In particular, Van Uitert and Borst have studied GPS networks with heavy-tailed input and extended the results obtained for a single-node model by Borst, Boxma and Jelenković mentioned above.

They analyzed the tail behaviour of the workload distribution of a particular flow i with heavy-tailed traffic characteristics at the Nth node on its path. Two network configurations are considered, (i) other flows join the path of flow i and (ii) flows can branch off at any node, with cross traffic as a special case. Under certain conditions they prove that the tail behaviour of the workload distribution of flow i is equivalent to the tail behaviour of the workload distribution in a *two-node* tandem queue where flow i is served in isolation at constant rates depending only on the average rates of the other flows.

Project MOBILECOM

R.J. Boucherie & O.J. Boxma. The STW project *Stochastic network analysis for the design of self-optimising cellular mobile communications systems* investigates the relation between mobility of users and capacity required in cellular mobile networks. Within this project call blocking probabilities and capacity allocation policies have been investigated both for systems in equilibrium and for systems with parameters varying in time. Furthermore, fair channel sharing policies for circuit switched data services (HSCSD) and packet switched data services (GPRS) have been studied.

Research not associated with any particular project within PNA2.1

J. van den Berg. Van den Berg's activities are primarily reported under PNA3. In particular the following two of his research activities are of interest for PNA2: Random Sampling and Self-organized criticality.

S.C. Borst. Bedekar, Borst, Ramanan, Whiting, and Yeh have identified optimality properties for scheduling downlink transmissions to data users in CDMA data networks.
Borst, Mandelbaum, and Reiman have obtained rules for determining the staffing level in call centers so as to optimally balance the salary cost of agents against the quality-of-service experienced by customers.

O.J. Boxma. Adan, Boxma, and Resing have prepared an invited survey on the analytic solution of queueing models with multiple waiting lines.

Traffic networks – PNA2.2

Project CONTROL

J.H. van Schuppen. As part of EU Project VHS, a case study of a hybrid system has been studied. A piecewise-linear hybrid system model of a juice processing plant has been developed. Control problems for this system have been formulated and require further study. A deliverable of the project has been written.

A tutorial paper on modelling and control of hybrid systems has been written and submitted for publication.

In cooperation with the postdoc A. Al-Falou (University of Groningen) a study was started of hierarchical control of discrete-event systems and of hybrid systems.

L.C.G.J.M. Habets and J.H. van Schuppen. A fundamental study has been started of piecewise-linear hybrid systems. This class is a subclass of the class of piecewise linear systems introduced by E.D. Sontag. Polydral sets and algorithms for these sets have been studied. The investigation is being continued.

Project DACCORD

J.H. van Schuppen. The project has been formally terminated on February 28. During 1999 lectures on the project have been presented on the

project at several meetings and universities. The investigation on the existence of Nash equilibria for games of route control has been continued.

Control and system theory – PNA2.3

Project RESI

J.H. van Schuppen. Research on the approximation problem was continued on the approximation problem of stationary Gaussian processes by the output of a time-invariant finite-dimensional Gaussian system, according to the divergence rate criterion. With Dr. L. Baratchart (INRIA Sophia Antipolis) an investigation has been started on the infimization problem, about the analytic and topological properties of the first order conditions. Further work is required.

Research was continued on the stochastic realization problem for σ-algebra families. A characterization has been obtained for minimality of a σ-algebra that makes two σ-algebras conditional independent. These conditions admit a system theoretic interpretation. In addition, a necessary and sufficient condition has been formulated for a σ-algebra family to satisfy the condition of a stochastic system. From this characterization follow several properties of stochastic systems. A paper was submitted to a conference and has been accepted for publication.

Project *RESI* is financially supported by the European Commission through the Program Training and Mobility of Researchers (TMR) and Project System Identification (SI). The financial support is primarily for visiting postdocs and PhD students.

Project SICA

D. Jibetean, B. Hanzon. Together with Dr. R.L.M. Peeters (University of Maastricht) investigations were started in application of techniques from constructive and computer algebra to several problems in the area of system identification, including optimal model order reduction, identifiability analysis and optimization problems arising in this field.

PhD Theses

R. Núñez Queija. *Processor-Sharing Models for Integrated-Services Networks.* It will be defended on January 20, 2000.

Knowledge Transfer

- CWI in Bedrijf, October 9. S.C. Borst (presentation).
- SCHARM '99 workshop, Philips Research Labs, Eindhoven, December 8–9. S.C. Borst (mini-course), O.J. Boxma (mini-course).

Organization of Conferences, Workshops, Courses, etc.

- Twenty-Fourth Conference on the Mathematics of Operations Research (Lunteren, January 12–15): S.C. Borst, A.M.H. Gerards, L.C.M. Kallenberg.
- Queueing Colloquium (CWI, February 24): S.C. Borst.
- 2nd International Workshop on Hybrid Systems – Computation and Control (HSCC'99), March 29–31. Workshop Chairmen were Prof. F.W. Vaandrager (KUN) and J.H. van Schuppen. There were 72 participants.
- EURANDOM workshop 'Heavy tails and queues' (Eindhoven, April 12–16): O.J. Boxma, J. Wessels.
- Course Control of discrete-event systems of the Belgian Graduate Program in Systems and Control, University of Leuven, Leuven, Belgium, from 23 April till 12 May, J.H. van Schuppen (co-lecturer).
- Queueing Colloquium (CWI, October 27): S.C. Borst.
- EURANDOM workshop 'The stochastics of integrated services communication networks' (Eindhoven, November 15–17): O.J. Boxma, J. Wessels.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- Twenty-Fourth Conference on the Mathematics of Operations Research, Lunteren, January 12–15: R.J. Boucherie, S.C. Borst, O.J. Boxma, R. Núñez Queija.
- Participation in meeting of Project VHS, Grenoble, France, January 27–29, J.H. van Schuppen.
- Working visit Univ. Osnabrück, February 11–12: O.J. Boxma (lecture).
- Queueing Colloquium, CWI, Amsterdam, February 24: S.C. Borst, R.J. Boucherie, O.J. Boxma, J.W. Cohen, R. Núñez Queija.
- Working visit KPN Research, Leidschendam, March 12: R. Núñez Queija.

- Working visit Bell Laboratories, Murray Hill NJ, USA, March 22, March 26–April 2: S.C. Borst.
- Infocom '99 Conference, New York NY, USA, March 23–25: S.C. Borst.
- Working visit Universities of Tel-Aviv, Haifa, Hebrew University of Jeruzalem, March 23–30: O.J. Boxma (lectures).
- Participation in the Symposium State of the art in probability and statistics, University of Leiden, March 23–24: J.H. van Schuppen.
- Participation in the 2nd Workshop Hybrid Systems – Computation and Control (HSCC'99), Berg en Dal, The Netherlands, March 29–31 J.H. van Schuppen (Workshop Co-Chairman and Chairman of two sessions).
- Participation in 34$^{\text{th}}$ Nederlands Mathematisch Congres and Symposium Wiskunde Toegepast, University of Utrecht, Utrecht, 8 April, R.J. Boucherie, J.H. van Schuppen. Lecture by J.H. van Schuppen *Dynamic routing control of motorway networks.*
- EURANDOM workshop 'Heavy tails and queues', Eindhoven, April 12–16: R.J. Boucherie, S.C. Borst (lecture), O.J. Boxma (org.), J.W. Cohen, R. Núñez Queija.
- Participation in the Expert-Workshop Traffic Control, Department of Civil Engineering, Delft University of Technology, April 26: J.H. van Schuppen.
- Working visit Technion, Haifa, Israel, May 16–23: S.C. Borst.
- Participation in the System Theory Day, Department of Mathematics, University of Groningen, May 19: J.H. van Schuppen.
- Participation in meeting of project VHS, Bad Malente – Gremsmühlen, Germany, May 15–18: J.H. van Schuppen. Lecture *VHS Case Study 4.*
- 16th Int. Teletraffic Congress, Edinburgh, June 7–11: R.J. Boucherie (lecture), S.C. Borst (lecture), O.J. Boxma, R. Núñez Queija (lecture).
- Participation in the DISC Summer School on Identification for control, June 21–24: Veldhoven, The Netherlands: D. Jibetean.
- Working visit to the Department of Computer Science, University of Oldenburg, Oldenburg, Germany, July 12–13: J.H. van Schuppen. Lecture *Control and system theory of hybrid systems.*
- Applied Probability Conference, Ulm, Germany, July 26–28: R.J. Boucherie (lecture), O.J. Boxma (lecture), R. Núñez Queija (lecture), M.J.G. van Uitert.
- Participation in the Workshop on the Dynamics of Switching, Université de Liège, Liège, Belgium, August 30: J.H. van Schuppen.
- Working visit to the Department of Automatic Control of the Lund Institute of Technology, Lund, Sweden, September 17: J.H. van Schuppen. External examiner of the licentiate thesis of Sven Hedlund. Lecture *Dynamic route control of motorway networks.*
- Participation in the Trail Seminar 'Recent advances in traffic flow modelling and control', Delft, September 20: J.H. van Schuppen. Lecture *Dynamic route control of motorway networks.*
- Participation in the 8th ERNSI Workshop System Identification, Theoule, France, September 27–29: B. Hanzon, D. Jibetean, J.H. van Schuppen. Lecture by J.H. van Schuppen *System Identification approximation of Gaussian systems.*
- Annual meeting Belgische Vereniging voor Statistiek, Oostende, Belgium, October 7–8: O.J. Boxma (lecture).
- IMA workshop on Scaling Phenomena in Networks, Minneapolis, October 22–24, O.J. Boxma.
- Queueing Colloquium, CWI, Amsterdam, October 27: S.C. Borst (org.), R.J. Boucherie (lecture), O.J. Boxma, J.W. Cohen, R. Núñez Queija, M.J.G. van Uitert.
- Working visit to INRIA Sophia Antipolis, Sophia Antipolis, France, September 30–October 1: B. Hanzon, D. Jibetean, J.H. van Schuppen.
- Participation in the ERCIM 10th year Anniversary, Amsterdam, November 4–5: D. Jibetean, J.H. van Schuppen. Lecture by J.H. van Schuppen *Control and system theory.*
- Participation in VHS meeting, Grenoble, France, November 8–10: J.H. van Schuppen. Lecture: *Control of piecewise-linear hybrid systems.*
- Working visit to the University of Maastricht, November 8–26: D. Jibetean.
- EURANDOM workshop 'The stochastics of integrated services communication networks', Eindhoven, November 15–17: S.C. Borst (lecture), O.J. Boxma (org.), J.W. Cohen, R. Núñez Queija (lecture), M.J.G. van Uitert.
- Participation in the 38th IEEE Proceedings on Decision and Control, Phoenix, AZ, USA, December 7–10: J.H. van Schuppen. Participation in the meetings of the IEEE Control Systems Society Board of Governors and of the

IEEE Transaction on Automatic Control Editorial Board.
- Working visit to the Institute for Evolutionary Biology and Ecological Sciences of the University of Leiden, December 23: J.H. van Schuppen.

PhD students taking graduate courses

- D. Jibetean, Courses of *Dutch Institute on Systems and Control* (DISC), Mathematical models of systems, Design methods for control systems, Utrecht, September 6 through December 20.
- M.J.G. van Uitert, Courses *Landelijk Netwerk Mathematische Besliskunde*, Combinatorial Optimization 1, Stochastic Optimization 1, Utrecht, September 20 through December 6.

Memberships of Committees and Other Professional Activities

S.C. Borst:
- Professor of Stochastic Operations Research, Eindhoven University of Technology.
- Member of Technical Staff, Bell Laboratories, Lucent Technologies, Murray Hill, USA.
- Task manager 'Traffic Control, Resource Allocation and Link Dimensioning' of the project 'Quality in Future Networks' of the Telematics Institute.
- Member of IFIP Working Group 7.3.
- Associate editor of the journal *Operations Research Letters*.
- Associate editor of the journal *Performance Evaluation*.
- Member of the program committee of the SPIE '99 conference (Boston, September 1999).
- Member of the program committee of the SIGMETRICS 2000 conference (Santa Clara, June 2000).

O.J. Boxma:
- Professor of Stochastic Operations Research, Eindhoven University of Technology.
- Area editor of *Operations Research Letters*.
- Associate editor of the journals *Markov Processes and Related Fields; Mathematics of Operations Research; Performance Evaluation; Queueing Systems*.
- Member of IFIP Working Group 7.3 (also of its membership election committee).
- Project leader NWO-EW project 'Regular variation in broadband ISDN'.
- One of the leaders of the NWO-EW groot project 'Stochastic networks'.
- Member of the EURANDOM project 'Stochastic networks'.
- One of the coordinators of the STW project 'Stochastic network analysis for the design of self-optimising cellular mobile communications systems'.
- Member of the PhD committee of B. Stavrov (TUD).
- Member of the program committee of Performance '99 (Istanbul, August 1999).
- Member of the Scientific (daily) board of research school Stieltjes.
- Member of the Management Team of research school BETA.
- Member of the daily board of LNMB.
- Member TWON committee (Toekomst Wiskunde Onderzoek Nederland) of the Akademieraad Wiskunde.
- Member of the NWO-committee 'Networks'.
- Member of the 'benoemingsadviescommissie Hoogleraar Besliskunde' (VU).
- Chairman of the organizing committee of the 37th 'Mathematisch Congres' (Eindhoven, April 2001)

J.W. Cohen:
- Member of the advisory board of Telecommunication Systems.
- Honorary member of the IAC of ITC.

B. Hanzon:
- Associate professor Vrije Universiteit.

J.H. van Schuppen:
- Professor of System Theory at Eindhoven University of Technology.
- Co-Editor of the journal *Mathematics of Control, Signals, and Systems* since 1994.
- Department Editor of the journal *Discrete Event Dynamic Systems* since 1990.
- Associate Editor at Large of the journal *IEEE Transactions Automatic Control* since 1998.
- Coordinator of the Project System Identification (SI) that is financially supported by the European Commission through the Program Training and Mobility of Researchers (TMR), since 1998.
- Chairman of the Steering Committee of the ERCIM Working Group Control and System Theory, since 1995.
- Member of the PhD committees for: Dr. Y. Boers (TUE, February 18). Dr. D. Pik (VU, June 2). Dr. ir. W.R.M. Jeurissen (TUE, July 6). Dr. G. Fabian (TUE, September 1). Dr. S.P. Hoogendoorn (TUD, September 20). Dr. S. Schalk (KUB, December 17).

- Member of the Users Committee of the NWO-STW Project Stochastic network analysis for the design of self optimising cellular mobile communication systems (AEC.4412).
- Member of the Steering Committee of the International Symposia on the Mathematical Theory of Networks and Systems, since 1989.
- Member of the Steering Committee of the Workshop Series Hybrid Systems, since March 1997.
- Member of IFAC Technical Committee on Stochastic Systems, since 1994.
- Member of Scientific Committee of the Workshop on Discrete Event Systems 2000, scheduled for August 2000 (WODES2000).
- Member of the International Program Committee of the 1999 European Control Conference.
- Member of the Dutch Institute of Systems and Control (DISC), since September 1995.

Visitors

- P.A. Whiting (Bell Laboratories, Murray Hill NJ, USA), February 22–26 (lecture).
- H.J. Sussmann (Rutgers University, Piscataway, NJ, USA), July 1. Lecture presented at the Vrije Universiteit in Amsterdam.
- C.D. Charalambous (McGill University, Montréal, Quebec, Canada), July 19–22. Lecture *Multipath channel models for short-term fading.*
- A.L. Stolyar (Bell Laboratories, Murray Hill NJ, USA), November 19 (lecture).

Book

F.W. Vaandrager, J.H. van Schuppen (eds.). (1999). *Hybrid Systems: Computation and Control - Second International Workshop, HSCC'99*, Berg en Dal, The Netherlands, March 1999, Proceedings, Lecture Notes in Computer Science, Volume **1569**, Springer, Berlin.

Papers in Journals and Proceedings

A. Bedekar, S.C. Borst, K. Ramanan, P.A. Whiting, E.M. Yeh (1999). Downlink scheduling in CDMA data networks. *Proc. Globecom '99*, Rio de Janeiro, Brazil.

S.C. Borst, R.J. Boucherie, O.J. Boxma (1999). ERMR: a generalised Equivalent Random Method for overflow systems with Repacking. P. Key, D. Smith (eds.). *Teletraffic Engineering in a Competitive World*, North-Holland Publ. Cy., Amsterdam, 313–323.

S.C. Borst, O.J. Boxma, P.R. Jelenković (1999). Generalized Processor Sharing with long-tailed traffic sources. P. Key, D. Smith (eds.). *Teletraffic Engineering in a Competitive World*, North-Holland Publ. Cy., Amsterdam, 345–354.

S.C. Borst, O.J. Boxma, P.R. Jelenković (1999). Induced burstiness in Generalized Processor Sharing queues with long-tailed traffic flows. *Proc. of the 37th Annual Allerton Conference on Communication, Control, and Computing*, Urbana-Champaign, Illinois, USA.

S.C. Borst, E.G. Coffman, E.N. Gilbert, P.A. Whiting, P.M. Winkler (1999). Time-slot allocation in wireless TDMA. *Proc. Performance '99*, Istanbul, Turkey.

S.C. Borst, K.G. Ramakrishnan (1999). Optimization of template-driven scheduling mechanisms: regularity measures and computational techniques. *Journal of Scheduling* **2**, 19–33.

O.J. Boxma, J.W. Cohen (1999). Heavy-traffic analysis for the GI/G/1 queue with heavy-tailed distributions. *Queueing Systems* **33**, 177–204.

O.J. Boxma, J.W. Cohen, Q. Deng (1999). Heavy-traffic analysis of the $M/G/1$ queue with priority classes. P. Key, D. Smith (eds.). *Teletraffic Engineering in a Competitive World*, North-Holland Publ. Cy., Amsterdam, 1157–1167.

O.J. Boxma, D. Perry, F.A. van der Duyn Schouten (1999). Fluid queues and mountain processes. *Probability in the Engineering and Informational Sciences* **13**, 407–427.

J.M. van den Hof, J.H. van Schuppen (1999). Positive matrix factorization via extremal polyhedral cones. *Linear Algebra and its Appl.* **293**, 171–186.

D. Brigo, F. LeGland, B. Hanzon (1999). Approximate Filtering by Projection on Exponential Manifolds of Densities. *BERNOULLI (J. of the Bernoulli Society)* **5**, 495–534.

R.L.M. Peeters, B. Hanzon (1999). Symbolic Computation of Fisher Information Matrices for Parametrized State-Space Models. *Automatica* **35**, 1059–1071.

B. Hanzon, M. Olivi, R.L.M. Peeters (1999). Balanced Realizations of Discrete-Time Stable All-Pass Systems and the Tangential Schur Algorithm. *Proceedings of the European Control*

Conference 1999, ECC99, Karlsruhe, Germany.

R. Núñez Queija, J.L. van den Berg, M.R.H. Mandjes (1999). Performance evaluation of strategies for integration of elastic and stream traffic. P. Key, D. Smith (eds.). *Teletraffic Engineering in a Competitive World*, North-Holland Publ. Cy., Amsterdam, 1039–1050 (CWI Report PNA-R9903).

J.H. van Schuppen, A.G. Steenbeek, P.R. de Waal (1999). Variable route directives for motorway networks. *Proc. Symposium Wiskunde Toegepast*, Utrecht, The Netherlands.

J.H. van Schuppen, A.G. Steenbeek, P.R. de Waal (1999). Route control with variable route directives for motorway networks, P.H.L. Bovy, S.P. Hoogendoorn (eds.). *Recent Advances in Traffic Flow Modelling and Control*, Proceedings of the expert seminar on recent advances in traffic flow modelling and control, Delft, The Netherlands, Chapter 3.

CWI Reports

The following CWI reports were published by members of theme PNA2. See page 6 for the complete titles of the reports.

PNA-R9901 PNA-R9903 PNA-R9910
PNA-R9911 PNA-R9916

Other Publications

S.C. Borst, O.J. Boxma, P.R. Jelenković (1999). *Coupled Processors with Regularly Varying Service Times.* Memorandum COSOR 99-11, Eindhoven University of Technology.

O.J. Boxma, Q. Deng (1999). *Asymptotic Behaviour of the Tandem Queueing System with Identical Service Times at both Queues.* Memorandum COSOR 99-02, Eindhoven University of Technology, The Netherlands.

O.J. Boxma, Q. Deng, J.A.C. Resing (1999). *Polling Systems with Regularly Varying Service and/or Switchover Times.* Memorandum COSOR 99-10, Eindhoven University of Technology, The Netherlands.

O.J. Boxma, Q. Deng, A.P. Zwart (1999). *Waiting-time Asymptotics for the M/G/2 Queue with Heterogeneous Servers.* Memorandum COSOR 99-20, Eindhoven University of Technology, The Netherlands.

O.J. Boxma, I. Kurkova (1999). *The M/G/1 Queue with two Service Speeds.* EURANDOM Report 99–057.

J.J.H. Fey, J.H. van Schuppen (1999). *Verification and Control of a Juice Processing Plant – Intermediate Report.* Deliverable CS.4.1, EU ESPRIT LTR Project Verification of hybrid systems.

M.R.H. Mandjes, M.J.G. van Uitert (1999). *Transient Analysis of Traffic Generated by Bursty Sources, and its Application to Measurement Based Admission Control.* KPN report PU-99-31622, KPN Research, Leidschendam, The Netherlands.

M.J.G. van Uitert (1999). *Measurement-based Admission Control.* KPN report SV-99-31212, KPN Research, Leidschendam, The Netherlands.

Stochastics – PNA3

Staff

- Dr. J. van den Berg, senior researcher (0.9 fte, until December 1), theme leader (0.9 fte, after December 1)
- Dr. K.O. Dzhaparidze, senior researcher
- Prof. dr. M.L. Eaton, senior visitor (NWO, 1.0 fte until July)
- Dr. R. Helmers, senior researcher
- R. van der Horst, programmer (0.5 fte)
- Prof. dr. M.S. Keane, theme leader (0.8 fte, until December 1), senior researcher (0.2 fte, after December 1)
- Drs. B. Lemmens (UvA), PhD student (NWO, 0.2 fte)
- A. Lukács, postdoctoral fellow (NWO)
- I W. Mangku, PhD student (Indonesian cooperation)
- Dipl.-math. S. Rolles, PhD student (EURANDOM, 0.2 fte)
- Dr. P.J.C. Spreij (UvA), senior researcher (0.2 fte)
- Prof. dr. S.M. Verduyn Lunel (VU), advisor (0.2 fte)
- Drs. M. Vervoort, PhD student (NWO, 0,2 fte)
- D. White, PhD student (NWO, 0.2 fte, until September)
- Drs. J.H. van Zanten, PhD student (NWO, 1.0 fte)

Scientific Report

Highlights

Keane was elected in October, 1999, as foreign member of the Chilean Academy of Sciences.

The Research Training Networks Proposal 'Statistical Methods for Dynamical Stochastic Models' (Dzhaparidze, Spreij) has been accepted by the European Commission.

A proposal by *Helmers* for a PhD position in the framework of a KNAW programme (cooperation between the Netherlands and Indonesia) has been accepted.

Van den Berg has visited Georgia Institute of Technology during the spring quarter of 1999.

A project proposal by *Van den Berg*, involving a PhD position, has been accepted by NWO-GBE.

Research of J. van den Berg and A. Lukács

Van den Berg and *R. Brouwer* (student at UvA) have completed a study on random rampling, with emphasis on the monomer-dimer model. The results are reported in Brouwer's master's thesis, and in a joint paper which will appear in a special issue of the *Journal of Mathematical Physics*.

During the spring quarter Van den Berg visited Georgia Institute of Technology, where he gave a graduate course on Markov fields and phase transitions, and had many useful discussions with P. Tetali, in particular about mixing times of Markov chains.

Van den Berg and *J. Kahn* (Rutgers University) have completed a paper on a new correlation inequality which is expected to be useful in Percolation Theory.

Motivated by an article in *Science* about so-called self-organized critical behaviour of forest fires, they started to investigate new models, which on one hand are simple to describe, and on the other hand are expected to be closer to reality. To get more feeling for the models, Van den Berg and Lukács studied a one-dimensional version. Even this seemingly simple case led to an interesting and quite complicated combinatorial expression, which could be analyzed using the literature. Currently they investigate the case where the underlying spatial structure is represented by a regular tree. Computer simulations suggest a fascinating limit behaviour (when the graph is very large). Attempts to analyze the model mathematically has led to challenging problems. These models also have interesting connections with certain processes in the brain. Part of this work is joint work with Utrecht University (R. Meester).

Lukács has studied correlation inequalities of BK-type. The main goal is to further generalize Reimer's famous result. This is a very difficult problem. Another, more general, goal is to shed more light on the relations between various notions of negative dependence. Progress has been made and more results are expected.

Lukács has also revised his paper (with N. Seifter) on finite contractions of graphs with polynomial growth, which has now been accepted by *European Journal of Combinatorics*.

Research of K.O. Dzhaparidze, P.J.C. Spreij and J.H. van Zanten

The third paper in the series of introductory papers by K.O. Dzhaparidze on the mathematical background of options pricing in securities markets has been published in the CWI Quarterly. Using the material of these papers, Dzhaparidze spent the first half of this year on the preparation of a textbook 'Introduction to Option Pricing in a Securities Market' for publication in the CWI series of lecture notes. It will be published at the beginning of 2000.

Within the framework of the general theory of statistical inference for stochastic processes, K. Dzhaparidze and J.H. van Zanten completed a report (CWI report PNA-9912) on Bernstein-type inequalities. Later the material has been revised and submitted for publication to the journal 'Stochastic Processes and Applications'. Another report (CWI report PNA-9909) has been completed by J.H. van Zanten, the revised version of which has been submitted to the journal 'Statistical Inference for Stochastic Processe's under the title 'On the uniform convergence of the empirical density of an ergodic diffusion'. J.H. van Zanten has revisited his CWI report PNA-9814 and wrote a paper 'A multivariate central limit theorem for continuous local martingale's that has been accepted by the journal 'Statistics and Probability Letters'. An important extension of this work is still in progress, a number of interesting results have already been accomplished and a follow-up report by J.H. van Zanten is under preparation, with the tentative title 'The Stable CLT for Local Martingales via Embedding'. The survey paper 'Some aspects of modelling and statistical inference for financial models', by K.

Dzhaparidze, P.J.C. Spreij and J.H. van Zanten, has been accepted for publication in 'Statistica Neerlandica'. P.J.C. Spreij delivered an invited lecture on this work during the annual meeting of the Belgian Statistical Society. K. Dzhaparidze, P.J.C. Spreij and E. Valkeila (Helsinki) have continued their joint research that resulted in the work titled 'Hellinger and information processes in filtered experiments', splitted in two parts. The first part 'General concepts' can be found as Report nr: 99-18, KdV Institute for Mathematics, University of Amsterdam. The second part 'Explicit representations and example's needs a final touch. Both parts will be submitted for publication. Yet another paper, 'On exponential families of filtered statistical experiments', by the same authors is under preparation.

E. Valkeila gave a talk on their joint results at the annual workshop (recently in Freiburg) of our HCM research programme 'Statistical Inference for Stochastic Processes'. At this meeting the participant teams from Amsterdam, Berlin, Copenhagen, Freiburg, Helsinki, Padova and Paris agreed upon the Research Training Networks Proposal to the European Commision, titled 'Statistical Methods for Dynamical Stochastic Models'. This proposal has been accepted now and they will be able to officially start collaboration from May, 2000. The CWI team intends to participate in the next workshop scheduled at Padua, May 25–27, 2000.

Research of R. Helmers and I W. Mangku

Helmers published an article joint with R. Zitikis (Winnipeg) on estimating Poisson intensities, when only one realization of the Poisson process is observed. A paper on bootstrapping elementary symmetric polynomials, with A.J. van Es (Amsterdam) and M. Hušková (Prague), was accepted for publication by Statistica Neerlandica, while a revised version of a paper on rare errors will appear in Biometrika. The collaboration with B.Y.Jing (HongKong) on saddlepoint approximations and with M.Hušková (Prague) on changepoint estimation was continued (in cooperation with R.van der Horst). Helmers also worked (with R.van der Horst) on the 'Stringer bound', a well-known confidence upper bound for the total error amount in dollar-unit sampling, a topic of great relevance in statistical auditing.

I W. Mangku continued his PhD research on statistical estimation of Poisson intensity functions. Three articles were completed (reports PNA-R9913/14/15). The first of these (joint with Helmers) is an invited paper, that will appear in the Proceedings of an international conference on Mathematics and its Applications, held in Yogyakarta, Indonesia, in July. The second and third paper (the last one joint with Helmers and R.Zitikis (Winnipeg), who visited CWI for a month) were submitted for publication. Mangku gave invited talks on his work in Yogyakarta, Bandung and also in Winnipeg, where he stayed the month of November, visiting the Department of Statistics of the University of Manitoba.

Research of M.S. Keane

Keane's research in 1999 can be described in three broad classes:

1. Developments for the future

In this class, the essential thrusts were attempts to make substantial progress on known and difficult problems, notably reinforced random walks, noncommutative classification problems in ergodic theory, asymptotic number theory, and various industrial applied mathematics questions arising in collaboration with Philips Research Laboratories, Eindhoven, and Hewlett Packard Research Laboratory, Bristol. These are long-term efforts and become visible in the future in the two groups below.

2. Concrete results in preparation

In this class, provisional titles and names and locations of collaborators are listed for concrete results in various stages of preparation.

- Inference with improper priors (statistics, with M.L. Eaton (CWI, Minneapolis).
- Integer tilings by translation (number theory, with E.M. Coven (Middletown).
- Superexponential convergence in delay equations (analysis, with S.M. Verduyn Lunel, VUA and Leiden).
- Homomorphisms and isomorphisms of noncommutative Bernoulli schemes (ergodic theory, with T. Hamachi, Fukuoka).
- Metastable limit theorems for convolutions on motion groups, with applications to robotic control (probability, with D. Maslen, Dartmouth).
- Cycle times for nonexpansive maps (dynamical systems, with J. Gunawardena, Bristol, and C.T. Sparrow, King's College, Cambridge).

- Consistent polymer measures (statistical physics, with R. van der Hofstad, Delft).
- Dimension of dynamically defined fractals (dynamical systems, with M. Mori, Tokyo).

3. Completed articles, submitted or accepted for publication

- Residuality of Dynamical Morphisms, with R.M. Burton and J. Serafin, to appear in Colloquium Mathematicum (special volume).
- On Sums of Independent Pseudo-isotropic Random Vectors, with R. Ger and J. Misiewicz, to appear in Journal of Theoretical Probability.
- Maximum Likelihood Estimation in Principal Component Analysis with Noise Perturbation: a Gaussian Model, with J.-L. Philoche, submitted.

In addition, several projects are in progress as advisor for Philips Research Laboratories in Eindhoven, which will be released in due course. Keane is supervisor (or joint supervisor) of the following PhD students:

B. Lemmens (with S.M. Verduyn Lunel)
I W. Mangku (with R. Helmers)
M.Z.M. Marintcheva-Petrova (with W. Rey and P. Notten)
M. Nuyens (with A. Balkema)
S. Rolles
B.A.M. Schouten
M. Vervoort (with M. van Lambalgen)
H.van Zanten (with K. Dzhaparidze and P. Spreij)

In September 1999, D. White successfully defended his doctoral dissertation under the direction of Keane and Meester, at the University of Utrecht. This thesis contains many original ideas; perhaps the most salient is what the experts now call the DW-set (after Damien White), allowing a significant improvement (more than 50 percent) of the lower bound estimate for the Mandelbrot critical percolation probability.

Schouten and Vervoort will defend their dissertations in 2000.

Knowledge Transfer

Advisory positions M.S. Keane

- Philips Research Laboratories, Eindhoven (1 day/week)
- Hewlett-Packard Laboratory, Bristol (1 month/year)
- EURANDOM, Eindhoven (1/2 day/week)

Organization of Conferences, Workshops, Courses, etc.

J. van den Berg:

- Workshop Probability and Physics of Disordered Systems, held in Budapest, August 1999; Van den Berg and Keane were co-organizers (with D. Szász and B. Tóth (Budapest)).

M.S. Keane:

- Chair, Committee for Conferences on Stochastic Processes
- Co-organizer Bijeenkomst Stochastici, Lunteren (with De Gunst and Van Zwet)
- National Graduate Course in Ergodic Theory, Utrecht (10 lectures).

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- Invited lectures M.S. Keane: 19 lectures in Germany, England, The Netherlands, Japan, Israel, France, USA.
- Working visits M.S. Keane: Tokyo (2 weeks), Tel Aviv (1 week), Bristol (1 month), Cambridge (1 week).
- HCM workshop on Statistical Inference for Stochastic Processes, Munzingen (Freiburg), May 27–29. Lecture: *On information in posterior w.r.t. prior in filtered experiments.* (Dzhaparidze and Spreij).
- Annual Meeting of PhD Students in Stochastics, Lunteren, November 15–19, Lecture: *On the uniform convergence of local time* (Van Zanten).
- K.O. Dzhaparidze, Collaboration with the University of Helsinki: working visit Helsinki, December 14–19.
- P.J.C. Spreij, Collaboration with the University of Helsinki: working visit Helsinki, October 27–November 1.
- Annual Lunteren Stochastics meeting, November 15–17: All members (Keane co-organizer).
- P.J.C. Spreij, Eurandom, May 3–5, 8 hours of lectures on Stochastic Calculus
- P.J.C. Spreij, Annual meeting of the Belgian Statistical Society, October 7–8 (lecture).
- State of the Art in Probability and Statistics, Symposium in honour of Willem van Zwet, Leiden, March 23–26, 1999: R.Helmers, I W. Mangku.

- Working visit (+ three invited lectures) Department of Mathematics, Gadjah Mada University, Yogyakarta, Indonesia, May 2–15: R. Helmers.
- Working visit (+invited lecture) Institute of Technology, Bandung, Indonesia, May 16–18: R. Helmers.
- XX International Seminar on Stability Problems for Stochastic Models, Lublin-Naleçzów, Poland, September 5–11: R. Helmers (with lecture).
- International conference on Mathematics and its Applications, Yogyakarta, Indonesia, July 26–29: I W. Mangku (invited lecture).
- Working visit (+invited lecture) Institute of Technology, Bandung, Indonesia, August 12: I W. Mangku.
- Working visit (+invited lecture) University of Manitoba, Winnipeg, Canada, November 7–December 5: I W. Mangku.
- Working visit University Rome, 1 week in February: J. van den Berg (lecture).
- Visit Georgia Institute of Technology, April–June: J. van den Berg (graduate course, seminar talk, workshop lecture).
- Workshop Probability and Physics of Disordered Systems, Budapest, two weeks in August: Van den Berg and Keane (co-organizers), Lukács.
- Workshop Stochastic Analysis, Oberwolfach, 1 week in November: Van den Berg (lecture).
- Working visit Technical University Budapest, 1 week in November/December: Van den Berg (lecture).
- Mark Kac seminar, regular attendance: Van den Berg (lecture in February), Keane and Lukács.
- Symposium in honour of Prof. dr. P. Holewijn, VU, September 13: all members of PNA3 (Keane co-organizer).
- Visit Georgia Institute of Technology (workshop and working visit), ten days in April, A. Lukács (seminar talk).
- Working visit University of South-Carolina, Columbia (USA), 3 days in May: A. Lukács (seminar talk).

Memberships of Committees and Other Professional Activities

J. van den Berg:
- Co-organizer of a Dutch-Hungarian project supported by NWO.
- Member of the PhD committee for D. White (Utrecht).
- Chairman of the Master's thesis committee for R. Brouwer (Univ. of Amsterdam).

K.O. Dzhaparidze:
- Member of the committee FWA (Financiële Wiskunde Amsterdam).
- (with P.J.C. Spreij and J.H. van Zanten) Members of the Research Training Network DYNSTOCH.

R. Helmers:
- Stieltjes coordinator Cooperation project 'Applied Mathematics and Computational Methods' 1995–1999, between The Netherlands and Indonesia.
- Advisor PriceWaterhouseCoopers, Amsterdam
- Member Steering committee Research Statistical Auditing of the Limperg Institute, the Inter University Research Institute for Accountancy in The Netherlands.
- Participation in 'Extended Programme Applied Mathematics' 1999–2004, a follow-up cooperation project of KNAW, between The Netherlands and Indonesia.

M.S. Keane:
- KNAW, board MRI, ERCOM, CCSP, ARW.
- Coordinating Editor *Indagationes Mathematicae.*
- Editorial board of CWI Tracts & Syllabi.
- Editorial boards of other journals: *Dynamics and Stability of Systems, Journal of Probability and Mathematical Statistics*).
- PhD committees: D. White and E. van Zwet (UU).
- Gutachter Gradwerten-Kolleg Berlin, Schwerpunkt Stochastiek DFG.
- President, Committee Toekomst van de Wiskunde in Nederland.

P.J.C. Spreij:
- Chairman Stichting FWA (Financiële Wiskunde Amsterdam).
- Member of the board of the Mathematical Statistics section of the VVS (Dutch scociety for statistics and operations research).

Visitors

- P. Shields (Toledo), K. Simon (Budapest), M. Maejima (Yokohama), J. Steif (Gothenburg), I. Meilijson (Tel Aviv), B. Kitchens (Yorktown Heights), J. Serafin (Wroclaw), E. Coven (Middletown), D. Gilat (Tel Aviv), Y. Maeda (Yokohama), R. Zitikis (Ottawa).

Miscellaneous

J. van den Berg:

- Graduate course on Markov Fields and Phase Transition at Georgia Institute of Technology.
- Supervision by Van den Berg of the Master's thesis research of R. Brouwer (UvA).
- Probability course, in the fall semester at the University of Amsterdam. (This takes place in the framework of a 0.2 fte swap with P. Spreij).
- J. van den Berg and M. Keane are the Dutch coordinators for a joint NWO-OTKA grant for cooperation between Hungary and The Netherlands.

R. Helmers:

- R. Helmers wrote bookreviews on 'Bootstrap methods and their applications' by A.C.Davison and D.V.Hinkley for *Nieuw Archief voor Wiskunde* and on 'Decoupling, From Dependence to Independence' by V.H.de la Peña and E.Giné for the *Journal of the American Statistical Association.*

Papers in Journals and Proceedings

J. van den Berg, J.E. Steif (1999). On the existence and non-existence of finitary codings for a class of random fields. *Ann. Probab.* **27**, 1501–1522.

J. van den Berg (1999). On the absence of phase transition in the monomer-dimer model. *Perplexing Problems in Probability* (Festschrift in honor of Harry Kesten), 185–195, Birkhäuser.

K. Dzhaparidze (1999). Introduction to Option Pricing in a Securities Market – III: Gaussian Approximation. *CWI Quarterly* **12**(1), 23–63.

R. Helmers, R. Zitikis (1999), On estimation of Poisson intensity functions. *The Annals of the Institute of Statistical Mathematics* **51**, 265–280.

CWI Reports

The following CWI reports were published by members of theme PNA3. See page 6 for the complete titles of the reports.

PNA-R9902	PNA-R9904	PNA-R9909
PNA-R9912	PNA-R9913	PNA-R9914
PNA-R9915	PNA-R9917	PNA-R9918

Other Publications

K.O. Dzhaparidze, P.J.C Spreij (1999). Statistical methods for financial and other dynamical stochastic models. *ERCIM News* **38**, 9–10.

K. Dzhaparidze, P.J.C. Spreij, E. Valkeila (1999). *Hellinger and Iinformation Processes in Filtered Experiments, Part I: General Concepts*, KdV Institute for Mathematics, University of Amsterdam, Report nr: 99–18.

Signals and Images – PNA4

Staff

- F.M. Dekking (0.2, TU Delft), researcher
- T.Q. Deng (NUFFIC)
- H.J.A.M. Heijmans, theme leader
- L. Kamstra (NWO, from October 1), PhD student
- M.S. Keane, researcher
- A.A.M. Kuijk, researcher
- A.J. Lenstra (0.1, Eurandom), researcher
- M.N.M. van Lieshout, researcher
- H.G. ter Morsche (TU Eindhoven), researcher
- P.J. Oonincx, PhD student
- E.J. Pauwels, researcher
- G. Piella (STW, from August 1), PhD student
- B.A.M. Schouten, PhD student
- A.G. Steenbeek, programmer
- N.M. Temme, researcher (until December 31)
- B.J. Whitcher (0.2, Eurandom), researcher
- P.M. de Zeeuw, programmer

Scientific Report

General

It is being recognized increasingly that many of the problems encountered in the field of image processing and vision research cannot be 'solved' only through the development of faster hardware or more efficient algorithms, but that they require a deeper understanding of the intrinsic difficulties. The advent of the world-wide web and the problems that it poses (compression, transmission, digital watermarking, indexing and searching, etc.) has even further increased this necessity, and resulted in a growing interest in sophisticated mathematical models and theories.

The research in this theme is subdivided into four subthemes. The subtheme Coding, Indexing, and Retrieval (PNA4.1) is concerned with research issues in the area of storage, indexing,

and retrieval of visual information. In particular is directed towards the development of mathematical methodologies that enable the generation of content-based description of images. The subtheme Wavelets (PNA4.2) is concerned with research on wavelets and their applications, in particular in the area of seismic signal processing. Subtheme PNA4.3 (Morphological Image Processing) concentrates on research issues in the field of mathematical morphology, and finally, subtheme PNA4.4 (Stochastic Geometry) is concerned with modelling and analysis of random geometric structures using techniques from spatial statistics and stochastic and integral geometry.

Extensive cooperations and contacts are maintained with researchers from the academic world as well as researchers from other national institutes (KNMI, TNO) and industry. External financing comes from the Dutch NWO and STW programme, the British Council, NATO, and INTAS (sponsored by the European Commission).

Research Highlights

The employment of fractal transforms for image recognition, realized by the construction of invariant features based on statistics stemming from the fractal image transform.

The development of unsupervised image-segmentation based on nonparametric clustering in different feature-spaces.

New design methods for morphological wavelets (e.g. max-lifting scheme).

Construction of a new algebraic framework for linear and nonlinear scale-spaces

New results on statistical inference for general random set models and application of likelihood-based estimation techniques that take advantage of modern Markov chain Monte Carlo methods.

Coding, Indexing and Retrieval – PNA4.1

The ubiquity and rapid growth of digital multimedia databases has spawned a number of challenging problems regarding the indexing, storage and retrieval of information. These problems are particularly pressing for image databases as there is no general set of canonical features that adequately captures the variety and wealth of visual information. In some cases a query can be launched using keywords only, but there are a number of important applications where keywords are non-existent or of limited use and the search is primarily vision-driven. It is the explicit goal of Content-Based Image Retrieval (CBIR) to design algorithms and interfaces that will assist the user in this task. Research conducted within this subtheme addresses a number CBIR-related problems, such as image-segmentation, multi-scale and hierarchical feature extraction, indexing and similarity search.

Unless images are relatively homogeneous, global similarity matching is often too crude to produce acceptable results and segmention is an important first step to improve the accuracy of the search. For this reason, Eric Pauwels' research has concerned itself mainly with the development of a segmentation algorithm that is based on nonparametric clustering. To this end, pixels are mapped in an appropriate feature-space, whereupon nonparametric density estimation is used to extract clusters. More specifically, the aim is to find the simplest density that is still compatible with the data, and then label the clusters accordingly. Compatibility is defined in terms of the Kolmogorov-Smirnov distance between the proposed model and the observed data. This approach allows the retrieval system to identify perceptually salient regions that can be used as the starting point for a region-based similarity matching between images.

Currently, the research is focusing on the question to what extent the complementary information in edge-maps and the regions extracted by cluster-based segmentation, can be integrated to further improve the quality of segmentations.

Ben Schouten and Paul de Zeeuw examined the use of a standard fractal coding technique as a tool for the construction of hierarchical image indexing and searching schemes. Based on statistics amassed during the fractal decomposition, features have been derived invariant to perturbations like rotation, translation, folding and the application of gloss. They are currently investigating whether it is feasible to make some of the features invariant to zooming in and out as well. A feature invariance measure is introduced, which reveals the degree of invariance of a feature with respect to a database. Early experimental results look promising.

Image size reduction can be used e.g. to save screen space, for browsing, to produce multi-resolution image structures and as a preprocessing step to speed-up image processing algorithms. Image size reduction can be obtained by sampling

and filtering but also by removing less relevant outer regions (cropping). Fons Kuijk and Ben Schouten investigated autocropping on the basis of edge detection and morphological analysis. The issue was how to perform 'perception-based' image cropping (preferably non-parametric and cheap!).

Algorithms have been developed using MATLAB. MATLAB offers a gradual migration from slow experimental code to fast production code. Time-critical elements of the algorithms have been implemented in C. These algorithms have been made callable from any C program via an API and a server process. Characteristics of this MATLAB Engine server setup are:

- Fast setup of interprocess communication (< 0.01 sec.);
- Transparent distributed processing;
- C program completely shielded off from the MATLAB environment;
- Migration towards full C implementation is possible.

To accommodate experimentation a MATLAB-based graphics user interface mirroring the API has been implemented.

Wavelets – PNA4.2

The research of P.J. Oonincx has been focused on time-frequency operators that are related to affine transformations in phase space. Together with Dr. H.G. ter Morsche (TUE) he described the class of these operators and derived an integral representation for such operators. Using these operators certain energy localisation problems in phase space have been solved.

Furthermore, P.J. Oonincx completed his PhD Thesis, to be defended in February 2000.

The research of wavelet analysis for a certain geophysical application was continued. In this application the stratification of impedance beneath the earth's is to be reconstructed. Artificially invoked waves are reflected at interfaces where the impedances change rapidly. The recorded seismic data need to get rid of components that correspond to the groundmotion and blur the information of interest. An algorithm involving rotation and wavelet analysis / synthesis has been reported on. After exploration of the wavelet-Radon and two-dimensional discrete wavelet transform an approach by wavelet-packets was investigated as well. Results appear to be improving by the latter approach. The research in the phase of completion and another final report is in preparation.

Morphological Image Processing – PNA4.3

In 1998, Heijmans started a collaboration with J. Goutsias (Johns Hopkins University, Baltimore) on development of a general theory on nonlinear (in particular, morphological) multiresolution decompositions of images. One of the ambitious goals of this project is to make a systematic study of nonlinear (morphological) wavelets. Various reports and papers have been published over the past two years. Furthermore, two PhD students, Gemma Piella (from August 1 onwards, sponsored by STW) and Lute Kamstra (from October 1 onwards, sponsored by NWO) have started new research in this direction.

The work with Van den Boomgaard of the University of Amsterdam on the algebraic construction of an axiomatic framework of image scale-spaces has been continued. Two conference papers have been submitted and a technical report is to be finished very soon.

Originally, mathematical morphology was developed for binary images. By its very definition, involving the use of matching patterns called structuring elements, it treats the foreground and background of an image in a complementary fashion. This dual character of morphology was preserved when it was extended to grey-scale images. By choosing a different paradigm abandoning the a priori distinction between foreground and background, it is possible to construct a 'new morphology' which is intrinsically self-dual. Work in this direction has been initiated by Heijmans and Kresch (HP Laboratories, Haifa).

Stochastic Geometry – PNA4.4

The Boolean model is the most well-known random set, and built from mutually independent grains. However, likelihood based statistical inference for this model is largely undeveloped. To develop such a theory, Van Lieshout and Van Zwet (Utrecht, now at Berkeley) used modern Markov chain Monte Carlo methods to calculate the likelihood and perform the optimisation. The results formed part of Van Zwet's PhD thesis, which was successfully defended in September. They are currently summarising the results for publication.

In collaboration with G. Huurneman, A. Stein (Wageningen) and B.D. Whitcher (Eurandom)

the research project on denoising radar images of a region in Botswana was continued. Wavelet techniques were used to resolve the problem of speckle noise inherent in such images; multi-resolution stochastic classification methods are being implemented to segment the images according to vegetation. Lenstra has developed a theoretical framework for information bounds.

Van Lieshout and Molchanov (Glasgow) worked on optimisation problems within the framework of cluster analysis for spatial point processes. They dealt with this problem using optimisation tools in the space of measures recently developed by Molchanov and Zuyev (1997). Within this context, locations of parent points are assumed to be random and described by some finite measure that can be interpreted as intensity measure for a Poisson point process, so that the parents are located at the points of this process.

Van Lieshout proved that independent superposition of Markov point processes with respect to the same neighbourhood relation preserves the Hammersley-Clifford factorisation up to second order. If the processes are identically distributed, the third order interaction structure is preserved as well, and the superposition of standardised locally stable Markov point processes converges weakly to a Poisson process.

PhD Theses

- P.J. Oonincx, *Mathematical Wavelet Analysis: Wavelets, Wigner Distribution and a Seimic Application*, University of Amsterdam, February 2000.

Knowledge Transfer

- Heijmans has given an undergraduate course (Stochastiek voor Informatici) at the University of Leiden.
- ASCI course 'Mathematical Morphology: Principles, Algorithms and Applications', September 13–17 (3 lectures by H.J.A.M. Heijmans).
- Van Lieshout gave an undergraduate course on probability at the University of Utrecht.
- Schouten had several contacts with people from Hoogovens who are studying filliform-corrosion. This is a process in which a local corrosion cell transports through a surface in a way that is similar to Brownian Motion. Hoogovens is interested in the fractal dimension of the motion and seeks a relationship between the fractal dimension and the physical properties of the material.

Organization of Conferences, Workshops, Courses, etc.

- CWI in Bedrijf: Investment in Knowledge Infrastructure, CWI, October 8, 1999. Lecture (*Wat zien ik*) about Content Based Image Retrieval and Visual Intelligence (B. Schouten).
- INTAS workshop 'Multi-scale Image Analysis' at Minsk, Belarus, May 17. Organized by Heijmans with Alexander Tuzikov (Minsk).
- Workshop on 'Automatic multi-scale segmentation of satellite images' at Eurandom, March 5, 1999. Organized by van Lieshout
- Session on 'Simulation theory' at the 10th INFORMS Applied Probability Conference held at the University of Ulm, Germany, July 26–28, 1999. Organized by van Lieshout
- Workshop on 'Stochastic geometry' to be held at Eurandom, Spring 2000. Organized by van Lieshout
- Signals and Images Seminar, the Spatial Stochastics Seminar and the PNA colloquium (CWI Amsterdam). Organized by van Lieshout

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

H.J.A.M. Heijmans:
- MAS colloquium, CWI Amsterdam, January 11: (+ lecture)
- PNA colloquium, CWI Amsterdam, February 10: (+ lecture).
- Pattern Recognition and Image processing May 18–20, Minsk, Belarus, (plenary lecture + lecture).
- INTAS workshop 'Multi-scale Image Analysis' May 17, Minsk, Belarus, (lecture).
- Working visit to Computing Center, Moscow, May 21: (+ lecture).
- Conference VISUAL'99, Amsterdam, June 2–4.
- Working visit to Johns Hopkins University, Baltimore, USA, September 2–9.
- Workshop on 'Image Processing, Multiresolution and Statistics', Atlanta, USA, September 10–12: (+ poster).
- Working visit to HP Laboratories, Haifa, Israel, November 20–26
- Working visit to Technion, Haifa Israel, November 23: (+ lecture).

M.N.M. van Lieshout:
- Scientific Meeting, CWI, Amsterdam, February 26. Invited talk *Parameter estimation for random sets.*
- Automatic multi-scale segmentation of satellite images, Eurandom, Eindhoven, March 5. Talk *Set-geometric models in image analysis.*
- Semstat, Eurandom, Eindhoven, March 15–20.
- Symposium on the state of the art in probability and statistics in honour of Willem van Zwet, Leiden, March 23–26.
- Spatial modelling, inference and computation in image analysis, Chalmers University of Technology, Sweden, March 18–22. Invited talk *Interpolating and extrapolating spatial patterns.*
- Stieltjesmiddag, University of Amsterdam, May 31. Invited talk *Maximum likelihood estimation for Boolean models.*
- Spatial Stochastics Seminar Maximum likelihood estimation for Boolean models, June 29.
- 10th INFORMS Applied Probability Conference, University of Ulm, Germany, July 26–28. Invited talk *Interpolating and extrapolating spatial patterns.*
- Bijeenkomst Stochastici, Lunteren, November 15–17.
- Working visit to Prof. dr. I. S. Molchanov, University of Glasgow funded by an NWO/British Council fellowship, October 18–29. Invited talk *Propagation of spatial interaction under superposition.*
- Eurandom, December 10. Invited talk *Parameter estimation for random sets*

Other PNA4 members

- SHELL SIEP-RTS Symposium on P-S wave separation, Rijswijk, The Netherlands, March 30: P.J. Oonincx (invited lecture).
- Symposium Wiskunde Toegepast, Utrecht, The Netherlands, April 8: P.J. Oonincx (invited lecture).
- ICIP 99, International Conference on Image Processing, Kobe, Japan, October 24–27: B. Schouten.
- Visual 99 Third International Conference on Visual Information Systems, Amsterdam, June 2–4: B. Schouten, E. Pauwels (+presentation).
- FE 99 Fractals in Engineering, Delft, The Netherlands. June 14–16: B. Schouten (+presentation)
- Computer Center of the Academie of Sciences, Moscou, Russia, May 16–23, 1999: B. Schouten (working visit).
- Dagstuhl Workshop on Content-Based Image and Video Retrieval, Wadern, Germany, December 6–10: E. Pauwels (Invited Talk).
- FWO-workshop on Optical Appearance of Metallic Surfaces, Vrije Univ. Brussel, Belgium, December 2: (E. Pauwels).
- Eurographics '99, Milan, Italy, September 7–11: A.A.M. Kuijk.
- Woudschoten conference on numerical mathematics, Zeist, October 6–8: De Zeeuw.

Memberships of Committees and Other Professional Activities

B.A.M. Schouten:
- Proposed member for the ELINTEX committee of the European Community. Elintex is a network for the promotion of application of electronic and information technologies in the textile industry.

E. Pauwels:
- Co-advisor and Member of PhD Committee Wanda Guedens, Limburgs Universitair Centrum, Belgium.

A.A.M. Kuijk:
- Member program committee 1999 Siggraph/ Eurographics Workshop on Graphics Hardware

H.J.A.M. Heijmans:
- Member of editorial board *Journal of Mathematical Imaging and Vision.*
- Editor of electronic newsletter *Morphology Digest.*
- Editor of a special issue of *Fundamenta Informaticae* devoted on mathematical morphology (with J. Goutsias; to appear 2000).
- Coordinator of INTAS project 96–785 *Multiscale Image Analysis and Applications.*
- Member of Programme Committee of the sixth International Conference on Computer Graphics and Image Processing (GKPO2000), Podlesice, Poland, May 15–19, 2000.
- Member of Technical Committee of 15th International Conference on Pattern Recognition (ICPR'2000), Barcelona, Spain,September, 3–8, 2000.
- Member of Technical Committee of IEEE Conference on Image Processing, (ICIP 2000), Vancouver, USA, September 10–13, 2000.
- Member of Technical Committee of Fifth International Symposium on Mathematical Morphology (ISMM2000), Palo Alto, USA, June 20–28, 2000

M.N.M. van Lieshout:

- Member steering committee Complex stochastic models, Eurandom.
- Member reading committee MSc L. Spierdijk, Free University Amsterdam, June 10, 1999; *The spatial modelling of telecommunications networks, a point process approach.*
- Member reading and committee PhD committee E.W. van Zwet, Utrecht, September 3, 1999; *Likelihood devices in spatial statistics.*
- Member reading committee PhD J. Lund, The Royal Veterinary and Agricultural University Copenhagen, Denmark; *Statistical inference and perfect simulation for point processes observed with noise.*

P.M. de Zeeuw:

- Secretary Werkgemeenschap Numerieke Wiskunde.
- Editor *Het Nummer* (newsletter Werkgemeenschap Numerieke Wiskunde).

Visitors

- J.-C. Pesquet, CNRS - Université Paris Sud, June 7–11.
- J. Goutsias, Johns Hopkins University, Baltimore, USA, June 4–19.
- A. Tuzikov, Academy of Sciences, Minsk, Belarus, November 8–19.
- S.M.C. Pereira, University of Western Australia, March 12–April 4.
- I.S. Molchanov, University of Glasgow, Scotland, UK, August 23–31.
- E.H. Blake, University of Cape Town, May 31–June 25.
- V. Tsurkov, Computing Center of the Academy of Sciences, Moscow; December 15–19.

Seminar speakers

- January 19 : H. Matzinger, Eurandom
- January 26 : R. Huele, University of Leiden
- February 2 : J. Swart, University of Nijmegen
- February 9 : H. ter Morsche, Eindhoven University of Technology
- February 23 : P. van der Wal, Delft University of Technology
- March 2 : G. Alberts, University of Nijmegen
- March 9 : R. Zitikis, Ottawa
- March 30 : A. Stein, Wageningen Agricultural University
- April 27: B. Witcher, Eurandom/CWI
- May 4: M. Loewe, Eurandom
- May 11 : S. Olabarriaga, University of Amsterdam
- May 18 : P. Spreij, University of Amsterdam
- May 25 : Z. Struzik, CWI/INS1
- June 1 : R. Gill, University of Utrecht
- June 8 : J-C. Pesquet, Paris Sud
- June 15: J. Goutsias, Johns Hopkins
- June 22 : Th. Gevers, University of Amsterdam
- June 29: M-C. van Lieshout, CWI.

Software Developed

- *Fracfeat*: a textural image feature extractor (B.A.M. Schouten and P.M. de Zeeuw). The feature extractor uses the fractal transform of an image to extract information about the texture within the image. The code is under further development.

Book

O. Barndorff-Nielsen, W.S. Kendall, M.N.M. van Lieshout (1999). *Stochastic Geometry: Likelihood and Computation*, CRC Press (Chapman and Hall list), London, UK.

Papers in Journals and Proceedings

H.J.A.M. Heijmans, J. Goutsias (1999). Constructing Morphological Wavelets with the Lifting Scheme. *Pattern Recognition and Information Processing, Proceedings of PRIP'99*, Minsk, 65–72.

H.J.A.M. Heijmans (1999). Connected morphological operators for binary images. *Computer Vision and Image Understanding* **73**(1), 99–120.

H.J.A.M. Heijmans (1999). Easy recipes for morphological filters. E.R. Dougherty, J.T. Astola (eds.). *Nonlinear Filters for Image Processing*, SPIE/IEEE Series on Imaging Science & Engineering, 163–205.

H.J.A.M. Heijmans (1999). Introduction to connected operators. E.R. Dougherty, J.T. Astola (eds.). *Nonlinear Filters for Image Processing*, SPIE/IEEE Series on Imaging Science & Engineering, 207–235.

H.J.A.M. Heijmans, C. Ronse (1999). Annular filters for binary images. *IEEE Transactions on Image Processing* **8**(10), 1330–1340.

M.N.M. van Lieshout (1999). Size-biased random closed sets. *Journal of Pattern Recognition* **32**, 1631–1644.

O. Haggstrom, M.N.M. van Lieshout, J. Moller (1999). Characterisation and simulation results including exact simulation for some spatial point processes. *Bernoulli* **5**, 641–659.

W.S. Kendall, M.N.M. van Lieshout, A.J. Baddeley (1999). Quermass-interaction processes: conditions for stability. *Advances in Applied Probability (SGSA)* **31**, 315–342.

E. Thonnes, M.N.M. van Lieshout (1999). A comparative study on the power of Van Lieshout and Baddeley's J-function. *Biometrical Journal* **41**, 721–734.

M.N.M. van Lieshout, A.J. Baddeley (1999). Indices of dependence between types in multivariate point patterns. *Scandinavian Journal of Statistics* **26**, 511–532.

P.J. Oonincx (1999). A Wavelet Method for Detecting S-Waves in Seismic Data. *Computational Geosciences* **3**, 111–134.

P.J. Oonincx, S.J.L. van Eijndhoven (1999). Multiresolution Analyses in Hilbert Spaces. *Indagationes Mathematicae* **10**, 369–382.

P.J. Oonincx, R. Sleeman, T. van Eck (1999). A Wavelet Method for Detecting S-Waves. *Proceedings Symposium Wiskunde Toegepast*, Utrecht.

Ben A.M. Schouten, Paul M. de Zeeuw (1999). Feature Extraction using fractal Codes. D.P. Huijsmans, A.W.M. Smeulders (eds.). *Visual Information and Information Systems, Third International Conference, VISUAL'99*, Amsterdam, June 1999, Lecture Notes in Computer Science **1614**, Springer, Heidelberg, 483–492.

E.J. Pauwels, G. Frederix (1999). Finding Salient Regions. *Images: Nonparametric Clustering for Image Segmentation and Grouping. Computer Vision and Image Understanding* **75**, Nos 1/2, 73–85.

G. Frederix, E.J. Pauwels (1999). Automatic Interpretation based on Robust Segmentation and Shape-Extraction. *Proc. of VISUAL'99: Third International Conference on Visual Information Systems LNCS* **1614**, Amsterdam, 769–776.

E.J. Pauwels, G. Frederix (1999). Cluster-Based Segmentation of Natural Scenes. *Proc. of ICCV'99: 7th International Conference on Computer Vision*, 997–1002.

CWI Reports

The following CWI reports were published by members of theme PNA4. See page 6 for the complete titles of the reports.

PNA-R9905 PNA-R9906 PNA-R9908 PNA-R9919

Other Publications

H.G. ter Morsche, P.J. Oonincx (1999). *On the Integral Representations for Metaplectic Operators.* RANA 99-44, TU Eindhoven.

Volkskrant. *Niets is Cultuur* about the meaning of the number zero in art and science. 1-1-1999. (interview with Schouten)

SOFTWARE ENGINEERING

General Overview

'The general theme of cluster SEN is the application of fundamental research to practical problems in software engineering. The quality of scientific work is genrally excellent. The cluster as a whole is very successful in attracting external funding'.

We are pleased to be able to start our overview of SEN's activities in 1999 with the above quotation, stemming from the report of the 1999 NWO evaluation committee which reviewed mission, strategy and performance of the CWI as a whole. The four themes of SEN were ranked as follows in this assessment: SEN1 – very good; SEN2 – excellent; SEN3 – very good; SEN4 – excellent. The ranking of SEN4 contributed in a significant way to the decision to upgrade former pilot theme SEN4 to a full-fledged theme (as of September 1). We now list some further selected highlights and facts of interest:

- The SEN staff produced approximately 90 publications (in the categories *Papers in Journals and Proceedings, Reports* and *Other Publications*; several members of SEN acted – jointly with external colleagues – as editors of conference proceedings or contributed volumes (W.B. Langdon: *Advances in Genetic Programming* 3, MIT Press; W.B. Langdon: Genetic Programming, *Proc. of EuroGP '99*, Springer; S. Mauw: *CONCUR 99*, Springer; J.J.M.M. Rutten: *Proc. CMCS '99*, ENTCS). Also, W.J. Fokkink completed a book on Process Algebra (to be published in 2000 by Springer) and, jointly with coauthors, a book on the railway interlocking language LARIS (to be published in 2000 as CWI Publication).
- Three PhD degrees were awarded to SEN members: C.H.M. van Kemenade. *Recombinative Evolutionary Search*, UL (advisor J.N. Kok). J. Romijn, *Analysing Industrial Protocols with Formal Methods*, UT (advisors H. Brinksma, F.W. Vaandrager). J. Warners, *Nonlinear Approaches to Satisfiability Problems*, TUE (advisors J.F. Groote, J. van Leeuwen).
- Interaction between SEN and Dutch universities remained intensive. SEN members De Bakker, Groote, Klint and Klop had part-time positions as professor at VUA, TUE, UvA and VUA. Klop was furthermore assigned part-time to a project at KUN. Arbab and La Poutré taught courses at UL and VUA. Several researchers who have their main affiliation with some Dutch university spent part of their time on some form of assignment at a SEN theme. In 1999 these included: dr. W.J. Kowalczyk (VUA), prof. dr. J. Treur (VUA), dr. S. Mauw (TUE), dr. V. van Oostrom (UU), dr. H. Zantema (UU). Two university professors (J.A. Bergstra, UvA/UU, J.N. Kok, UL) acted as consultant to a SEN theme.
- A sizable part of SEN's research was performed in various collaborations with partners from Dutch industry (examples include CAP Gemini, ING, KPN Research, Philips Research, Signaal and Roccade). Most of this work was organized in three projects which form part of the program of the national Telematics Institute, viz. the projects
  - Domain Specific Languages (SEN1)
  - Systems Validation Centre (SEN2)
  - Autonomous Systems of Trade Agents (SEN4).
- Numerous SEN projects were funded by NWO, in particular the section on Informatics of the Physical Sciences Council. One project was completed succesfully with the PhD thesis of J.P. Warners. One project was discontinued in view of the insufficient performance of the researcher involved. Three new projects were started (R. Lämmel, M.B. de Jong, F. Alkemade), and one ongoing project (with A. Baltag

as postdoc) was extended with the appointment of a PhD student (F. Bartels). Four ongoing projects were continued (researchers W.C. de Leeuw, S.P. Luttik, M.B. van der Zwaag and R. van Stee).

- Much effort was spent on the preparations for a start-up company entitled Software Improvement Group. This activity has its roots in the work of theme SEN1; its initial focus will be on software renovation applications and document generation. Its formal incorporation is expected in the first half of 2000; it will then establish the first spin-off company of cluster SEN.

Staff

- Interactive Software Development and Renovation – SEN1

  - P. Klint
  - J.A. Bergstra
  - M.G.J. van den Brand
  - A. van Deursen
  - J. Heering
  - H. Huitema
  - M. de Jonge
  - A.S. Klusener
  - C. Konstapel
  - T. Kuipers
  - R. Lämmel
  - W.C. de Leeuw
  - R. van Liere
  - L.M.F. Moonen
  - J.D. Mulder
  - P.A. Olivier
  - E.H. Saaman
  - J. Scheerder
  - J. Visser

- Specification and Analysis of Embedded Systems – SEN2

  - J.F. Groote
  - J.A. Bergstra
  - W.J. Fokkink
  - J.W. Klop
  - I.A. van Langevelde
  - B. Lisser
  - S.P. Luttik
  - S. Mauw
  - V. van Oostrom
  - J. van de Pol
  - M.A. Reniers
  - J.M.T. Romijn
  - Y.S. Usenko
  - J.J. van Wamel
  - J. Warners
  - H. Zantema
  - M.B. van der Zwaag

- Coordination Languages – SEN3

  - J.J.M.M. Rutten
  - F. Arbab
  - J.W. de Bakker
  - A. Baltag
  - F. Bartels
  - C.L. Blom
  - M.M. Bonsangue
  - F.J. Burger
  - M. Coccia
  - C.T.H. Everaars
  - A. Fagot
  - J. den Hartog
  - A. Scutellá

- Evolutionary Computation and Applied Algorithms – SEN4

  - J.A. La Poutré
  - F. Alkemade
  - S.M. Bohté
  - M. Bot
  - D.D.B. van Bragt
  - E. Gerding
  - M.B. de Jong
  - C.H.M. van Kemenade
  - J.N. Kok
  - W.J. Kowalczyk
  - W.B. Langdon
  - J. Sprenger
  - R. van Stee
  - J. Treur
  - M.C. van Wezel
  - R.W.T. Wildenberg

- Secretary:

  - J.J. Bruné-Streefkerk

CWI Reports

SEN-R9901. J.J.M.M. Rutten. *Automata, Power Series, and coinduction: taking input derivatives seriously* .

SEN-R9902. M. de Jonge, T. Kuipers, J. Visser. *HASDF: A generalized LR-parser generator for Haskell* .

SEN-R9903. E. de Klerk, H. van Maaren, J.P. Warners. *Relaxations of the satisfiability problem using semidefinite programming* .

SEN-R9904. M.G.J. van den Brand, M. de Jonge. *Pretty-printing within the ASF+SDF meta-environment: a generic approach* .

SEN-R9905. J.F. Groote, J.P. Warners. *The propositional formula checker HeerHugo* .

SEN-R9906. M.G.J. van den Brand, P. Klint, P.A. Olivier. *Compilation and memory management for ASF+SDF* .

SEN-R9907. W.B. Langdon. *Size fair and homologous tree crossovers* .

SEN-R9908. A. van Deursen, P. Klint, C. Verhoef. *Research issues in the renovation of legacy systems* .

SEN-R9909. A. van Deursen, L.M.F. Moonen. *Understanding COBOL systems using inferred types* .

SEN-R9910. T. Arts, I.A. van Langevelde. *Verifying a smart design of TCAP A synergetic experience* .

SEN-R9911. M. de Jonge. *boxenv.sty: A LaTeX style file for formatting box expressions* .

SEN-R9912. S.P. Luttik. *Cylindric process algebras with conditionals give substitutionless μCRL* .

SEN-R9913. W.B. Langdon, R. Poli, P. Nordin, T. Fogarty. *Late-breaking papers of EuroGP-99* .

SEN-R9914.S.P. Luttik. *Complete axiomatisations of weak-, delay- and η-bisimulation for process algebras with alternative quantification over data* .

SEN-R9915. J.M.T. Romijn. *Model checking the HAVi leader election protocol.*

SEN-R9916. A. van Deursen, T. Kuipers. *Building documentation generators* .

SEN-R9917. Y.S. Usenko. *A Comparison of Spin and the μCRL toolset on the HAVi leader election protocol* .

SEN-R9918. J.M.T. Romijn, J.G. Springintveld. *Exploiting symmetry in protocol testing.*

SEN-R9919. J.M.T. Romijn. *A timed verification of the IEEE 1394 leader election protocol.*

SEN-R9920. J. Heering, P. Klint. *Semantics of programming languages: A tool-oriented approach* .

SEN-R9921. J.J.M.M. Rutten. *Coalgebra, concurrency, and control.*

SEN-R9922. A. Baltag, L. Moss, S. Solecki. *The logic of public announcements, common knowledge and private suspicions.*

SEN-R9923. A. Baltag. *Truth-as-Simulation: Towards a Coalgebraic Perspective on logic and games.*

SEN-R9924. M.M. Bonsangue, J.N. Kok. *Towards an infinitary logic of domains: Abramsky logic for transition systems.*

SEN-R9925. F. Arbab, M.M. Bonsangue, F. de Boer. *A coordination language for mobile components.*

SEN-R9926. Y. Azar, L. Epstein, R. van Stee. *Resource augmentation in load balancing.*

Interactive Software Development and Renovation – SEN1

Staff

- Prof. dr. P. Klint, theme leader
- Prof. dr. J.A. Bergstra, advisor
- Dr. M.G.J. van den Brand, project leader
- Dr. A. van Deursen, project leader
- J. Heering, project leader
- Drs. H. Huitema, PhD student
- Drs. M. de Jonge, project member (from April 1)
- C. Konstapel, student
- Dr. A.S. Klusener, postdoc (from July 1)
- Drs. T. Kuipers, project member
- Dr. W.C. de Leeuw, postdoc
- Dr. R. Lämmel, postdoc (from August 1)
- Ir. R. van Liere, project leader
- Drs. L.M.F. Moonen, project member (from April 1)
- Dr. J.D. Mulder, postdoc
- Drs. P.A. Olivier, project member (from November 1)
- Drs. E.H. Saaman, PhD student
- Drs. J. Scheerder, project member
- Drs. J. Visser, project member (from April 1)

Scientific Report

The group has continued and extended its efforts to develop advanced tools that address software engineering problems such as prototyping, program understanding, program optimization, and visualization of large software systems.

The research was concentrated in four areas: language prototyping, software renovation, optimization of software, and interactive visualization environments.

Language prototyping is based on the ASF+SDF Meta-Environment, a system for interactive language development and incremental programming environment generation. It serves as an environment for developing application languages (domain specific languages) (SEN1.1 and SEN1.5), tools for software renovation (SEN1.1), and tools for program analysis and optimization (SEN1.2). The Meta-Environment itself is also the subject of a major renovation (SEN1.4). Work on interactive visualization environments focuses on the management of scientific data and Virtual Reality (SEN1.3).

Software Renovation – SEN1.1

The objective of the software renovation group is to develop tools and techniques to support the maintenance and understanding of legacy systems.

During 1999, research focused on the area of program understanding, and addressed the following questions:

(1) What sort of information should be derived from legacy systems;
(2) How should this information be extracted from legacy systems, using parsing and lexical analysis;
(3) What filtering, abstraction, and combinations should be applied to the wealth of data that can be derived from legacy sources, using techniques such as cluster analysis, concept analysis, and type inferencing techniques;
(4) How should this information be presented to the end user, using techniques such as hypertext and graph visualization. Key element in the research on program understanding is integration: viewing a legacy system from all possibly meaningful perspectives, and combining these different views.

Part of the research on program understanding was done in collaboration with software house Roccade, which is deploying some of the techniques developed within SEN1.1 for the purpose of generating hypertext documentation from COBOL legacy systems.

Optimization of Scientific Software – SEN1.2

Bragge(UiB), Haveraaen (UiB), Heering, Visser(UU): Reimplementation of the CodeBoost source-to-source optimizer for PDE solvers written in a 'coordinate-free' style was started using Visser's Stratego system, which allows specification of the rewrite strategies to be used by the transformation rules.

Lämmel, Verhoef (UvA)—supported by NWO-EW project *Generation of Program Tranformation Systems*, which started on August 1: Work was initiated on Grammar Engineering, including systematic modification of Cobol grammars by tranformation for software renovation purposes.

Interactive Visualization Environments – SEN1.3

The objectives of the visualization group are to study, develop, and put into practice methods for interactive scientific visualization. Primary areas of interest are high performance visualization and the application of biological objects in virtual reality.

W. de Leeuw and R. van Liere continued work on novel presentation techniques for turbulent flow fields. A new method for visualizing flow topology was developed and presented.

De Leeuw continued work on the project 'Analysis of biologial structures with virtual reality techniques'. A prototype system was developed and made available to project members at the E.C. Slater Institute.

J. Mulder and R. van Liere developed a new software architecture for portable virtual reality applications. This work serves as a basis for future software developed by this group.

J. Mulder continued work on viewing methods in virtual environments. A new technique for enhancing fishtank virtual environments was developed.

H. Huitema initiated work on interactive molecular visualization in virtual environments by studying time critical solvent surface generation algorithms. This work cevolved from a joint CWI/GMD project.

R. van Liere and W. de Leeuw initiated a study on the merits of applying virtual environments to information visualization.

ASF+SDF – SEN1.4

The objective of the ASF+SDF group is to realize a redesign and reimplementation of the ASF+SDF Meta-Environment. In 1999, the efficiency of the parser generator, an ASF+SDF specification, was improved by reimplementing one of the phases in C. The implementation of the SGLR parse table interpreter was improved, in particular with respect to its handling of ambiguous grammars. A connection between the ASF+SDF interpreter and the generic debugging framework (TIDE) was established allowing us to debug ASF+SDF specifications. This has not yet been integrated in the Meta-Environment itself.

A number of other projects based on the above technology were carried out. A standalone tool for expanding RISLA financial product specifications was developed in cooperation with CAP-GEMINI, and a parser that can be accessed via the Internet was developed for CoFI, the Common Framework Initiative which is devel-

oping the CASL specification language.

Domain-Specific Languages – SEN1.5

The DSL Project is one of the projects of the Telematica Instituut. The aims of the research activities within the DSL Project are to: (1) Develop methods for selecting suitable DSL domains, and for capturing domain knowledge into a DSL and its compiler; (2) Develop metatools for the rapid prototyping of domain-specific languages; (3) Gain more experience, via case studies, with the use of domain-specific languages in a commercial setting.

In 1999, the project has resulted in (1) work on an annotated bibliography in the area of domain-specific languages, and program understanding techniques in order to distill domain knowledge from legacy systems (see also SEN1.1); (2) work on the ASF+SDF Meta-Environment to support language prototyping (see also SEN1.4); (3) case studies with industrial and academic partners. In collaboration with Lucent (Hilversum) and First Result Consultants, opportunities for regenerating existing C-code from high-level, domain-specific visual languages were investigated.

The SEN1.5 group closely cooperates with SEN1.1, SEN1.2, and SEN1.4.

Knowledge Transfer

The work of the SEN1 group is attracting more and more interest from industry. For that reason, the second half of 1999 has been used to investigate the possibilities of a spin-off company. The initial focus will be on software renovation applications, such as documentation generation. Prospects are hopeful, and it is likely that the year 2000 will see the birth of a new CWI spin-off company under the name 'Software Improvement Group'.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- *Working visit University of Rostock*, Rostock, Germany, January 14–15: M.G.J. van den Brand (*Compilation and memory management for ASF+SDF*), P. Klint (*Term rewriting for sale*).
- *CSMR '99*, Amsterdam, March 3–5: P. Klint.
- *ETAPS '99*, Amsterdam, March 20–28: M.G.J. van den Brand (*Compilation and memory management for ASF+SDF*), A. van Deursen (*Research issues in software renovation*), P. Klint (*Research issues in system renovation*), T. Kuipers, J. Scheerder.
- *Program Analysis Workshop*, Dagstuhl, Germany, April 11–16: A. van Deursen and L. Moonen (*Type inference for Cobol systems*).
- *Working visit LORIA Nancy*, Nancy, France, May 2–8: M.G.J. van den Brand, J. Scheerder.
- *Working visit INRIA Paris*, Paris, France, May 8–10: M.G.J. van den Brand.
- *ESEC/FSE '99*, PC meeting, Bern, Switzerland, May 8–18: P. Klint.
- *IWPC '99*, Pittsburgh, USA, May 5–7: A. van Deursen (*Understanding COBOL via types*), L. Moonen (*Understanding Cobol using types*).
- *ICSE '99*, Pittsburgh, USA, May 17–21: A. van Deursen, T. Kuipers (*Identifying objects using cluster and concept analysis*).
- *SSR '99*, Pittsburgh, USA, May 21–23: A. van Deursen (*Identifying objects using concept and cluster analysis*).
- *VisSym '99*, Vienna, Austria, May 26–28: W.C. de Leeuw (*Visualization of global flow structures using multiple levels of topology*), R. van Liere (*PVR: Architecture for Portable VR*).
- *E.U. PSE*, Barcelona, Spain, June 12–18: R. van Liere (*Advances in interactive visualization*).
- *COFI-tools meeting*, Bremen, Germany, June 24–26: M.G.J. van den Brand.
- *International Conference Software Maintenance*, Oxford, UK, August 31–September 3: A. van Deursen and T. Kuipers (*Building documentation generators*).
- *First Scottish Functional Programming Workshop*, Stirling, Scotland, August 29–September 2: R. Lämmel (*Editing higher-order functions*).
- *WADT '99*, Bonas, France, September 15–19: M.G.J. van den Brand (*Development of parsing tools for CASL using generic language technology*).
- *Working visit LORIA Nancy*, Nancy, France, September 19–25: M.G.J. van den Brand.
- *9th Int. Workshop on Logic-Based Program Synthesis and Transformation*, Venice, Italy, September 21–29: R. Lämmel (*Projections of programs revisited*).
- *DSL '99*, Austin, USA, October 2–5: A. van Deursen and L. Moonen (*ATerm and ASDL: Towards a common Re interchange format and Toolbus for reverse engineering interoperability*).

- *WCRE '99*, Atlanta, USA, October 5–9: A. van Deursen and L. Moonen (*ATerm and ASDL: Towards a common Re interchange format and Toolbus for reverse engineering interoperability*).
- *Annual Meeting of GI*, Paderborn, Germany, October 5–8: R. Lämmel (*A Language for design patterns*).
- *IEEE Visualization '99*, San Francisco, USA, October 29–30: W.C. de Leeuw (*Collapsing flow topology using area metrics*), R. van Liere (*Automation vs interaction: What is best for big data*).
- *IPA Falldays on Component-based Software Development*, Dordrecht, November 10: P. Klint (*An Overview of the ToolBus Coordination Architecture*), P. Olivier (*Generic debugging of distributed Toolbus applications*).
- *Working visit Baan Company*, Barneveld, November 12: M.G.J. van den Brand, A. van Deursen, M. de Jonge, P. Klint, T. Kuipers, L. Moonen.
- *Software Architecture '99*, Amsterdam, November 18–19: A. van Deursen, M. de Jonge, P. Klint, T. Kuipers, L. Moonen.
- *RISLA Meeting*, CAP-GEMINI, Utrecht, November 26: M.G.J. van den Brand.
- *NPIV '99*, Kansas City, November: R. van Liere, W.C. de Leeuw. (*Exploration of large image collections using virtual reality devices*).
- *Wetenschappelijke Visualisatie en Virtual Reality*, November: R. van Liere (*Applications of VR and visualization applied in HPC*).

Memberships of Committees and Other Professional Activities

M.G.J. van den Brand:
- Programme Committee member CSMR 2000.

A. van Deursen:
- Programme Committee member IEEE IWPC'99, IEEE WCRE'99

P. Klint:
- President European Association for Programming Languages and Systems (EAPLS).
- Member Conseil Scientifique INRIA.
- Member steering committee ETAPS (European Joint Conferences on Theory and Practice of Software).
- Editor Science of Computer Programming.
- Member PhD committees: R. Lämmel (Univ. Rostock, January 15), R. Krikhaar (TUE, June 29), J. Saraiva (Univ. Utrecht, December 9).

J.D. Mulder:
- Programme Committee member Eurographics Virtual Environments '99, EG/IEEE VisSym '99.

W.C. de Leeuw:
- Programme Committee member Eurographics Virtual Environments '99, EG/IEEE VisSym '99.

R. van Liere:
- Programme Committee member Eurographics Virtual Environments '99, EG/IEEE VisSym '99, IEEE Vis '99, Eurographics '99, IEEE Computer Graphics & Applications, IEEE CiSE.

Visitors

- J. Carriere, S. Woods (Software Engineering Institute, Pittsburgh, March 2)
- A. Winter (Universität Koblenz, April 23)
- Darius Blasband (RainCode, June 11)
- Amnon H. Eden (Tel Aviv University and Uppsala University, August 19)
- Paul Jansen (QA Systems, September 23)
- Ira Baxter (Semantic Designs, September 24)

Software Developed

- (SEN1.4)
  - Improved SGLR parse table interpreter.
  - Improved parse table generator.
  - Combination of GSE structure editor and Emacs.
  - C version of ATerm library.
  - Generic prettyprinting tools.
  - Prototype of ELAN parser in cooperation with LORIA (Nancy, France).

Papers in Journals and Proceedings

M.G.J. van den Brand, P. Klint, P. Olivier (1999). Compilation and memory management for ASF+SDF. *Compiler Construction (CC '99)*, LNCS **1575**, 198–213.

S. Bünnig, P. Forbrig, R. Lämmel, N. Seemann (1999). A programming language for design patterns. *Proceedings of the GI-Jahrestagung 1999*, Informatik '99, Reihe Informatik aktuell.

A. van Deursen, T. Kuipers (1999). Identifying objects using cluster and concept analysis, *Proceedings 21st International Conference on Software Engineering (ICSE '99)*. ACM, 246–255.

A. van Deursen, T. Kuipers (1999). Building documentation generators. *Proceedings International Conference on Software Maintenance*, IEEE Computer Society, 40–49.

A. van Deursen, L. Moonen (1999). S. Woods (ed.). *Understanding COBOL Systems using inferred types*, 7th Int. Workshop on Program Comprehension. IEEE Computer Society, 74–83.

A. van Deursen, P. Klint, C. Verhoef (1999). Research issues in the renovation of legacy systems. *Fundamental Approaches to Software Engineering (FASE '99)*, LNCS **1577**, 1–21.

R. Lämmel (1999). Editing higher-order functions. *Draft proceedings 1st Scottish Functional Programming Workshop*, University of Stirling, Bridge of Allan, Scotland (Also accepted for post proceedings).

R. Lämmel, G. Riedewald, W. Lohmann (1999). Projections of programs revisited. *Preproceedings of LOPSTR '99.*

W.C. de Leeuw, R. van Liere (1999). Visualization of global flow structures using multiple levels of topology. *Proceedings EG/IEEE VisSym '99*, 45–52.

W.C. de Leeuw, R. van Liere (1999). Collapsing flow topology using area metrics. *Proceedings IEEE Visualiztion '99*, 349–354.

R. van Liere, J.D. Mulder (1999). PVR – An Architecture for Portable VR Applications. *Proceedings of the Virtual Environments Conference 5th Eurographics Workshop*, Springer-Verlag, 125–135.

J.D. Mulder, J.J. van Wijk, R. van Liere (1999). A survey of computational steering environments. *Future Generation Computer Systems* **15**, 119–129 (Special issue on Scientific Visualization).

CWI Reports

The following CWI reports were published by members of theme SEN1. See page 35 for the complete titles of the reports.

SEN-R9902	SEN-R9904	SEN-R9906
SEN-R9908	SEN-R9909	SEN-R9911
SEN-R9916	SEN-R9920	

Other Publications

A. van Deursen, P. Klint (1999). Programmatuur. *ICT-zakboekje Informatie- en Communicatietechnologie*, PBNA, 664–738. (In Dutch)

P. Klint (1999). Leven op een software vulkaan. *Automatisering Gids*, week **50**.

J.D. Mulder, R. van Liere (1999). Visualisatie en virtual reality. *ICT-zakboekje Informatie- en Communicatietechnologie*, PBNA, 402–422. (In Dutch)

R. Oudejans, J. Visser (1999). *Reverse Engineering and Code Generation — Feasibility Study*, CWI / First Result Consulting.

Specification and Analysis of Embedded Systems – SEN2

Staff

- Prof. dr. ir. J.F. Groote, theme leader
- Prof.dr. J.A. Bergstra, advisor
- Dr. W.J. Fokkink, project member (from July 1)
- Prof. dr. J.W. Klop, project leader
- Drs. I.A. van Langevelde, project member
- Drs. B. Lisser, programmer
- Drs. S.P. Luttik, junior researcher (NWO-EW) (PhD student)
- Dr. S. Mauw, project member (seconded)
- Dr. V. van Oostrom, project member
- Dr. J. van de Pol, project member (from September 1)
- Dr. ir. M.A. Reniers, project member (till August 31)
- Dr. J.M.T. Romijn, junior researcher (PhD student) (till July 31)
- Drs. Y.S. Usenko, project member
- Dr. J. van Wamel, project member
- Dr. ir. J.J. Warners, junior researcher (NWO-EW) (PhD student) (till August 31)
- Dr. H. Zantema, project member (seconded) (from November 1)
- Drs. M.B. van der Zwaag, junior researcher (NWO-EW) (PhD student)

Scientific Report

1999 was for SEN2 a fruitful year of growth, inspiration and success. The group and its research was judged 'excellent' by the visiting committee during the summer. In the beginning of the fall the group was strengthened by two additional senior researchers, Wan Fokkink and Jaco van de Pol. Also Hans Zantema, working at Utrecht University, decided to start working for two days

a week in SEN2. One of the major research assets, the μCRL toolset reached a level of maturity to make it publicly available. Its potentials are sufficient to attract the attention of industries such as Philips and Hollandse Signaal where it found active application. Several researchers left. Joost Warners and Judi Romijn because they finished their PhD theses. Michel Reniers changed his temporary employment for a permanent assistant professor position at the Eindhoven University of Technology. SEN2 entered 2000 with vacancies for 4 PhD students and 3 researchers.

Wan Fokkink started working in SEN2 on July 1 1999. He completed a book on process algebra published by Springer-Verlag, and wrote two chapters for the handbook on process algebra to be published by Elsevier. One chapter is on structural operational semantics (with L. Aceto and C. Verhoef), the other on recursive operators (with J. Bergstra and A. Ponse). He also completed a book on the railway interlocking language LARIS (with J.F. Groote, M. Hollenberg and B. van Vlijmen), to be published in the CWI publications series. He wrote an article on precongruence formats for a range of preorders (with B. Bloom and R. van Glabbeek, submitted to the LICS '2000 symposium) and an article on an omega-complete axiomatization for interleaving (with B. Luttik, submitted to the ICALP '2000 colloquium). He visited the Rabobank Testing Day in Utrecht and the Dutch Testing Day in Eindhoven, chaired a session at the CONCUR conference in Eindhoven, and participated in a joint CWI/GMD meeting in Bonn. He was contact person for the CWI in the 5th framework proposal FRANCESCA, and task manager in the Systems Validation Centre from September 1 onward.

J.W. Klop. The year 1999 was the second year of 0.4 secondment to the KUN, where *J.W. Klop* worked in the group of H.P. Barendregt which is concerned with typed lambda calculi and proof checkers. A study on descendants and origin tracking in first-order rewriting and lambda calculus was completed. A study on proof systems for cyclic term graphs (e.g. recursive types) was started. Most work was devoted to completing a book 'Term Rewriting Systems', with R.C. de Vrijer, M. Bezem and others (scheduled to appear end of 2000).

Izak van Langevelde completed the verification of an optimisation of the SS No. 7 Transaction Capabilities Procedures in cooperation with Dr. Thomas Arts from the Ericsson Computer Science Laboratory in Stockholm, Sweden. In this verification the specification language μCRL was used, supported by the μCRL tool set, developed at CWI, and the Caesaer/Aldebaran tool set, developed at INRIA/Rhone-Alpes. This study revealed and fixed a number of bugs in the optimised design.

Subsequently, he joined the Onderzoek naar Randvoorwaarden voor de Konstruktie van Embedded SysTemen (ORKEST) where he took up the specification and verification of the coordination language SPLICE in μCRL in cooperation with Dr. Paul Dechering from Hollandse Signaalapparaten in Hengelo. This project, which has already been concluded, resulted in a detailed model of SPLICE which allows automatic verification, and the definition and verification of a number of properties.

In the context of the Systems Validation Centre, he worked on an evaluation framework for formal methods, which aims at the systematic gathering of data on the application of formal methods in practice, with as ultimate goal the acquisition of knowledge on what methods suit what kind of verifications for what kind of systems. The concrete results of this task are guidelines for elaborate evaluation reports and a questionnaire form for a concise overview of the relevant characteristics of a verification project. The work on this evaluation framework is a cooperative effort with the other SVC partners, i.e. Telematics Institute and Twente University.

Another activity that was initiated in the Systems Validation Centre is the development of an open-specification, open-source file format for labelled transition format. A common problem with existing file formats, e.g. the .bcg file format is that the exact specification of the file format and the source of their interfaces are not publicly available, which hampers efficient interfacing with existing tool sets. The SVC file format is developed in cooperation with Twente University.

Finally, in the Systems Validation Centre he worked on swapping bisimulations, a symbolic reduction strategy for linear processing process equations. Although the practical use of the strategy developed and implemented so far is limited, it is worth to be worked out further, given the importance of symbolic reduction as a key to the verification of even larger systems.

Bert Lisser made an extension of the μCRL toolset which contains four data reduction tools.

He described these tools in an as yet unpublished paper titled 'Reducing state spaces by symbolic reasoning about formal specifications', and gave a demonstration of these tools in a CONCUR'99 session. He extended the simulator, which is part of the μCRL toolset, with extra functions.

A first release of the μCRL toolset, which is available for several Unix systems, was completed and can be obtained via ftp.

For an application at Philips he extended the μCRL toolset with a tracebuilder which generates specific action traces. The last action of these traces is determined by the user.

Kees Everaars (SEN3) and *Bert Lisser* wrote a paper titled Coordination of a Parallel Proposition Solver, which appeared in the proceedings of COORDINATION '99.

Bas Luttik continued his work on the formalisation of μCRL. Together with J.F. Groote he gave a complete axiomatisation of weak bisimulation for process algebras with a construct for alternative quantification over data (reported in SEN-R9914). He also gave a purely algebraic definition of the operation for alternative quantification over data, establishing a link with algebraic logic, in particular with Cylindric Algebras (reported in SEN-R9912). With this definition the complicated notion of substitution in a setting with binders was eliminated. The second part of 1999 his research was mainly devoted to the theory of interleaving. A new axiom scheme was discovered that was proved to make the existing equational theory of interleaving inductively complete. At the University of Amsterdam, S.P. Luttik gave a course on process algebra and he was a teaching assistant for a course on program algebra.

Sjouke Mauw performed research in several areas. The research on Message Sequence Charts was successfully continued. Research on the Write-All problem resulted in a paper. The research project conducted in collaboration with the Telematics Institute ended successfully.

Vincent van Oostrom worked on various rewriting techniques, as well as on the book 'Term rewriting systems'.

Jaco van de Pol wrote a technical report on formal requirements engineering for Hollandse Signaalapparaten. He also investigated theorem proving by extending BDDs with equalities. This resulted in a submission to CAV 2000, and a prototype implementation (jointly with Jan Friso Groote). Work on BDDs also led to a submission to RTA 2000 (jointly with Hans Zantema).

Jaco van de Pol also wrote a tool to translate μCRL specifications into PVS and Isabelle. In this way the automated capabilities of these theorem provers on formulae that are relevant for the verification of distributed systems can be assessed.

He re-specified the sliding window protocol, and verified some finite instantiations with the μCRL toolset. This protocol will also be used in the symbol verifications, as in the two preceeding items.

Together with Jan Friso Groote, Jaco is working on the use of a local property of distributed systems, called confluence, in the verification of such systems.

Moreover, Jaco worked three months for Philips Natlab, in order to investigate how automatic test cases can be generated for MPEG audio decoders.

Finally, Jaco co-authored a number of research-proposals.

Michel Reniers worked on the extension of μCRL with time. Currently he and M. van de Zwaag, J. van Wamel and J.F. Groote are still collaborating on this subject. Furthermore, M.A. Reniers and J.F. Groote have prepared a chapter for the 'Handbook of Process Algebra'. The subject of this chapter is algebraic process verification. This handbook will be published in 2000 by Springer-Verlag. M.A. Reniers has also been preparing a chapter on the semantics of interworkings for this handbook with S. Mauw from Eindhoven University of Technology.

From January until March, *Judi Romijn* has finished the last two case studies of the Philips/SMC project 'Specification, Testing and Verification of Software for Technical Applications'. The research on one of these case studies led to the discovery of errors in part of the Philips HAVi protocol. The research on the other case study was accepted for presentation in the FMICS 1999 workshop.

The months April until July were spent on finishing her PhD thesis, based on the research for the Philips project.

Yaroslav Usenko The research on the HAVi Leader Election Protocol, and the comparison of SPIN and the μCRL Toolkit on this protocol was finished. The results are presented in the report SEN-R9917.

The cooperation within the framework of the Dr. Tesy project was intensified in 1999. Ac-

cording to the project workplan, the informal description of the case study was developed, and the kernel of the case study was formalized in μCRL. The results of the project were reviewed by the EC.

From May 1999 Y.S. Usenko joined the work on theoretical foundations of the linearization procedure used in the μCRL toolset. A draft version of the paper describing the linearization process for parallel pCRL has been completed. An algorithm for the linearization of the whole μCRL was sketched and will be prepared for publication in 2000.

The main activities of last year of *Jos van Wamel* were concentrated on the HAVi conformance test project, which was done together with people from Philips Research (contract research). Also people from other companies that are part of the HAVi consortium were involved.

During the first 8 to 9 months the CWI part of the work was carried out jointly with Thijs Cobben (about 50/50). The last part of the work was done by Jos alone. It was finished in December.

The final deliverables were

1. A comprehensive set of correctness requirements for HAVi implementations, directly derived from the standard.
2. A large number of test cases, which cover the requirements exhaustively.

In the autumn the work was presented by Jan Springintveld for a large audience at the Nederlandse Testdag at Philips Natlab.

Important to note is that the document with test cases has become an official addendum to the international HAVi standard. All devices that are claimed to be HAVi-compliant are assumed to pass the relevant tests from the test document. This year, also quite some time was spent on the revision and extension of older work on timed μCRL.

Other milestones were the presentation of earlier work on the subject at the WDS workshop in Iasi, Romania (September), and the acceptance and final submission of an article about hybrid systems in *Science of Computer Programming*.

Joost Warners finished his PhD thesis. Furthermore he worked on the publication of the HeerHugo theorem prover.

During 1999 *Hans Zantema* mainly worked on decision trees, decision tables and BDDs. Together with Hans Bodlaender (also employed at UU) he proved that both for decision trees and decision tables the problem of finding a smallest representation is NP-hard. For decision trees this resulted in the report (UU-CS-1999-02) *Finding small equivalent decision trees is hard*, by H. Zantema, H.L. Bodlaender which has been accepted for publication in the International Journal of Foundations of Computer Science. For decision tables the work appeared as the report (UU-CS-1999-31) *Sizes of decision tables and decision trees*, by H. Zantema, H.L. Bodlaender. This work has been submitted.

During 1999 *Mark van der Zwaag* was employed as a second year OIO (PhD student), half of the time at CWI and half of the time at the University of Amsterdam. He worked on various extensions of μCRL with time. This resulted in a draft paper on timed branching bisimulation that includes a timed cones and foci theorem. Also, he is working with Jan Friso Groote, Jos van Wamel and Michel Reniers on a joint paper on timed μCRL.

Jan Friso Groote's work was mainy directed to three topics. In the first place there was work on the toolset. The intention was to release the toolset in January 1999. For this the tool had to be stabilized, and documentation had to be written. The tool (version 1.0) was indeed put on the web. However, it has been under continuous development throughout 1999. Currently version 1.09 is available. J.F. Groote has contributed to virtually all parts of the toolset, be it the rewriter, the state space generator or the lineariser. Experiments have been carried out for future extensions. Together with J. van Wijk of Eindhoven University a prototype state viewer has been constructed. Together with J. van de Pol work has been done on a symbolic formula manipulator to extend the potential of the toolset to do symbolic analysis considerably. Also work has been done on describing and implementing a partial confluence checker to reduce huge state spaces.

Besides the work on the toolset work has been done on wait free algorithms. Together with Wim Hesselink (Groningen University) and Sjouke Mauw work has been done on a wait free algorithm for the Write-All problem, where a number of faulty processors must reset a block of memory. A particularly nice and practically efficient algorithm for this problem has been designed. Together with Hesselink a wait-free algorithm for parallel hash-tables has been designed. Due to the extreme parallellism of this algorithm, it has

been decided to verify this algorithm using PVS (Prototype Verification System). This has taken far more time than expected, and this project will require also much time in 2000 to be finished.

Third, J.F. Groote has invested a lot of time in the Systems Validation Centre, a research project under the umbrella of the telematics top institute. The goal of this project is to make analysis techniques available for a wider (industrial) audience. A special task within this project was the design of a method to classify and compare different formal case studies. Several case studies have been classified according to this frame.

PhD Theses

- J.M.T. Romijn. *Analysing Industrial Protocols with Formal Methods.* Thesis advisors Prof. Brinksma and Prof. Vaandrager, October 15, Twente University.
- M.A. Reniers. *Message Sequence Chart: Syntax and Semantics.* Thesis advisors Prof. dr. J.C.M. Baeten and Prof. dr. ir. L.M.G. Feijs, June 7, Eindhoven University of Technology.
- J.P. Warners. *Nonlinear Approaches to Satisfiability problems.* Thesis advisors Prof. dr. ir. J.F. Groote and Prof. dr. J. Van Leeuwen, September 14, Eindhoven University of Technology.

Knowledge Transfer

- On January 22 the Systems Validation Centre has been officially openened with a series of lectures specially tuned for developers of critical software. There were approximately 50 visitors.
- On June 17 an IPA course has been given by J.F. Groote on μCRL for PhD students participating in the research school IPA.
- On July 12 J.F. Groote gave a lecture on the risks of software at the Hoofdafdeling Waterbouw of the Rijkswaterstaat in Utrecht.
- Sjouke Mauw participated in a project with Telematics Institute which was successfully finished in 1999.
- Jaco van de Pol wrote the Final report on formal requirements engineering for Hollandse Signaalapparaten. This report is spread among software engineers, and forms the basis of an internal shadow-process, in which the traditional specification approach will be compared with the formal approach.
- Jaco van de Pol participated in a Project at Philips, on automatic test generation of MPEG audio decoders. This resulted in an intermediate report, and the final report is nearly finished. The project required over 20 visits to Philips Natlab in Eindhoven.
- Dr. TESY project: contacts with GOSNIAS, MSU (Moscow), GMD: Y. Usenko.

Organization of Conferences, Workshops, Courses, etc.

- J.F. Groote, Chair Organizing committee CONCUR '99.
- J.W. Klop together with J. Rutten organized on March 29 the yearly Symposium Day of the NVTI.
- S. Mauw, Co-chair CONCUR '99.
- S. Mauw, Organiser of VFM'99 and ITU SG9 experts meeting.
- S.P. Luttik organized a weekly seminar (PAM) on process theory, protocol verification, term rewriting and theorem proving.
- Izak van Langevelde succeeded Michel Reniers as project secretary of the Systems Validation Centre.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- *Proces Algebra Meeting*, Amsterdam, January: S. Mauw (*Why men (and octopuses) cannot juggle a four ball cascade*).
- *Opening of the Systems Validation Centre*, Amsterdam, January 22, J.F. Groote (*Analyse van grotere processen*).
- *Systems Validation Centre Kickoff Meeting*, Amsterdam, February 22: I.A. van Langevelde.
- *Dr. TESY Working Meeting*, Berlin, Germany, February 17–21: Y. Usenko (*An Overview of the μCRL Toolset*).
- *Inaugural lecture*, Eindhoven University of Technology, March 5: J.F. Groote (*We moeten software leren beheersen*).
- *ETAPS '99*, Amsterdam, March 20–28: J.F. Groote.
- *Working visit University of Pisa*, Pisa, Italy, March 27–31: J.W. Klop (*Origin tracking in first-order term rewriting*).
- *Working visit University of Edinburgh*, Edinburgh, UK, April 10–13: J.W. Klop (*Infinitary term rewriting*).

- *Working visit ETSI*, Sophia Antipolis, France, May 6–7: M.B. van der Zwaag.
- *6th SIAM conference on optimization*, Atlanta, USA, May 10–12: J.P. Warners (*Mathematical programming techniques for Satisfiability solving*).
- *Proof Tools Day*, Eindhoven, May 25: J. van de Pol (*Process algebra in Isabelle/HOL*).
- *Tutorial on Message Sequence Charts*, IPA course on formal methods, University of Twente, Enschede, June: S. Mauw, M.B. van der Zwaag.
- *One day IPA course on μCRL*, Enschede, June 17: J.F. Groote.
- *MSC and data: dynamic variables*, Ninth SDL Forum, Montreal, Canada, June: S. Mauw.
- *IFM '99*, York, UK, June 28–29: J. v.d. Pol (*Modular Formal Specification of Data and Behavior*).
- *Formal Methods for Industrial Critical Systems*, Trento, Italy, July 10–18: I.A. van Langevelde (*How μCRL supported a smart redesign of a real-life Protocol*), J.M.T. Romijn (*A Timed Verification of the IEEE 1394 Leader Election Protocol*).
- *Lecture Hoofdafdeling Waterbouw Rijkswaterstaat*, Utrecht, July 12: J.F. Groote (*Over fouten in software*).
- *Logic Colloquium '99*, Utrecht, August 2–4, three hour tutorial Ten topics in term rewriting, J.W. Klop.
- *ESSLLI '99*, Saarbrücken, Germany, August 17–28: V. van Oostrom (*Course (Advanced) Term Rewriting*).
- *Zuidelijk Interuniversitair Colloquium*, Eindhoven, September: S. Mauw (*An algorithm for the asynchronous Write-All problem based on process collision*).
- *Dr. Tesy Project Meeting*, Moscow, Russia, September 5–10: J.F. Groote (*The language μCRL and the μCRL toolset*), Y. Usenko (*Formal Specification of the Navigation System in μCRL*).
- *Types Summerschool* (*Theory and Practice of Formal Proofs*), Giens, France, August 30–September 12: J. van de Pol (*Proofs of Correctness of Protocols*).
- *CONCUR '99*, Eindhoven, August 23–28: W.J. Fokkink.
- *WDS '99*, Iasi, Roumania, August 23–September 6: J. van Wamel.
- *Algemeen colloquium CWI*, Amsterdam, September 24: J.F. Groote (*About proof checkers*).
- *Process Algebra Meeting*, CWI, Amsterdam, October: S. Mauw (*An algorithm for the asynchronous Write-All problem based on process collision*).
- *Nederlandse Testdag*, Eindhoven, November 3: J. van de Pol.
- *Habilitation Dr. E. Ohlebusch and working visit to group of Prof. R. Giegerich*, Bielefeld, Germany, November 29–30: J.W. Klop.
- *ERCIM 10th Anniversary Event*, Amsterdam, November 4: J.F. Groote.
- *Dr. TESY Review Meeting*, Berlin, Germany, November 17–19: Y. Usenko (*Formal Specification of the Navigation System in μCRL*).
- *GMD-CWI Cooperation Meeting*, Bonn, Germany, November 29: W.J. Fokkink, Y. Usenko.
- *System Theory Day on Complementarity Systems*, Eindhoven, November 30: J.F. Groote (*Process algebra and hybrid systems*).

Memberships of Committees and Other Professional Activities

J.F. Groote:
- Professor of Computer Science at the Eindhoven University of Technology.
- Leader task C of Systems Validation Centre
- Moderator of the concurrency mailing list.
- Member IPA, Dutch Graduate School for Programming and Algorithmics.
- Reviewer *Zentralblatt für Mathematik*.
- Secretary of the PhD committee for Ed Voermans, Eindhoven University of Technology (Inductive Datatypes with Laws and Subtyping - A Relational Model).
- Member of PhD committee Geert Janssen, Eindhoven University of Technology (Logics for Digital Circuit Verification).
- Secretary PhD committee for Michel Reniers, Eindhoven University of Technology (Message Sequence Chart. Syntax and Semantics).
- First promotor for Joost Warners, Eindhoven University of Technology (Nonlinear approaches to Satisfiability Problems).
- Member PhD committee Judi Romijn, Twente University (Analysing Industrial Protocols with Formal Methods).
- Member PhD committee for Maurice Heemels, Eindhoven University of Technology (Linear Complementarity Systems: A Study in Hybrid Dynamics TUE (1999).

J.W. Klop:
- Professor of Computer Science at the Vrije Universiteit, Amsterdam

- Head of Department Theoretical Computer Science, Vrije Universiteit Amsterdam.
- Member editorial board CWI Tracts and Syllabi.
- Member of IFIP WG 1.6 on Term Rewriting.
- Member Program Committee CSL2000.
- Member Science Committee IPA.
- Chairman Dutch Association for Theoretical Computer Science (NVTI).
- Editor of NVTI Nieuwsbrief (jointly with J. Rutten, J.J. Bruné).
- Member promotion committee of Joeri Engelfriet, Free University, February 4.
- Member promotion committee of Marc Ruijs, Nijmegen University, June 29.
- Member promotion committee of Milena Stefanova, Nijmegen University, June 22.
- Member Habilitation Committee Dr. D. Plump, University of Bremen, December 22.
- Member Habilitation Committee Dr. E. Ohlebusch, University of Bielefeld, November 23.
- Member promotion committee Jan Zwanenburg, Eindhoven University of Technology, December 8.

S. Mauw:

- CONCUR '99, Co-chair (Activities: Program, Publicity, Submissions, Proceedings, Organization).
- VFM '99, Co-organizer. Guest editor of *Computer Languages* special issue for VFM '99.
- SDL'99, Member program committee.

M. Reniers:

- Secretary and leader task A Systems Validation Centre.

V. van Oostrom.

- LC'99, organizing committee member.
- ICALP'99, Prague, programme committee member
- LICS'00, Santa Barbara, programme committee member
- Member of the IFIP Working Group on Term Rewriting (WG1.6).

M.B. van der Zwaag:

- Teaching assistant for the University of Amsterdam undergraduate course on Program Algebra.

Visitors

- M. van Osch, trainee, January.
- T. Arts, Ericsson Telecom AB, February 22–26 (*Case studies within Ericcson Telecom on the use of Formal Verification*).
- Prof. Alexander A. Letichevsky (Glushkov Institute of Cybernetics) March 24–25 (*Interaction of agents and environments*).
- P. Bellec from 'Magistère de Modelisation Mathématique et Méthodes Informatiques (Mathematical Institute of Rennes), June 17–August 17, Traineeship: '*The Davis Putnam rule can blow up a resolution proof exponentially*'.
- Dr. Nikolaj S. Nikitchenko, December 6–7 (*Composition Nominative Systems and their Application in Programming, Logic and Transport*).

Developed Software

- The μCRL toolset with a simulator, state space generator, linear process compiler and several other tools has been constructed by J.F. Groote and B. Lisser. Available via http://www.cwi.nl/~mcrl
- Automatic test case generator for MPEG audio decoders (work for Philips): J. van de Pol.
- Prototype implementation for BDDs with equality: J. van de Pol.

Book

J. C. M. Baeten, S. Mauw (eds.). *CONCUR '99, Proceedings of the 10th International Conference on Concurrency Theory*, August 24–27 (1999). Lecture Notes in Computer Science **1664**. Springer Verlag.

CWI Reports

The following CWI reports were published by members of SEN2. See page 35 for the complete titles of the reports.

SEN-R9903	SEN-R9905	SEN-R9910
SEN-R9912	SEN-R9914	SEN-R9915
SEN-R9917	SEN-R9918	SEN-R9919

Papers in Journals and Proceedings

T. Arts, I.A. van Langevelde (1999). How μCRL supported a smart redesign of a real-life protocol. S. Gnesi, D. Latella (eds.). *Proceedings of the 4th International ERCIM Workshop on Formal Methods for Industrial Critical Systems*, 31–53.

L. Aceto, W. Fokkink, C. Verhoef (1999). Conservative extension in structural operational semantics. *Bulletin of the EATCS* **69**, 110–132.

L. Aceto, J.F. Groote (1999). A Complete Equational Axiomatization for MPA with String Iteration. *Theoretical Computer Science* **211**, 339–374.

A. Belinfante, J. Feenstra, R.G. de Vries, J. Tretmans, N. Goga, L. Feijs, S. Mauw, L. Heerink (1999). Formal test automation: A simple experiment. G. Csopaki, S. Dibuz, K. Tarnay (eds.). 12th *Int. Workshop on Testing of Communicating Systems*, Kluwer Academic Publishers, 179–196.

I. Bethke, J.W. Klop, R.C. de Vrijer (1999). Extending partial combinatory algebras, *Math. Struct. in Comp. Sc.* **9**, 483–505.

B. Cabon, S. de Givry, L. Lobjois, T. Schiex, J.P. Warners (1999). Radio Frequency Assignment Benchmarks. *Constraints* **4**(1), 79–89.

A.G. Engels, L.M.G. Feijs, S. Mauw (1999). MSC and data: dynamic variables. R. Dssouli, G.v. Bochmann, Y. Lahav (eds.). *Proceedings of the Ninth SDL Forum*, Elsevier Science Publishers B.V. Montreal, Canada, 105–120.

J.F. Groote, R. Mateescu (1999). Verification of Temporal Properties of Processes in a Setting with Data. A.M. Haeberer (ed.). *Proceedings of the 7th International Conference on Algebraic Methodology and Software Technology AMAST'98 (Amazonia, Brazil)*, volume **1548** of *Lecture Notes in Computer Science*, Springer Verlag, 74–90.

J.F. Groote, J.J. van Wamel (1999). Basic theorems for parallel processes in timed μCRL. *Proceedings Workshop for Distributed Systems*, Technical Report 99–03, University Alexandru Ioan Cuza, Iasi, Romania.

W. Janssen, R. Mateescu, S. Mauw, P. Fennema, P. van der Stappen (1999). Model checking for managers. D. Dams, R. Gerth, S. Leue, M, Massink (eds.). *Theoretical and practical aspects of SPIN Model Checking, Proceedings of the 5th and 6th International SPIN Workshops*, LNCS **1680**, Springer Verlag, Toulouse, France, 92–107.

B. Knaack, S. Mauw (1999). The usage of MSC with uBET-toolsupport in the software development process. *Network development and support department*, International call processing symposium. Lucent Technologies.

S. Mauw, M.A. Reniers (1999). Operational semantics for MSC'96. *Computer Networks and ISDN Systems* **31**(17), 1785–1799.

J. van de Pol, J. Hooman, E. de Jong (1999). Modular Formal Specification of Data and Behaviour. *Proceedings IFM '99*, York, UK, 109–128.

Other Publications

E. Brinksma, J.F. Groote (1999).Validatietechnieken houden complexe systemen hanteerbaar. *Automatisering Gids.*

J.F. Groote (1999). *We moeten software leren beheersen.* Inaugural Speech, Technische Universiteit Eindhoven.

J.F. Groote, W.H. Hesselink, S. Mauw, R. Vermeulen (1999). *An Algorithm for the Asynchronous Write-All Problem Based on Process Collision*, Computing Science Report, Department of Computer Science. Eindhoven University of Technology.

Coordination Languages – SEN3

Staff

- Dr. J.J.M.M. Rutten, theme leader
- Dr. F. Arbab, researcher
- Prof. dr. J.W. de Bakker, cluster head and researcher
- Dr. A. Baltag, NWO-EW postdoc
- Drs. F. Bartels, NWO-EW PhD student (from September 1)
- Drs. C.L. Blom, programmer
- Dr. M.M. Bonsangue, postdoc
- F.J. Burger, programmer
- M. Coccia, Erasmus student (from October 1)
- Drs. C.T.H. Everaars, programmer
- Dr. A. Fagot, postdoc (till September 1)
- Drs. J. den Hartog, VU seconded (from August 1)
- Drs. A. Scutellá, NWO-EW PhD student (till August 1)

Scientific Report

Coordination models and languages focus on such key issues in Component Based Software Engineering as specification, interaction, and dynamic composition of components. The work in this

theme has been on both formal methods and applications of coordination languages, notably addressing the following issues:

1. Study of the foundations of computation, notably operational semantics and coalgebraic methods, on which formal methods for the development of debugging and visualization tools for *Coordination languages* can be based (SEN3.1, SEN3.4);
2. Development of and experiments with the language 'Manifold' and its visual programming and debugging environment (SEN3.2);
3. Using the Manifold system to work on real applications of coordination programming in numerical computing (in collaboration with MAS2 Piet Hemker and Barry Koren), distributed constraint satisfaction (in collaboration with PNA1 Krzysztof Apt), Command and Control simulation systems (in collaboration with H. Arciszewski, TNO-FEL) (SEN 3.3);
4. Mutual cross-fertilization of the formal and applied activities of 1, 2 and 3.

Formal methods for coordination languages – SEN3.1

Together with Zavattaro (Univ. of Bologna), Arbab, De Bakker, Bonsangue, Rutten, and Scutellá have completed the construction of an operational semantics for Manifold. It is based on a collection of layered transition systems, in which the higher-level transition system abstracts away the (computational) semantics of the lower-level processes, and is concerned only with their (mutually engaging) externally observable behaviour. The model will serve as a formal basis for the further development of the programming environment for Manifold, in SEN3.2.

Together with J. Kok (Leiden University) and G. Zavattaro (Bologna University), M.M. Bonsangue has developed a formal framework for comparing the relative expressive power of different coordination languages, considering also the intended architectures on which each language is executed. This notion has been used for comparing coordination models based on components that communicate through different types of broadcast.

Together with F. de Boer (Utrecht University), F. Arbab and M.M. Bonsangue defined a core language for specifying dynamic networks of communicating and mobile processes. The research has moved in two directions. One towards a definition of compositional partial correctness semantics for the language, and another towards an embedding of an abstract version of Manifold into the language.

The NWO-EW project COLA has been terminated by NWO, in agreement with the project leaders at CWI. Both the actual performance of the PhD student on this project, *Scutellá*, and the expectations about the future were so low that it seemed no longer justified to continue the project.

Matteo Coccia (Scuola Normale, Pisa) has started to work for his master thesis on a tile model of Manifold.

Experimental testbed for control-oriented coordination – SEN3.2

Improvements and enhancements to the Manifold system continued in 1999. A set of new atomic process interface functions was developed, allowing utilization of generalized containers and filters by atomic process programmers at a higher level of abstraction. Such higher level functions are instances of common 'computation patterns' useful in many applications.

Coordination applications - SEN3.3

The work on the application of Manifold in parallelization and distribution of numerical computation (with MAS2) continued in 1999 under the project BINGO (Everaars, Arbab, and Koren) funded by NCF. Andries Stam (University of Leiden) finished his project producing Manifold protocols for parallel and distributed branch and bound algorithms. The work with PNA1 on coordination of distributed constraint systems (E. Monfroy, K. Apt, C.L. Blom, and F. Arbab) continued in 1999 and resulted in prototype implementation of a generic Manifold coordination scheme for the chaotic iteration method for constraint propagation. This result is very encouraging and joint work in this area is to expand and continue in 2000.

Exploratory research: Coalgebraic models of computation – SEN3.4

Rutten has continued his work on the theory of *coalgebra* and *coinduction*. The previous results on coinduction for regular languages and automata have now been generalized to the family of *formal power series*. This has led to the use of (behavioural) differential equations as a coinductive definition format, and to non-deterministic

representations of (analytic and generating) functions. In cooperation with Jan van Schuppen (PNA2), first applications of coalgebra to the supervisory control problem of discrete event systems have been found. In particular, coinductive proof principles for the controllability (of one language with respect to another) have been established. Worldwide interest in the subject of coalgebra is continuing, as was illustrated by the well attended second international workshop on Coalgebraic Methods in Computer Science (CMCS '99, co-organized by Rutten), which was held in Amsterdam. Bartels has initiated his work in the context of the NWO-EW project PROMACS, on coalgebraic models of probabilistic systems.

Alexandru Baltag continued his work in the context of the NWO-EW project PROMACS on the connection between coalgebras and modal logic. He generalized the logic introduced by L. Moss (for characterizing coalgebraic bisimulation) to a coalgebraic modal logic, which captures the (coalgebraic) notion of simulation introduced by A. Thijs. He also explored some relations between coalgebras and gametheory, giving a coalgebraic semantics to a large class of games and using it to define and prove game-theoretic properties by coinduction. On the other hand, he continued his work on epistemic actions, in the context of the Spinoza project LIC. He developed a complete calculus of epistemic actions, and later generalized it to a notion of epistemic processes, used to explore issues of game-theory (strategies and equilibrium points), communication (exchange of messages, learning, information-update, misinformation) and security (hidden or suspicious actions, wiretaping, trust, secrecy).

Jerry den Hartog, part-time seconded from the Vrije Universiteit Amsterdam, continued his research on semantics and proof techniques for languages with probabilistic notions. This work was discussed in a group with De Bakker, Baltag and Rutten as further members.

Organization of Conferences, Workshops, Courses, etc.

- ACG – the Amsterdam Coordination Group. ACG is an—on average biweekly—seminar in which ongoing research on coordination languages and models, and on coalgebra, is discussed by members and former members of SEN3, and invited visitors. External participants include Dr. F. de Boer (UU), Prof. dr. A. de Bruin (EUR), Dr. E. de Vink (KPN Research), Dr. B. Jacobs (KUN), Drs. J.J. den Hartog (VUA), Prof. dr. J.N. Kok (UL), Dr. E. Monfroy (PNA1).
- CMCS '99 – second international workshop on Coalgebraic Methods in Computer Science, Amsterdam, March 20–21.
- Coordination '99 – Third International Conference on Coordination Models and Languages, Amsterdam, The Netherlands, April 26–28 1999. Sponsored by IPA and KNAW, in cooperation with ACM SIGSOFT.
- 'Semantische Perspectieven: wetenschappelijk symposium t.g.v. de zestigste verjaardag van Jaco de Bakker', Scientific symposium, Amsterdam, May 28.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- *Coordina meeting*, Pisa, Italy, January 20–23: F. Arbab (*The Coordination Language Manifold*), J.W. de Bakker, M.M. Bonsangue (*Are Shared Coordination Models Distributed?* and *A Structural Operational Semantics for Manifold*), F.S. de Boer (*Generic process algebras*).
- *Coordination '99 Program Committee Meeting*, Bologna, Italy, January 26: F. Arbab.
- *Invited lecture*, Antwerpen University, Department of Mathematics, Antwerpen, Belgium, January 29: M.M. Bonsangue (*One stone, two birds: how to cook partial orders and metric spaces in one structure*).
- *FMOODS '99*, Florence, Italy, February 14–18: M.M. Bonsangue (*Developing Object-oriented Distributed Systems*).
- *Workshop on Modal Logic and Coalgebra*, UvA, February 18: A. Baltag, J.W. de Bakker, J.J.M.M. Rutten (*Coalgebra, an introduction*).
- *SAC '99*, San Antonio, USA, February 27–March 3: M.M. Bonsangue (*Comparing coordination models based on shared distributed replicated data*).
- *Invited course*, ETL Tsukuba, Japan, February 22–March 3: J.J.M.M. Rutten (*A series of lectures on Coalgebra*).
- *Invited lecture*, University of Tsukuba, Japan, March 1: J.J.M.M. Rutten (*Automata and coinduction*)
- *ETAPS '99*, Amsterdam, March 20–28: J.W. de Bakker.
- *CMCS '99*, Amsterdam, March 20–21: F. Arbab, A. Baltag, J.W. de Bakker, J.J.M.M. Rutten.

- *IPPS/SPDP '99 – IRREGULAR '99*, San Juan, Puerto Rico, April 12–16: C.T.H. Everaars (*Dynamic process composition and irregular communication patterns*).
- *School in Logic and Computation*, Edinburgh, UK, April 10–13: A. Baltag (*Truth-as-simulation: a coalgebraic perspective*).
- *Working visit*, Prof. P. Inverardi, Rome, Italy, April 15–16: F. Arbab.
- *Coordination '99*, Amsterdam, April 26–28: F. Arbab, J.W. de Bakker, M.M. Bonsangue (*Comparing Software Architectures for Coordination Languages*), F. Burger, C.T.H. Everaars (*Coordination of a Parallel Proposition Solver*), J.J.M.M. Rutten, A. Scutellá (*Simulation of Conference Management Using an Event-driven Coordination Language*).
- *Coordina project meeting*, Amsterdam, April 29: F. Arbab, J.W. de Bakker, M.M. Bonsangue.
- *MFPS '99*, New Orleans, USA, April 28–May 1: J.J.M.M. Rutten.
- *Working visit*, University of Toronto (Dr. F. van Breugel), Toronto, Canada, May 3: J.J.M.M. Rutten.
- *Working visit*, Ecole Polytechnique Montreal (Prof. J. Thistle), Canada, May 4: J.J.M.M. Rutten (*An introduction to coalgebra*).
- *Working visit*, McGill University (Prof. P. Panangaden), Montréal, Canada, May 5: J.J.M.M. Rutten.
- *Graduate Seminar of the CS Dept. University of Dresden*, Dresden, Germany, May 6–12: A. Baltag.
- *London-Amsterdam Modal Logic Meeting*, UvA, June 14–15: A. Baltag (*A Dynamic-Epistemic Logic*).
- *Invited paper, PDPTA '99*, Las Vegas, USA, June 28–July 1: F. Arbab (*Coordination Programming for Parallel and Distributed Applications*).
- *5th International SPIN Workshop*, Trento, Italy, July 5: A. Fagot.
- *ICALP '99*, Prague, Czech Republic, July 11–15: J.J.M.M. Rutten (*Automata, power series and coinduction*).
- *Logic Colloquium '99*, Utrecht, August 2–4: J.J.M.M. Rutten (*Coinduction and behavioural differential equations, invited plenary lecture*).
- *ESSLLI '99*, Utrecht, August 9–21: A. Baltag (*A logic of Epistemic Actions*).
- *Working visit University of Como*, Como, Italy (Prof. B. Walters), September 20–24: F. Arbab (*The Coordination Language Manifold*).
- *5th Framework IST proposal meeting, University of Ulster*, Ulster, Ireland, September 3: F. Arbab.
- *Workshop on Categorial models of Concurrency*, Dresden, Germany, October 10–13: J.J.M.M. Rutten (*Coinduction and behavioural differential equations, invited lecture*).
- *ESPRIT KIT project meeting*, Brussels, Belgium, October 17–20: F. Arbab.
- *Amsterdam-Aachen Logic Meeting*, Aachen, Germany, November 5: A. Baltag (*A Dynamic Logic for Games as Processes*)
- *IPA Fall days*, Dordrecht, November 8–12: F. Arbab ('Overture' and 'Tutorial on Coordination' and 'Overview of Manifold'), J.W. de Bakker, F. Bartels, M. Bonsangue (*Comparing Coordination Models*), M. Coccia, C.T.H. Everaars (*Coordination Programming in Manifold*), J.J.M.M. Rutten.
- *ILLC Workshop on Logic and Games*, UvA, November 19–20: A. Baltag (*A Logic for Games*).
- *International Summer School on Logic, Universal Algebra, and Theoretical Computer Science*, Johannesburg, South Africa, December 6–10: A. Baltag (invited course on games and logic), J.J.M.M. Rutten (invited course on coalgebra).

Memberships of Committees and Other Professional Activities

F. Arbab:

- Editorial Board Member, *Computers & Graphics, An International Journal.*
- Editorial Board Member, *Parallel Computing* journal.
- Coordinator, ESPRIT INCO-DC EC project 962144.
- Advisory Board Member, *Euro-Par'99*, Toulouse, France, August 31–September 3, 1999.
- Program Committee Member, *PARALLEL COMPUTING '99*, Delft, August 1999.
- Program Committee Member, *International Conference on Coordination Models and Languages (Coordination '99)*, Amsterdam, The Netherlands, April '99.
- Local Organization Co-Chair, *International Conference on Coordination Models and Languages (Coordination '99)*, Amsterdam, The Netherlands, April '99.
- PhD Committee Member for R.H.M.C. Kelleners, Eindhoven University, June 8, 1999.

- Program Committee Member, *International Symposium on Advanced Distributed Systems*, Guadalajara, Jalisco, Mexico, March 8–10, 2000.
- Co-chair, Coordination session, International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA'2000), June 26–29, 2000, Las Vegas, Nevada, USA.
- PhD Committee Outside Member for Andrea Sosio, University of Milan, Italy.
- Course Instructor, Special Topics on Component Based Software Engineering, Computer Science Department, Leiden University, Fall 1999.
- Program Committee member, IPA Fall-days on Component-based Software Development, November 8–12, 1999, Dordrecht, The Netherlands.
- Member IPA, Dutch Graduate School Institute for Programming and Algorithmics.
- Member of the Esprit Working Group 24512 Coordina.

J.W. de Bakker:

- Professor of Computer Science, Vrije Universiteit Amsterdam.
- Member Koninklijke Nederlandse Akademie van Wetenschappen.
- Member Akademieraad voor de Wiskunde.
- Member Academia Europaea (AE).
- Member AE committee on Mathematics and Informatics.
- Editor Cambridge University Press Tracts in Theoretical Computer Science.
- Consulting editor, Wiley Series in Parallel Computing.
- Editor *Theoretical Computer Science.*
- Editor *Fundamenta Informaticae.*
- Associate editor *Journal of Computer and System Sciences.*
- Member emeritus IFIP Working Group 2.2 on Formal Description of Programming Concepts.
- Board member IPA, Dutch Graduate School Institute for Programming and Algorithmics.
- Member ESPRIT Working Group Coordina
- (Co)Project leader NWO-EW project COLA: Coordination Languages.
- Member Selection Committee Blaise Pascal chair, UL.
- Member of IFIP Technical Committee 1 on Foundations of Computer Science.
- Member PhD committee C.H.M. van Kemenade, UL, March 18.
- Member selection committee chair Information Systems, VUA.
- Member uhd assessment committee VUA, KUN, TUE.
- (Co)project leader NWO/EW project Biography of Aad van Wijngaarden.

A. Baltag:

- Member of the LIC group (Logic in Communication), at the UvA.

M.M. Bonsangue:

- Member of the user commitee of the STW project EIF.3959 'Formal design of industrial safety-critical systems'.
- Member IPA, Dutch Graduate School Institute for Programming and Algorithmics.
- Member of the Esprit Working Group 24512 Coordina.
- Supervisor master thesis of Matteo Coccia (Scuola Normale, Pisa, Italy).

J.J.M.M. Rutten:

- Member of the NWO-EW project COLA: Coordination Languages.
- Project leader of the NWO-EW project 'ProMACS: Probabilistic Methods for the Analysis of Continuous Systems'.
- Site coordinator of ESPRIT Working Group Coordina.
- Editor of Elseviers 'Electronic Notes in Theoretical Computer Science'.
- Board member of the 'NVTI' (Dutch Association of Theoretical Computer Science). Editor of NVTI's newsletter.
- Member IPA, Dutch Graduate School Institute for Programming and Algorithmics.
- Member OZSL, Dutch Research School in Logic.
- Member of the programme committee (and coorganizer) of the second international workshop on 'Coalgebraic Methods in Computer Science' (CMCS'99).
- Member of the programme committee (and coorganizer) of the third international workshop on 'Coalgebraic Methods in Computer Science' (CMCS 2000).
- Member of the programme committee of MFPS '99 (Mathematical Foundations of Programming Semantics).
- External examiner PhD thesis L. Pooyan-Weihs, Technical University, Berlin.
- Guest editor of Theoretical Computer Science, special issue of selected papers from CMCS '98.

Visitors

- Mark Bezem (University of Utrecht), January 19.
- Perry Groot (Free University, Amsterdam), February 9.
- Manuel Nunez (University of Madrid), April 13 (*The choice of Probabilistic Choices*).
- Bart Jacobs (University of Nijmegen), April 20 (*The temporal logic of coalgebras via Galois algebras*).
- Gianluigi Zavattaro (University of Bologna, Italy), April 26 - May 31.
- Matteo Coccia (Scuola Normale, Pisa, Italy), October 1 - present.
- Zoltan Esik (József Attila University, Szeged, Hungary), October 22 (*The equational logic of fixed points*).
- Jos Baeten, Suzana Andova (Eindhoven University of Technology), November 3, PROMACS project meeting.
- Mark Polman (EUR), December 14 (ADL-L).

Software Developed

- Enhancements to the Manifold compiler, runtime system, and its atomic process interface library, resulting in new versions.

Knowledge Transfer

- J.J.M.M. Rutten, introductory lecture on coalgebra, *Workshop on modal logic and coalgebra*, UvA, February 18.
- J.J.M.M. Rutten, invited course on coalgebra, ETL Tsukuba, Japan, February 22–March 3.
- J.J.M.M. Rutten, introductory lecture on coalgebra, Ecole Polytechnique Montréal, Canada, May 4.
- A. Baltag, invited course on games and logic, *International Summer School on Logic, Universal Algebra, and Theoretical Computer Science*, Johannesburg, South Africa, December 6–10.
- J.J.M.M. Rutten, invited course on coalgebra, *International Summer School on Logic, Universal Algebra, and Theoretical Computer Science*, Johannesburg, South Africa, December 6–10.
- F. Arbab, Seminar talk, Coordination models and languages, Computer Science Department, Leiden University, May 3, 1999.
- F. Arbab, University course, Special Topics on Component Based Software Engineering, Computer Science Department, Leiden University, Fall 1999.
- M.M. Bonsangue, invited lecture on quasi-metric spaces, Antwerpen University, Belgium, January 29.

Book

B. Jacobs, J.J.M.M. Rutten (eds.) (1999). *Proceedings of Second Workshop on Coalgebraic Methods in Computer Science (CMCS '99), ENTCS* **19**, Elsevier Science B.V.

Papers in Journals and Proceedings

J.J. den Hartog, E.P. de Vink, J.W. de Bakker. Full Abstractness of a Metric Semantics for Action Refinement. *Fundamenta Informaticae* **40**, 335–382.

E.P. de Vink, J.J.M.M. Rutten (1999). Bisimulation for probabilistic transition systems: a coalgebraic approach. *Theoretical Computer Science* **221**(1-2), 271–293.

J.J.M.M. Rutten (1999). Automata, power series, and coinduction: taking input derivatives seriously (extended abstract). J. Wiedermann, P. van Emde Boas, M. Nielsen (eds.). *Proceedings of ICALP '99*, LNCS **1644**, Springer, 645–654.

J.J.M.M. Rutten (1999). A note on coinduction and weak bisimilarity for while programs. *Theoretical Informatics and Applications (RAIRO)* **33**, 393–400.

F. Arbab (1999). Coordination Programming for Parallel and Distributed Applications. *Proceedings of the International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA '99)* **1**, Las Vegas, Nevada, USA, 1–10.

A. Baltag (1999). STS: A Structural Theory of Sets. *Logic Journal of IGPL* **7**(4), Oxford University Press, 481–515.

A. Baltag (1999). Interpolation and Preservation for Pebble Logic. *Journal of Symbolic Logic* **64**(2), 846–858.

M.M. Bonsangue, J.N. Kok (1999). Towards an infinitary logic of domains: Abramsky logic for transition systems. *Information and Computation* **155**, 170–201.

C.T.H. Everaars, B. Lisser (1999). Coordination of a Parallel Proposition Solver. P. Ciancarini, A.L. Wolf (eds.). *Proceedings of the Third International Conference on Coordination Languages and Models*, Amsterdam, The

Netherlands, Lecture Notes in Computer Science, **1594**, Springer-Verlag, 275–290.

K. Everaars, B. Koren, F. Arbab (1999). Dynamic Process Composition and Communication Patterns in Irregularly Structured Applications. *Proceedings of Irregular '99*, San Juan, Puerto Rico, Lecture Notes in Computer Science **1586**, Springer-Verlag, 1046–1054.

M.M. Bonsangue, J.N. Kok, K. Sere (1999). Developing Object-based Distributed Systems. P. Ciancarini, A. Fantechi, R. Gorrieri (eds.). *Proceedings of the 3rd IFIP International Conference on Formal Methods for Open Object-based Distributed Systems (FMOODS'99)*, Kluwer, 19–34.

M.M. Bonsangue, J.N. Kok, G. Zavattaro (1999). Comparing coordination models based on shared distributed replicated data. J. Carroll, H. Haddad, D. Oppenheim, B. Bryant, G.B. Lamont (eds.). *Proceedings of the 1999 ACM Symposium on Applied Computing (SAC '99)*, ACM press. San Antonio, Texas, USA, 146 –155.

M.M. Bonsangue, J.N. Kok, G. Zavattaro (1999). Comparing software architectures for coordination languages. P. Ciancarini, A. Wolf (eds.). *Proceeding of the 3rd international Conference on Coordination Languages and Models (Coordination 99)*, Amsterdam, The Netherlands, Lecture Notes in Computer Science **1594**, Springer-Verlag, 150–164.

CWI Reports

The following CWI reports were published by members of SEN3. See page 35 for the complete titles of the reports.

SEN-R9901	SEN-R9921	SEN-R9922
SEN-R9923	SEN-R9924	SEN-R9925

Other Publications

F. Arbab, K. Everaars, B. Koren (1999). Using Co-ordination to parallelize existing sequential programs. *ERCIM News* **36**, 33–34.

Evolutionary Computation and Applied Algorithmics – SEN4

Staff

- Dr. ir. J.A. La Poutré, theme leader
- Drs. F. Alkemade, junior researcher (PhD student) (from October 1)
- Drs. S.M. Bohté, junior researcher (PhD student)
- M. Bot, trainee (January 1–July 1)
- Dr. ir. D.D.B. van Bragt, postdoc
- Drs. E. Gerding, junior researcher (PhD student) (from November 1)
- Drs. M.B. de Jong, junior researcher (PhD student) (from November 1)
- Dr. C.H.M. van Kemenade, project member (till May 1)
- Prof. dr. J.N. Kok, advisor
- Dr. W.J. Kowalczyk, researcher (seconded; till September 1)
- Dr. W.B. Langdon, researcher
- J. Sprenger, programmer (till April 15)
- Drs. R. van Stee, junior researcher (PhD student)
- Prof. dr. J. Treur, senior researcher (seconded)
- Drs. M.C. van Wezel, project member (0.4 fte) (until March 1)
- R.W.T. Wildenberg, trainee (from October 1)

Scientific Report

The theme group SEN4 focused on evolutionary algorithms (SEN4.1), neural networks (SEN4.2), and discrete algorithms (SEN4.3), especially for problems related to management, economics, and e-commerce. Specific activities in these areas are selected and stated below.

Evolutionary Algorithms – SEN4.1

For evolutionary algorithms, the following results have been achieved on fundamentals of evolutionary computation and their applications.

Research was done and completed on the influence of evolutionary mechanisms on systems of agents that interact via the prisoner's dilemma game. Amongst others, the effects of fixed-opponent evolution, ecological evolution, and co-evolution were investigated. Co-evolution together with ecological evolution yielded more robust cooperation strategies than the other approaches; i.e., perform better against (new) various types of agents. The ecological evolution appears to be more realistic in its dynamics and is significantly related to the applied selection scheme. (D.D.B. van Bragt, C.H.M. van Kemenade, J.A. La Poutré.)

An evolutionary system, called EMINE, has been built with the purpose of studying emergent properties of bilateral negotiations. EMINE

stands for Evolutionary model for Multi-Issue NEgotiations. In this system, two populations, one of buyers and one of sellers, compete against each other in order to obtain the highest payoff, using an alternating offers negotiations protocol. The emphasis lies on negotiation with more than one issue, allowing win-win situations. Factors which have been studied are e.g. the effect of different selection schemes, the influence of the presence of deadlines, and time discounts. (E. Gerding, D.D.B. van Bragt, J.A. La Poutré.)

In addition, the fundamentals of evolutionary approaches for classical game theory on one issue have been investigated, especially by Evolution Strategies. Several classical game theoretic results have been investigated and obtained by this approach, thus laying a proper and solid base for extension and elaboration of the research problems with evolutionary approaches. (D.D.B. van Bragt, E. Gerding, J.A. La Poutré.)

Research was performed on stereotyping and the formation of social groups through tag use in populations playing the iterated prisoner's dilemma. Experiments were conducted using tag-mediated opponent selection, tag-mediated mate selection and tag-mediated strategy selection. The experiments showed that, under most circumstances, populations using tags reach a higher level of cooperation and do display more stable behaviour than populations that do not use tags, and that these affects were stabilized by recombination (sexual reproduction operators). (F. Alkemade, D.D.B. van Bragt, J.A. La Poutré.)

Furthermore, a start was made with research on electronic-market behaviour in the NWO-GBE project 'Evolutionary Exploration Systems for Electronic Markets'. A model with heterogeneous, bounded-rational agents was implemented for an economic market of the Cournot duopoly type and first results were obtained. (F. Alkemade, H.M. Amman (UvA), J.A. La Poutré.)

Work has been done on the theory and applications of genetic programming (GP). New genetic operators for GP been have devised, developed, and demonstrated. Also, aspects of the theory of how programs evolve have been extended and experimentally tested. For example studies of how the size and shape of programs change as they evolve, relating this to the distribution of programs particularly with respect to shape and likelihood of solving problems. This has revealed simple power law relationships of the bloating phenomena which can be used to predict future evolution and cast light on the usefulness or otherwise of existing biases and commonly used limits. These have led to the development of improved operators. (W.B. Langdon.)

Also, new ways of applying GP have been devised and tested. Especially, the usage of GP techniques for data mining problems was investigated, which rendered results that were often competitive or better than existing other approaches on several benchmark problems. (M. Bot and W.B. Langdon.)

Furthermore, research was performed on text classification and profiling. Especially, an approach of n-gram analysis of text, together with both k-nearest neighbours and genetic algorithms was implemented and tested. (W.B. Langdon and J.A. La Poutré.)

Neural Networks – SEN4.2

Research was performed on various aspects of fundamentals and applications of spiking neural networks.

Results on unsupervised clustering of data with spiking neural networks have been obtained based on a temporal Hebbian learning rule and layered, hierarchical networks. This yielded that advanced clustering problems with interlocking clusters or with large differences in scale could be solved by spiking neural networks. (S.M. Bohté, J.N. Kok, J.A. La Poutré.)

This unsupervised approach was also applied to non-parametric unsupervised classification problems in Remote Sensing data. This concerns the project on unsupervised image classification, carried out in cooperation with CRREL (Hanover USA) and CCSOM (University of Amsterdam). (S.M. Bohté, J.A. La Poutré, R.J. Mokken (CCSOM).)

Finally, research was done on developing a backpropagation algorithm for multi-delay spiking neurons (ongoing research). (S.M. Bohté, J.N. Kok, J.A. La Poutré.)

Discrete Algorithms – SEN4.3

Dynamic problem settings have been studied for fundamental and applied on-line optimization problems.

In the NWO-GBE project 'Dynamic Algorithms for On-Line Optimization', the on-line scheduling of jobs was studied, where jobs could be served partially to use the machines more efficiently, but preemptions are not allowed: the decision of how much time to spend on a particular

job has to be made in advance. Jobs have to start immediately on arrival or be rejected. A randomized lower bound for the competitive ration of 1.5 was obtained. Furthermore, algorithms with a deterministic upper bound for the competitive ratio of 1.83 for this problem were developed. (R. van Stee, J.A. La Poutré.)

Furthermore, the effects of resource augmentation in load balancing were examined. Algorithms were obtained with an exponentially decreasing (in the number of extra machines) competitive ratio, and an exponential lower bound. Also, an optimal preemptive algorithm was contructed and it was shown that the greedy algorithm is optimal for temporary tasks, if it has just one more machine. The research was performed in part while Dr. L. Epstein was visiting CWI. (R. van Stee, L. Epstein (Tel Aviv University).)

A start was made with the NWO-GBE project 'Quality of Service for Multimedia Systems'. Especially, literature research was performed and meetings with researchers from Philips Research Laboratories in Eindhoven were held. (M.B. de Jong, J.A. La Poutré.)

Trade Agents Project

A start was made with the Trade Agents projects ('Autonomous Systems of Trade Agents in E-Commerce'), a project funded by the Telematics Institute, and with project partners TNO, ING, an KPN (as of the year 2000). Several of the research activities described above where (also) part of this project, together with activities related to starting-up and literature overviewing. (J.A. La Poutré, D.D.B. van Bragt, E. Gerding, S.M. Bohté, W.B. Langdon.)

PhD Thesis

C.H.M. van Kemenade. *Recombinative Evolutionary Search*, PhD Thesis, Leiden University, March 1999, Thesis advisor: J.N. Kok.

Organization of Conferences, Workshops, Courses, etc.

- CEF'99 session on Evolutionary Computing (Conference on Computational Economics and Finance), Boston, USA, June 24–26, 1999: J.A. La Poutré.
- Member organising committee of GECCO'99, the Genetic and Evolutionary Computation Conference July 13 - 17, 1999, Orlando, Florida, USA: W.B. Langdon.
- Member Organising Committee of the Workshop on Theoretical aspects of GP, at GECCO'99: W.B. Langdon.

Knowledge Transfer

- J.A. La Poutré gave the course 'Search Techniques: Evolutionary Computation' and the course/seminar 'Complex Adaptive Systems: General Concepts and Economic Applications.' These were given at the Free University Amsterdam.
- W.B. Langdon gave seminars at the University of Leiden and Dortmund University, and a Tutorial at GECCO'99.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- *Universal Information Ecosystems*, Brussels, Belgium, March 18: E. Gerding.
- *Neural Coding*, Bremen, Germany, March 24–28: S.M. Bohté (*The effect of correlation on the fixing rate*).
- *EVO Workshop*, Göteborg, Sweden, May 25–30: W.B. Langdon.
- *Working Visit*, Dortmund, Germany, April, W.B. Langdon (*Genetic Programming and Data Structures*).
- *Workshop on 'Formal models of electronic commerce'*, Rotterdam, June 2–3: F. Alkemade.
- *Computational Economics and Finance CEF '99*, June 24–26: D.D.B. van Bragt (*The Influence of Evolutionary Selection Schemes on the Iterated Prisoner's dilemma*), J.A. La Poutré (*Governance and Matching*, paper by T.B. Klos (Faculty of Management and Organization, University of Groningen)).
- *Dagstuhl Seminar on Competitive Algorithms*, June 20–25: R. van Stee.
- *GECCO '99*, Orlando, USA, July 13–18: W.B. Langdon (*Foundations of Genetic Programming, and Size Fair + Homologous Crossover*).
- *Working Visit*, Göteborg, Sweden, August, W.B. Langdon.
- *Evonet Conference on Evolutionary Computing*, Antwerp, Belgium, October 5–7: D. van Bragt,
- *Seminar*, Limerick, Ireland, October 14–24: W.B. Langdon.

- *BNAIC '99*, Maastricht, November 3–4: D.D.B. van Bragt (*The Influence of Evolutionary Selection Schemes on the Iterated Prisoner's dilemma*), S.M. Bothé (*Unsupervised Clustering in a Network of Spiking Neural Networks*), M.B. de Jong, J.A. La Poutré, M. van Wezel (Neural Vision 2.0).
- *Seminar*, Birmingham, UK, November 5–8: W.B. Langdon (*Program Fitness Space*).
- *Electronic Commerce Congres*, The Hague, November 18: J.A. La Poutré.

Memberships of Committees and Other Professional Activities

J.A. La Poutré:
- Member of the Editorial Board of *Netnomics, journal for internet economics and e-commerce*; Baltzer Science Publishers.
- Member of the PhD Committee of C.H.M. van Kemenade: *Recombinative Evolutionary Search*, Leiden University, March 1999.
- Session organiser for CEF 1999 (Conference on Computational Economics and Finance): session on evolutionary computing in economics, Boston (USA), June 1999.
- Member of the program committee of the BNAIC'99 conference: the Eleventh Belgium-Netherlands Conference on Artificial Intelligence, Maastricht, November 3–4, 1999.

W.B. Langdon:
- Resource Review editor of *Genetic Programming and Evolvable Machines*.
- Co-chair of EuroGP'99, the Second European Workshop on Genetic Programming, Göteborg, Sweden, May 26–27, 1999.
- Member Programme committee of EvoISAP'99, the First European workshop on Evolutionary Image Analysis and Signal Processing.
- Member Programme committee of GECCO'99, the Genetic and Evolutionary Computation Conference July 13–17, 1999, Orlando, Florida, USA.

Visitors

- M. Herdy, Iteration GmbH, Berlin, Germany, February 4.
- T. Klos, Groningen University, February 18.
- T. Bäck, Managing Director (CASA) Dortmund, September 23.
- L. Epstein, Tel Aviv University, Israel, October 7–18.
- P. Nordin, Chalmers University of Technology, Sweden, November 17–18.
- J. Shaw, University of Sheffield, UK, November 10–12.

Software

- Neural Vision 2.0 for Rijkswaterstaat.
- Remote Sensing software.
- C++ and Java software to run GA and GP experiments.

Papers in Journals and Proceedings

S.M. Bohté, J.A. La Poutré, J.N. Kok (1999). Unsupervised Classification in a Layered RBF Network of Spiking Neurons. E. Postma, M. Gyssens (eds.). *Proceedings 11th Belgium-Netherlands Conference on Artificial Intelligence (BNAIC'99)*, Maastricht, The Netherlands, 257–258.

M. Bot, W.B. Langdon (1999). Application of genetic programming to induction of linear classification trees. E. Postma, M. Gyssens (eds.). *Proceedings of the Eleventh Belgium-Netherlands Conference on Artificial Intelligence (BNAIC'99)*, Kasteel Vaeshartelt, Maastricht, The Netherlands, 107–114.

D.D.B. van Bragt, C.H.M. van Kemenade, J.A. La Poutré (1999). The Influence of Evolutionary Selection Schemes on the Iterated Prisoner's Dilemma. *WWW-publication of the Fifth Conference on Computational Economics and Finance*, Boston, USA. Also in *Proceedings 11th Belgium-Netherlands Conference on Artificial Intelligence (BNAIC'99)*, Maastricht, The Netherlands, 43–50. Also published on invitation in the *Proceedings 9th Belgian-Dutch Conference on Machine Learning (BENELEARN'99)*, Maastricht, The Netherlands, 97.

F. Sian Chong, W.B. Langdon (1999). Java based distributed genetic programming on the internet. W. Banzhaf, J. Daida, A.E. Eiben, M.H. Garzon, V. Honavar, M. Jakiela, R.E. Smith (eds.). *Proceedings of the Genetic and Evolutionary Computation Conference* **2**, Morgan Kaufmann, Orlando, Florida, USA, 1229.

C.H.M. van Kemenade, J.N. Kok (1999). Cluster Evolution Strategies for Constrained Numerical Optimization. Z.W. Ras, A. Skowron (eds.). *Foundations of Intelligent Systems, 11th International Symposium, ISMIS 99*, Lecture

Notes in Artificial Intelligence **1609**, Springer-Verlag, 630–638.

C.H.M. van Kemenade, J.A. La Poutré, R.J. Mokken (1999). Density-Based Unsupervised Classification for Remote Sensing. Kanellopoulos, Wilkinson, Moons (eds.). *Machine Vision and Advanced Image Processing in Remote Sensing*, Springer-Verlag, Berlin, Germany, 248–258.

C.H.M. van Kemenade, J.A. La Poutré, R.J. Mokken (1999). Unsupervised Class Detection by Adaptive Sampling and Density Estimation. A. Stein, F. van der Meer (eds.). *Spatial Statistics and Remote Sensing*, Kluwer, 165–183.

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CWI Reports

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SEN-R9907 SEN-R9913 SEN-R9926

Other Publications

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MODELLING, ANALYSIS AND SIMULATION

General Overview

The research of MAS is organized into projects, which are connected to – and inspired by – the outside world through distinct applications. These projects are dealing with numerical analysis, large scale computing, computational fluid dynamics, and more theoretically oriented analysis for (partial) differential equations. They reflect the philosophy of MAS to contribute to these areas on the one hand and to keep, on the other hand, an open mind for problems and applications which are of high societal relevance. In this respect, knowledge-transfer is a key 'leitmotiv' in the work of MAS. In the international context, MAS is best characterized as a cluster with a SIAM signature.

MAS1 focused on numerical and PDE research, related to Environmental and Porous Media Applications, Mathematical Physics and Life Sciences. The numerical research was mainly concerned with 3D systems of nonlinear advection-diffusion-reaction equations modelling pollutant transport and chemistry in the atmosphere and surface water. New advection schemes and integration methods based on operator splitting, implicit-explicit and approximate matrix factorization techniques have been developed. The PDE research was in the direction of nonlinear evolution equations (parabolic and hyperbolic) and free boundary problems related to flow and transport in porous media. Mathematical Physics is a new and successful area, in particular because of the energetic leadership of Ebert. Exciting results were obtained concerning nonlinear dynamics and pattern formation in low temperature plasmas. Life Sciences is a new field which is developing rapidly under the dynamic leadership of Peletier. Many contacts were made with Amsterdam biologists and new projects were explored and defined.

The research of **MAS2** mainly involved numerical and computational analysis, resulting from extensive collaboration with industry, such as ship and aircraft building, electronic and chemical industry. Specific areas of interest were computational fluid dynamics (CFD), computational number theory (CNT) and initial value problems (IVP). Within CFD the work concentrated on advanced methods for systems of nonlinear conservation laws, multigrid and sparse grid solution methods, local grid adaptation and parallel computing. A particular research achievement was the development of a sparse grid algorithm for the three-dimensional equations of gas dynamics and the computation with this algorithm of the flow around an aircraft wing. CNT aimed at improving the factorization method 'Number Field Sieve'. Three factoring world records were established in 1999. One for the Special Number Field Sieve (SNFS): a 211-digit so-called Cunningham number, and two for the General Number Field Sieve (GNFS): a 140-digit and a 155-digit RSA numbers. The results offer cryptographers a reliable estimate of what is still a safe key size in practical RSA public-key crypto systems. IVP focussed mainly on the code PSIDE and the CWI Test Set.

The pilot theme **MAS3** started in 1998 with financial mathematics. This being a fairly new field at CWI, MAS3 has spent much of its time in establishing critical mass by hiring young researchers and mobilizing CWI staff, in exploring the mathematical problems involved and, last but not least, in developing contacts with potential users such as financial institutes and banks. In particular a program has been developed with the two Amsterdam universities which involves courses on Financial Time Series Analysis and Financial Engineering. Research topics that were identified include: statistics of stochastic processes, Monte Carlo and quasi-Monte Carlo methods for derivative pricing and risk management, and processes with heavy-tailed distributions. The young researchers Hoogland and Neumann have spent significant time on the setup and teaching of courses on Financial Engineering in the frame work of FWA (Financial Mathematics Amsterdam, a joint venture with UvA and VU). The pilot leader Schumacher left the CWI

in December 1999, to take up a position as full professor in Tilburg. Keane was willing to act as pilot leader ad interim.

Staff

- Environmental and Porous Media Applications – MAS1

  - J.G. Verwer
  - C.J. van Duijn
  - P.J. van der Houwen
  - U.M. Ebert
  - M. Arrayás
  - P.J.F. Berkvens
  - J.G. Blom
  - M.A. Botchev
  - C. Cuesta
  - I.A. Guerra
  - J. Hulshof
  - W.H. Hundsdorfer
  - J. Kok
  - D. Lanser
  - B. Lastdrager
  - W.M. Lioen
  - M.A. Peletier
  - P. Rodin
  - B.P. Sommeijer
  - N.M. Temme
  - F.J. Vermolen
  - R. Vidunas

- Industrial Applications – MAS2

  - P.W. Hemker
  - E.H. van Brummelen
  - S. Cavallar
  - J.L.M. van Dorsselaer
  - J. Frank
  - M. Genseberger
  - E. Havik
  - P.J. van der Houwen
  - J. Kok
  - B. Koren
  - P. Langereis
  - B. Lastdrager
  - M. Lewis
  - W.M. Lioen
  - M. Nool
  - J. Noordmans
  - H.J.J. te Riele
  - B.P. Sommeijer
  - F. Sprengel
  - J.J.B. de Swart
  - P. Wesseling

- Mathematics of Finance – MAS3

  - J.M. Schumacher
  - M.S. Keane
  - M.K. Çamlíbel
  - K.O. Dzhaparidze
  - J.K. Hoogland
  - C.D.D. Neumann
  - M.A. Peletier
  - H.J.J. te Riele
  - A.J. van der Schaft
  - J.H. van Zanten

- Secretary:

  - N. Mitrovic

CWI Reports

MAS-R9901. J.L. López, N.M. Temme. *Approximations of orthogonal polynomials in terms of Hermite polynomials.*

MAS-R9902. M.K.K. Cevik, J.M. Schumacher. *The robust regulation problem with robust stability.*

MAS-R9903. M.A. Peletier. *Non-existence and uniqueness results for the extended Fisher-Kolmogorov equation.*

MAS-R9904. C. Vuik, G. Segal, F.J. Vermolen. *A conserving discretization for a Stefan problem with an interface reaction at the free boundary.*

MAS-R9905. A.J. van der Poorten, H.J.J. te Riele, H.C. Williams. *Computer verification of the Ankeny-Artin-Chowla conjecture for all primes less than 100 000 000 000.*

MAS-R9906. P.J. van der Houwen, B.P. Sommeijer. *Factorization in block-triangularly implicit methods for shallow water applications.*

MAS-R9907. P.J. van der Houwen, B.P. Sommeijer. *Diagonally implicit Runge-Kutta methods for 3D shallow water applications.*

MAS-R9908. U.M. Ebert, W. van Saarloos. *Front propagation into unstable states: Universal algebraic convergence towards uniformly translating pulled fronts.*

MAS-R9909. H. Brunner, P.J. van der Houwen, B.P. Sommeijer. *Splitting methods for partial Volterra integro-differential equations.*

MAS-R9910. J.G. Blom, J.G. Verwer. *A comparison of integration methods for atmospheric transport-chemistry problems.*

MAS-R9911. G.W. Hunt, M.A. Peletier, M. Ahmer Wadee. *The Maxwell stability criterion in pseudo-energy models of kink banding.*

MAS-R9912. T. Lachand-Robert, M.A. Peletier. *An example of non-convex minimization and an application to Newton's problem of the body of least resistance.*

MAS-R9913. J.E. Frank, P.J. van der Houwen. *Parallel iteration of the extended backward differentiation formulas.*

MAS-R9914. J.K. Hoogland, C.D.D. Neumann. *Scaling invariance and contingent claim pricing.*

MAS-R9915. P.J. van der Houwen, B.P. Sommeijer. *Approximate factorization for time-dependent partial differential equations.*

MAS-R9916. J. Noordmans. *Adaptive sparse-grid combination-solutions for a singular perturbation problem.*

MAS-R9917. J.E. Frank, P.J. van der Houwen. *Diagonalizable extended backward differentiation formulas.*

MAS-R9918. D. Lanser, J.G. Blom, J.G. Verwer. *Spatial discretization of the shallow water equations in spherical geometry using Osher's scheme.*

MAS-R9919. J.K. Hoogland, C.D.D. Neumann. *Scaling invariance and contingent claim pricing II: path-dependent contingent claims.*

MAS-R9920. M.A. Peletier. *Sequential buckling: A variational analysis.*

MAS-R9921. P.J.F. Berkvens, M.A. Botchev, W.M. Lioen, J.G. Verwer. *A zooming technique for wind transport of air pollution.*

MAS-R9922. E.H. van Brummelen. *Analysis of the incompressible Navier-Stokes equations with a quasi free-surface condition.*

MAS-R9923. R. Chelluri, L.B. Richmond, N.M. Temme. *Asymptotic estimates for generalized Stirling numbers.*

MAS-R9924. F. Sprengel. *Some remarks on multilevel algorithms for finite difference discretizations on sparse grids.*

MAS-R9925. S. Cavallar, B. Dodson, A.K. Lenstra, P.C. Leyland, W.M. Lioen, P.L. Montgomery, B. Murphy, H.J.J. te Riele, P. Zimmermann. *Factorization of RSA-140 using the number field sieve.*

MAS-R9926. N.M. Temme, J.L. López. *The role of Hermite polynomials in asymptotic analysis.*

MAS-R9927. J.L. López, N.M. Temme. *Hermite polynomials in asymptotic representations of generalized Bernoulli, Euler, Bessel and Buchholz polynomials.*

MAS-R9928. F.J. Vermolen, J. Bruining, C.J. van Duijn. *Gel placement in porous media. Part I: Constant injection rate.*

MAS-R9929. F.J. Vermolen, G.J. Pieters, P.L.J. Zitha, J. Bruining. *A mathematical model for preflush treatment in an oil reservoir using a fully miscible fluid.*

MAS-R9930. B. Lastdrager, B. Koren, J.G. Verwer. *The sparse-grid combination technique applied to time-dependent advection problems.*

MAS-R9931. E.D. Havik, P.W. Hemker, W. Hoffmann. *Application of the overset grid technique to a model singular perturbation problem.*

MAS-R9932. C. Cuesta, C.J. van Duijn, J. Hulshof. *Infiltration in porous media with dynamic capillary pressure: travelling waves.*

MAS-R9933. P.W. Hemker, F. Sprengel. *On the representation of functions and finite difference operators on adaptive sparse grids.*

MAS-R9934. J.L.M. van Dorsselaer, M.E. Hochstenbach, H.A. van der Vorst. *Computing probabilistic bounds for extreme eigenvalues of symmetric matrices with the Lanczos method.* (Also appeared as Preprint # 1124, Mathematical Institute, Utrecht University.)

MAS-R9935. W.H. Hundsdorfer. *Accuracy and convergence of splitting with stabilizing corrections.*

Environmental and Porous Media Applications – MAS1

Staff

- Dr. J.G. Verwer, researcher, theme leader
- Prof. dr. ir. C.J. van Duijn, researcher, cluster and subtheme leader
- Prof. dr. P.J. van der Houwen, researcher, subtheme leader, CWI fellow
- Dr. U.M. Ebert, researcher, subtheme leader (NWO)
- Dr. M. Arrayás, postdoc (EU/UL)
- Dr. P.J.F. Berkvens, postdoc (NWO)
- Drs. J.G. Blom, researcher
- Dr. M.A. Botchev, postdoc (NWO)
- C. Cuesta, MSc, junior researcher (PhD student NWO)
- I.A. Guerra, MSc, junior researcher (PhD student)
- Dr. J. Hulshof, advisor (UL)
- Dr. W.H. Hundsdorfer, researcher
- Drs. J. Kok, researcher/programmer
- Ir. D. Lanser, junior researcher (PhD student NWO)
- Drs. B. Lastdrager, junior researcher (PhD student NWO)
- Drs. W.M. Lioen, programmer
- Dr. M.A. Peletier, researcher

- Dr. P. Rodin, guest researcher (Max Planck)
- Dr. B.P. Sommeijer, researcher
- Dr. N.M. Temme, researcher
- Dr. F.J. Vermolen, postdoc (EU/TUD)
- Dr. R. Vidunas, postdoc (NWO)

Scientific Report

MAS1 research deals with 'Applied Analysis, Numerical Analysis and Scientific Computing for Partial Differential Equations'. A small part of this work can be categorized as 'Mathematical Modelling'. Another small part concerns 'Asymptotics for special functions'. The subjects range from fundamental to practical and most of them are connected with a distinct application field.

Atmospheric flow and transport problems

The aim is to develop new, tailored numerical algorithms for large-scale atmospheric PDEs from the fields of air pollution modelling and atmospheric circulation. We have worked on three projects. (1) The first, on regional Long Term Ozone Simulation (LOTOS), has been supported by the national HPCN programme and finished end of '99. Co-operation took place with TNO-MEP. An extensive survey paper (MAS-R9825), by J.G. Verwer, J.G. Blom and W. Hundsdorfer on numerical and high performance computing aspects has been accepted for publication in the journal Surveys for Mathematics in Industry. The report MAS-R9910 (J.G. Blom and J.G. Verwer) comparing operator splitting to approximate matrix factorization within a Rosenbrock method will appear in the J. for Comp. and Appl. Math. (2) Related to LOTOS is the TM3 project. TM3 is a global atmospheric dispersion model in use by KNMI and IMAU and other European atmospheric institutes. With support from the NWO programme 'Wiskunde Toegepast' and NCF, we design new numerical algorithms for TM3 and work on parallelization. P.J.F. Berkvens, M.A. Botchev, W.M. Lioen and J.G. Verwer wrote the report MAS-R9921 on advection schemes and zooming. A shortened version has been published in the proceedings of the Conference 'Finite Volumes for Complex Applications', Duisburg, Germany, May '99. A report on the columnwise solution of vertical transport and chemical reactions is in preparation. A report on parallelization (NCF project) is planned for early 2000. (3) The third project is the PhD project of D. Lanser which focuses on atmospheric circulation. The long-term aim is to contribute to future generation grid-point weather forecast and climate models with grid resolutions far beyond existing ones used in spectral models. In 2000 this activity will be extended towards a co-operation with GMD/SCAI through the appointment of J. Frank as CWI-GMD postdoc. D. Lanser, J.G. Blom and J.G. Verwer have published a report on the spatial discretization of the spherical shallow water equations (MAS-R9918, under revision for the Journal of Computational Physics). A related report on time stepping issues is in preparation.

Flow and transport problems in surface water

The research concentrated on the transport of pollutants in surface water including chemical interactions. Since transport and chemistry are processes of a completely different nature taking place in three spatial dimensions, highly efficient tailor-made algorithms are needed. The research has been supported by the national HPCN programme and finished end of '99. Within the HPCN project we have co-operated with Delft Hydraulics and TU Delft. In the report MAS-R9906, P.J. van der Houwen and B.P. Sommeijer studied the convergence behaviour of iteration processes based on Approximate Factorization (AF) to solve the implicit relations in the underlying time integration method. This paper will appear in 'Applied Numerical Mathematics'. The same authors investigated in MAS-R9907 the influence on the convergence of the AF-process caused by a specific feature of the integration method. Based on the results of this analysis, they constructed special DIRK methods leading to optimal speed of convergence. These investigations will be published in 'J. Adv. in Comp. Math.'. The same authors have written a survey paper (MAS-R9915) on AF-based processes which will appear in the 'Millennium Issue of J. of Comp. and Appl. Math'.

Partial Differential Equations in Porous Media Research

The research is devoted to various aspects of flows in porous media and related nonlinear phenomena. (1) Project PDE/FBE, nonlinear partial differential equations and free boundary problems. In report MAS-R9932, C. Cuesta, C.J. van Duijn

and J. Hulshof have considered a model for non-static groundwater flow where the saturation-pressure relation is extended by a dynamic term. For this model, a rigorous study of global travelling wave solutions has been given, with emphasis on the role played by the dynamic term and the appearance of fronts. A further study was undertaken on the transport of solutes in the flow field induced by well-injection. There are marked differences between the two- and the three-dimensional situation. While the two-dimensional case has been examined several years ago, the three-dimensional case presented difficulties that now have been resolved. A paper on this topic (by C.J. van Duijn, I.A. Guerra, and M.A. Peletier) is in preparation. (2) The WELGEL project. In report MAS-R9928, F.J. Vermolen, H. Bruining and C.J. van Duijn have analyzed advective transport of polymers, crosslinkers and gel, taking into account non-equilibrium gelation, adsorption and precipitation. These equations have been studied in several steps using mainly analytical techniques. The results developed in this study can be used to validate numerical solutions obtained from commercial simulators. In report MAS-R9929, F.J. Vermolen, G.J. Pieters, P.L.J. Zitha and H. Bruining have proposed and analyzed a mathematical model for preflush treatment in an oil reservoir. The model, which is based on fully miscible two phase flow, predicts diversion behaviour of polymer-gel treatment from low permeability layers, and hence viscous preflush improves the efficiency of polymer-gel treatment.

Pattern formation and low temperature plasmas

A: Finances, formalities and collaborations: The research at CWI on pattern formation and low temperature plasmas started with U.M. Ebert's employment in 9/'98 on NWO funding, period 9/'98 – 8/'00. Her contract at CWI became permanent in 9/'99. The postdoc position of M. Arrayás (9/'99 – 8/'01) is paid by the European network 'Patterns, Noise and Chaos' through Leiden University. A successful proposal of Ebert at FOM-projectruimte '99 will allow the appointment of OIO D. Sijacic in '00 as well as visits of Dr. P. Rodin (Ioffe Inst. St. Petersburg and TU Berlin) of 12 months in total in '00 – '03. Two months of visit of Rodin in '99 were made possible by the Max Planck Prize of C.J. van Duijn. In '99, U.M. Ebert has been appointed leader of the FOM-working group TF-CWI (TF = Technische Fysica), which means that she will be the formal and scientific representative at CWI of the employer FOM (Utrecht) of D. Sijacic and P. Rodin. U.M. Ebert also has become leader of the new subtheme MAS1.4, and her research group has become part of the research school 'Center for Plasma Physics and Radiation Technology', coordinated at TU Eindhoven. The group profits from collaboration with numerical colleagues at CWI, in particular, with W.H.H. Hundsdorfer, and with the theoretical physics group of Prof. dr. W. van Saarloos at Leiden University. M. Arrayás and D. Sijacic aim at an analytical understanding of experiments at Münster University, at Philips and at TU Eindhoven. P. Rodin works on the explanation of experiments in St. Petersburg and Regensburg.

B: Science: U.M. Ebert's research at CWI focuses mainly on basic analytical aspects of nonlinear dynamics and on applications of concepts of nonlinear dynamics and pattern formation to low temperature plasmas. (1) Previous work of U.M. Ebert with W. van Saarloos (Leiden) on the universal algebraically slow convergence of pulled fronts has resulted in the extended research paper MAS-R9908. The paper is accepted for Physica D after revision. The universal algebraic convergence of pulled fronts also can be calculated for fronts generating periodic or chaotic structures (C. Storm, W. Spruijt, U. Ebert, W. van Saarloos (1999), *Universal Algebraic Relaxation of Velocity and Phase in Pulled Fronts Generating Periodic or Chaotic States*, Preprint Leiden University, submitted to *Phys. Rev. E.*). Such algebraic convergence ruins standard analytical approximation schemes (U. Ebert and W. van Saarloos (1999), *Breakdown of the Standard Perturbation Theory and Moving Boundary Approximation for 'Pulled' Fronts*, Preprint Leiden University, submitted to *Phys. Rep.*), as well as the advantages of numerical codes with adaptive grid refinement (W.H. Hundsdorfer, U.M. Ebert, in preparation). Pulled fronts also show a different response to multiplicative noise (A. Rocco from Barcelona, U.M. Ebert, W. van Saarloos, in preparation). (2) The understanding of pulled fronts is necessary for the study of impact ionization fronts in strong electric fields. Progress on the onset of ionization patterns in non-attaching and non-ionized gases has been made by M. Arrayás and U. Ebert by calculating the dispersion relation of

negative fronts for vanishing diffusion constant (in preparation). P. Rodin, W.H. Hundsdorfer and U. Ebert have studied aspects of planar impact ionization fronts in layered semiconductor structures for power electronics applications (in preparation). Numerical problems in simulating ionization fronts in higher dimensions have initiated the numerical research on pulled fronts with W.H. Hundsdorfer mentioned earlier under (1). (3) The article on diffusive motion of long polymer chains in Eur. Phys. J. B ('99) results from previous collaboration of U.M. Ebert with L. Schäfer (Essen University) and A. Baumgärtner (Forschungszentrum Jülich). (4) U.M. Ebert and M. Arrayás also have become involved in the analysis of phytoplankton bloom associated with the new subtheme on life sciences (in preparation).

Applications from the life sciences
This subject is new and will focus on PDE problems from biology and medicine. In 1999 contacts have been made with groups working in cell-, neuro- and microbiology from the two universities in Amsterdam (UvA and VU), the Netherlands Institute for Brain Research (NIH), and the Netherlands Cancer Institute (NKI). First research results and papers are expected in 2000. In 1999 we have started three activities. (1) A mathematical study into metabolic control in pathways by means of analytical and numerical investigations of diffusion-reaction systems which take into account molecular crowding (M.A. Peletier and J.G. Blom). This application comes from cell biology and has been proposed by cell-biologists from the UvA and VU. The ICES–KIS programme supports the project and the co-operation with the UvA and VU. (2) A numerical study of mixed parabolic-gradient systems (J.G. Verwer and B.P. Sommeijer). The application is axonal outgrowth from neurons during development of the nervous system, a problem proposed by a research group from the NIH. Currently we are seeking external support to set-up a long-lasting co-operation. (3) A pilot study into the numerical solution of a chemotaxis diffusion-reaction system modelling tumor growth (J.G. Verwer and A. Gerisch, University of Halle, Germany). The specific research question is whether such systems can be efficiently solved by operator splitting.

A variational analysis of buckling patterns
This is a continuation of work that M.A. Peletier started in Bath, United Kingdom. The emphasis lies in the application of variational concepts and techniques to identify properties of patterns that arise in localized buckling in long structures. This resulted in a first main publication (Report MAS-R9920, submitted to SIAM J. Math. Anal) in which the technique is set on a rigorous footing, and a characterization is given of a certain class of patterns. Additional results concern the development of a simple model for multilayer folding in geological structures (MAS-R9911, submitted to J. Struct. Geol). A spin-off result is described in MAS-R9903, which is now published in Nonlinearity, in which non-existence or uniqueness of solutions of a certain type is proved for a class of equations that arises in these applications. All of this work is done in collaboration with the Centre for Nonlinear Mechanics in Bath.

Newton's body of minimal resistance
This is part of an ongoing project in collaboration with T. Lachand-Robert (Paris). The problem, as originally formulated by Newton, is to find the form of a solid that offers the least resistance to a stream of particles. Only partially solved by Newton, important questions remain, among which the most important one the actual form of the minimal solid. In the report MAS-R9912 we prove an important, and unexpected, property of the solid: its surface is developable, i.e. can be piecewise constructed from flat surfaces that are bent without in-plane stretching. A second result, concerning optimization in a smaller class, is in preparation.

Asymptotics and special functions
R. Vidunas has been appointed within the NWO project *Algorithmic Methods for Special Functions by Computer Algebra* (a joint project with Prof. dr. T.H. Koornwinder, University of Amsterdam). He started on November 1 and his research at CWI is in the field of computer algebra methods for handling uniform asymptotic expansions of certain special functions. N.M. Temme wrote several CWI reports with J.L. López (Pamplona, Spain) on expanding polynomials in terms of other polynomials (say, Laguerre polynomials in terms of Hermite polynomials), in order to obtain asymptotic representations. With J. Segura and A. Gill (Alicante, Spain) he inves-

tigated numerical aspects of the solutions of an inhomogeneous Airy differential equation and of a class of Legendre functions; two papers have been submitted. With R. Chelluri and L.B. Richmond (Waterloo, Canada) he wrote a paper on generalized Stirling numbers, which has been accepted by the journal Analysis. N.M. Temme also wrote three outlines for chapters in the new edition of the Handbook for Mathematical Functions (Abramowitz and Stegun).

Separate numerical projects

(1) The PhD project of B. Lastdrager (NWO/GBE, jointly with MAS2) on the use of sparse-grid techniques for time-dependent PDE problems. The sparse-grid combination techniques have been examined for linear advection problems, see the report MAS-R9930 by B. Lastdrager, B. Koren and J.G. Verwer. A similar report on advection-diffusion problems is in preparation. The first report on the subject (MAS-R9823) is under revision for the journal Computing.

(2) In report MAS-R9904, C. Vuik, G. Segal and F.J. Vermolen have considered the dissolution of an Al_2Cu particle, with interface reactions, leading to a Stefan problem with non-smooth initial boundaries. The displacement of the free boundary has been computed by a finite element method based on the balance of atoms. Numerical results were obtained for the dissolution of an Al_2Cu particle in an Al-Cu alloy, with a varying rate of the interface reaction.

(3) In report MAS-R9935, W.H. Hundsdorfer has analyzed convergence properties of the method of Stabilizing Corrections, which is an internally consistent splitting scheme for initial-boundary value problems. To improve accuracy and stability of explicit terms, several extensions (multi-step and multi-stage) have been developed and analyzed for convection-diffusion-reaction equations.

(4) In a project commissioned by the Theoretical Physics group of FOM–Rijnhuizen, J. Kok carried out an investigation regarding the applicability of the VLUGR2 software to certain coupled IVP systems of second and fourth order PDEs, together with intensive testing of the software, with the prudent conclusion that the submitted problem exceeded the applicability domain of the VLUGR2 software.

Organization of Conferences, Workshops, Courses, etc.

- J.G. Verwer and J. Kok organized TASC Symposium 12, CWI, February 9.
- J.G. Verwer organized the Mini-Symposium Numerical Algorithms in Air Quality Modelling, at the Fifth SIAM Conference on Mathematical and Computational Issues in the Geosciences, March 24–27, San Antonio, Texas.
- M.A. Peletier co-organized the British Applied Mathematics Colloquium, Bath, United Kingdom, April 12–15, and ran a mini-symposium on Structural Geology during this meeting.
- C.J. van Duijn was a member of the organizing committee of the SIAM Conference on Mathematical and Computational Issues in the Geosciences, April 24–26, San Antonio.
- N.M. Temme organized the Mini-Symposium Methods and Applications of Asymptotic Analysis at The Fourth International Congress on Industrial and Applied Mathematics (ICIAM 99), Edinburgh, Scotland, July 5–9.
- J.G. Verwer organized the MAS-Colloquium 'Numerical Methods Used in Atmospheric Circulation Models', CWI, November 23.
- N.M. Temme is the organizer of the general monthly CWI seminar 'Scientific Meetings'.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- M.A. Peletier spent a month in Bath, United Kingdom, on a working visit (January 25–February 18).
- C.J. van Duijn. Visit to Heidelberg University, February 15–18. Collaboration with W. Jaeger and A. Mikelic. Lecture: *Effective equations for multi-phase flow.*
- N.M. Temme, March 1–5, visit to University of Zaragoza (Spain) (*The Role of Hermite Polynomials in Asymptotic Analysis*).
- 12e Symposium Plasmafysica en Stralingstechnologie, March 9–10, Lunteren. U. Ebert, (poster on *Basic Instabilities and Pattern Formation in Electric Discharges*).
- M.A. Peletier visited the University of Nebraska, March 16–23, and gave a lecture (*Localized Buckling in Geological Structures*).
- ITW Symposium, March 19, CWI. J.G. Verwer (*Rekenen aan luchtvervuiling*).

- Fifth SIAM Conference on Mathematical and Computational Issues in the Geosciences, March 24–27, San Antonio, Texas. C.J. van Duijn, co-organizer. J.G. Blom (*Long term ozone simulation*), D. Lanser (*A numerical grid-point based method for the Shallow Water Equations on the sphere*), J.G. Verwer (*Numerical Time Integration for Air Pollution Models*).
- Dutch Mathematical Congress, SWON/STW Minisymposium 'Wiskunde Toegepast', April 8, Utrecht. M.A. Botchev (*A Zooming Technique for Wind Transport of Air Pollution*).
- N.M. Temme, April 13, Technical University Eindhoven, Lecture in the General Mathematical Colloquium (*The Role of Hermite Polynomials in Asymptotic Analysis*).
- C.J. van Duijn. Visit to Universidad de Chile, April 15–29. Collaboration with R. Manasevich. Two lectures on mathematical issues in porous media flow.
- J.G. Verwer visited the INRIA institute CERMICS in Paris, April 7–9, in connection with joint research with Dr. B. Sportisse.
- Workshop of the EU-network *Patterns, Noise and Chaos*, May 6–8, Killarney, Ireland. U. Ebert (talk on *Streamer formation in gas discharges as a problem of interfacial pattern formation*)
- Symposium Numerical Solution of Initial Value Problems, May 21, Leiden. W. Hundsdorfer (*Monotonicity of linear two-step methods – application to convection equations*).
- M.A. Peletier gave an invited lecture at the 1999 AIO-course in Twente (*Sequential Buckling: A Variational Analysis*). June 7–11.
- Workshop on Mathematical Aspects of Materials Science: From Atomic to Continuum Scales, June 20–26, Schloss Ringsberg, Tegernsee, Germany. U. Ebert (talk on *Streamer formation in gas discharges as a problem of interfacial pattern formation*).
- N.M. Temme, June 21–25, International Workshop on Special Functions, Hong Kong (*The Role of Hermite Polynomials in Asymptotic Analysis*).
- The 18th Biennial Conference on Numerical Analysis, June 29 – July 2, Dundee. W. Hundsdorfer (*Partially implicit BDF2 blends for convection dominated flows*), B.P. Sommeijer (*Approximate factorization in time-dependent PDEs*).
- Workshop on Phase Change with Convection Modelling and Validation, June 24–26, Warsaw. F.J. Vermolen (*An asymptotic solution for the dissolution of particles in multi-component alloys*).
- International Conference in Memory of S.N. Kruzhkov on Nonlinear PDEs, June 28 – July 3, Besançon, France. C. Cuesta, I.A. Guerra.
- U. Ebert, July 5–6, visit and talk (*Strukturbildung in elektrischen Entladungen*) at the 'Seminar über Nichtlinearität und Unordnung in komplexen Systemen' at Univ. Magdeburg, Germany.
- U. Ebert, July 7, visit and talk (*Tips und Bemerkungen zu einer Karriere als Physikerin*) at the Frauensommerschule for female high school students at Univ. Essen, Germany.
- ICIAM99, July 5–9, Edinburgh. M.A. Botchev and P.J.F. Berkvens (*A Zoom Technique for Wind Transport of Air Pollution*), J.G. Verwer (*Results on splitting stiff advection-diffusion-reaction problems*), N.M. Temme (*Hermite-type Asymptotic Approximations of Classical Orthogonal Polynomials*).
- C.J. van Duijn. Visit to CSIRO–Land and Water, Canberra, Australia, July 13–22. Collaboration with R.A. Wooding. Lecture: *Stability criteria for density induced porous media flow.* Speech at the National Academy of Australia, Commemorative Gathering for J.R. Philip.
- 2nd International Symposium on Finite Volumes for Complex Applications, July, 19–22, 1999, Duisburg, Germany. M.A. Botchev (*A Zooming Technique for Wind Transport of Air Pollution*).
- ENUMATH 99, July 26–31, Jyväskyla, Finland. W.H. Hundsdorfer (*Locally implicit time stepping for convection dominated flows*).
- C.J. van Duijn. Workshop Pattern Formation in Physics and Engineering, Lorentz Centre, Leiden University, August 18–20. Lecture: *Multi-phase flow in porous media with micro structure.*
- C.J. van Duijn. Visit to Lyon University-1, September 5–8. Collaboration with A. Mikelic.
- TMR workshop Nonlinear Parabolic Equations and Related Topics, September 13–15, Leiden. C. Cuesta (*Dynamic capillary pressure in unsaturated groundwater flow: travelling waves*), I.A. Guerra (*Injection from a well with constant flow rate in 3D*), F. Vermolen.
- N.M. Temme, September 20–24, International Conference on Orthogonal Polynomials, Patras, Greece (*The Askey Scheme Viewed from Asymptotic Analysis*).

- M.A. Peletier gave an invited lecture in Köln (*Sequential Buckling: A Variational Analysis*). October 23.
- C.J. van Duijn. Visit to WIAS–Berlin, October 28–30, Meeting of Scientific Council.
- DWD Workshop at SCAI–GMD, Bonn, Nov 10. J.G. Verwer (*On local uniform grid refinement*).
- Scientific meeting of the CWI, November 19, U.M. Ebert (*Pattern formation and low temperature plasmas*).
- C.J. van Duijn. Multi-Scale and Homogenization Workshop, Heidelberg, November 29–December 3. Lecture: *Homogenization in porous media flow.*
- 8th workshop on the Solution of Partial Differential Equations on the Sphere, November 30–December 3, San Francisco, D. Lanser (*Spatial Discretization of the Shallow Water Equations in Spherical Geometry using Osher's Scheme*).
- 2nd Euregional WELT–PP (Workshop on the Exploration of Low Temperature Plasma Physics), December 2–3, Rolduc. M. Arrayás and U.M. Ebert (poster on 'Pattern Growth in Electric Discharges').
- W.H. Hundsdorfer visited INRIA – Rocquencourt, ESTIME, November 22–December 17, in connection with joint work with J. Jaffré.
- M.A.Botchev visited the group of R.P. Fedorenko at the Keldysh Institute for Applied Mathematics in Moscow on December 23, with an informal talk on local grid refinement and vertical transport—chemistry treatment in air pollution models.

Memberships of Committees and Other Professional Activities

J.G. Verwer:
- Member Advisory Committee of CMUC (The Centre for Mathematics of the University of Coimbra, Portugal).
- Senior Editor *Applied Numerical Mathematics.*
- Co-ordinator of the TASC project 'HPCN for Environmental Applications'.
- Member organizing committee 9th Seminar NUMDIFF – Numerical Solution of Differential and Differential-Algebraic Equations, Halle, Germany, Sept. 4–8, 2000.
- Committee member PhD thesis B. Sportisse, Ecole Polytechnique, Paris April 7 (*Contribution à la modélisation des écoulements réactifs: réduction des modèles de cinétique chimique et simulation de la pollution atmosphérique*).

C.J. van Duijn:
- Professor of Applied Mathematics, Delft University of Technology.
- Editor-in-Chief of *Computational Geosciences.*
- Member editorial board *Interfaces and Free Boundaries.*
- Vice-chairman of Scientific Council WIAS–Berlin.
- Chairman of the Panel of the NWO Priority Programme 'Nonlinear Systems'.
- Member PhD committee H. Bijl, Delft University of Technology, February 1 (Computation of flow at all speeds with a staggered grid).
- Member PhD committee S.M.P. Blom, Delft University of Technology, June 28 (*Relative permeability to near-miscible fluids*).
- Promotor of F.M. van Kats, Delft University of Technology, October 25 (*Aspects of upscaling in multi-phase flow problems*).
- External examiner PhD thesis N. Ramarosy, Université de Paris-Sud, Centre d'Orsay, January 22 (*Application de la méthode des volumes finis à des problèmes d'environnement et de traitement d'image*).

P.J. van der Houwen:
- Professor of Applied Mathematics, University of Amsterdam.
- Managing editor Letter Section *Journal of Computational and Applied Mathematics* (JCAM).
- Associate Editor *Zeitschrift für Angewandte Mathematik und Mechanik* (ZAMM).
- Co-chairman Biennial Conference on Numerical Methods for Differential Equations (NUMDIFF) and editor *NUMDIFF Proceedings.*
- Member Board of International Association for Mathematics and Computers in Simulation (IMACS).
- Member Committee Wetenschappelijk Gebruik Supercomputers (WGS).
- Member Scientific Committee Institute for Advanced Studies 'Stieltjes'.

U.M. Ebert:
- Member of the PhD committee of Ir. E.H.R. Gaxiola, March 15, TU Eindhoven
- Leader of the FOM-working group TF-CWI since August '99.
- Leader of the CWI-group of the research school 'Center for Plasma Physics and Radiation Technology' since July '99.

W.H. Hundsdorfer:

- Lecturer in AIO course on Numerical Methods for Initial Value Problems at the Thomas Stieltjes Institute (University of Leiden).

W.M. Lioen:
- Secretary organizing committee of the 1999 Woudschoten Conference on Numerical Analysis.

M.A. Peletier:
- Secretary of the Dutch Mathematical Society (Wiskundig Genootschap).

B.P. Sommeijer:
- Lecturer in the course Parallel Scientific Computing & Simulation (University of Amsterdam).
- Member organizing committee 9th Seminar NUMDIFF – Numerical Solution of Differential and Differential-Algebraic Equations, Halle, Germany, September 4–8, 2000.

N.M. Temme:
- Editor *Nieuws Analyse.*
- Editor *CWI Quarterly.*
- Editor *ZAMP.*
- Editor *Mathematics of Computation.*
- Editor *Methods and Applications of Analysis.*
- Editor *SIAM Journal on Mathematical Analysis.*
- Editor Update *Handbook of Mathematical Functions* ('Abramowitz and Stegun').
- Member of the governing board of the Stieltjes Institute for Mathematics and CWI-coordinator for the Dutch research schools in mathematics and computer science.

Visitors

- G. Strang (J.G. Verwer), MIT, 10.01–11.01.
- M. Bertsch (C.J. van Duijn), Italy, 16.01–19.01.
- B. Buffoni (M.A. Peletier), ETH Lausanne, January.
- R. Manasevich (C.J. van Duijn), Univ. Santiago, 01.02-15.02.
- G. Cats (C.J. van Duijn, J.G. Verwer), KNMI, 03.02.
- A. Mikelic (C.J. van Duijn), Univ. Lyon, 4.03–7.03.
- I. Brauer (U.M. Ebert), Inst. of Applied Physics, Univ. Münster, 15.04.
- B. Wingate (D. Lanser), Los Alamos National Laboratory, 20.04.
- S. Chen (J.G. Verwer), Purdue University, 23.04.
- D.L. Williamson (D. Lanser), NCAR Boulder, 26.04.
- M. Arrayás (U.M. Ebert), Lancaster University, 26.04–27.04.
- R. Kobayashi (U.M. Ebert), Hokkaido University, Sapporo, 26.05.
- W.R. Rossen (C.J. van Duijn), Univ. Texas at Austin, 6.06–19.06.
- J. Philip (C.J. van Duijn), CSIRO, 13.06–28.06.
- N. Neuss (C.J. van Duijn), IWR, Univ. Heidelberg, 14.06–18.06.
- J. Fuhrmann (C.J. van Duijn), WIAS, Berlin, 21.06–26.06.
- G. Galiano (C.J. van Duijn), University Ovideo, Spain, 9.07–17.07.
- A. Mikelic (C.J. van Duijn), Univ. Lyon, France, 15.08-17.08.
- D. Marchusin (C.J. van Duijn), Rio de Janeiro, Brasil, 21.08–28.08.
- D.F. Griffiths (J.G. Verwer), University of Dundee, 02.09–03.09.
- A. Gerisch (J.G. Verwer), University of Halle, 25.10–30.10.
- R. Lewandowski (C.J. van Duijn), Rennes, France, 08.11–10.11.
- J. Huisman (B.P. Sommeijer), Universiteit van Amsterdam, 16.11.
- W. Joppich (J.G. Verwer), GMD, Bonn, 22.11–23.11.
- M.P. Cullen (J.G. Verwer), ECMWF, Reading, 23.11–24.11.
- P. Rodin (U.M. Ebert), Ioffe Institute St. Petersburg and TU Berlin, work visits of 9 weeks in total in '99 (21.–28.03, 15.08–12.09, 28.11–26.12).

Software Developed

The aim of the LOTOS project (MAS1.1) was to build from scratch a 3D regional atmospheric dispersion model driven by wind fields and emissions from data bases in use by TNO. All the numerical software for LOTOS has been developed at CWI. In 1999 the final running CWI prototype has been transferred to TNO.

Within project MAS1.2 a similar model has been developed to simulate transport of pollutants and sediments in shallow seas. Currently a package is available for seas with arbitrary coastlines. Tuned visualization software has also been developed and attached to the numerical package.

Papers in Journals and Proceedings

P.J.F. Berkvens, M.A. Botchev, W.M. Lioen, J.G. Verwer (1999). A zooming technique for wind Transport of air pollution. R. Vilsmeier, F. Benkhaldoun, D. Hänel (eds.). *Finite Volumes for Complex Applications II, Problems and Perspectives*, Hermes Science Publications, Paris, 499–506.

M.A. Botchev, G.L.G. Sleijpen, H.A. van der Vorst (1999). Stability control for approximate implicit time-stepping schemes with minimum residual iterations. *Appl. Numer. Math.* **31**, 239–254.

C.J. Budd, G.W. Hunt, M.A. Peletier (1999). Self-similar fold evolution under prescribed end-shortening. *J. Math. Geol.* **31**, 989–1005.

S.P. Chen, M.S. Vossenberg, F.J. Vermolen, J. van de Langkruis, S. van der Zwaag (1999). Dissolution of β particles in an Al-Mg-Si alloy during DSC runs. *Materials Science and Engineering* **A272**, 250–256.

K.A. Driver, N.M. Temme (1999). Zero and pole distribution of diagonal Padé approximants to the exponential function. *Questiones Mathematicae* **22**, 7–17.

C.J. van Duijn, J.R. Philip (1999). Redistribution with air diffusion. *Water Resources Research* **35**, 2295–2300.

M. Guedda, D. Hilhorst, M.A. Peletier (1999). Blow-up of interfaces for an inhomogeneous aquifer. *Free Boundary Problems: Theory and Applications*, (Crete, 1997), Chapman & Hall/CRC Res. Notes Math., 409, Chapman & Hall/CRC, Boca Raton, FL, USA, 131–138.

P.J. van der Houwen, E. Messina, J.J.B. de Swart (1999). Parallel Störmer-Cowell methods for high-precision orbit computations. *Appl. Numer. Math.* **31**, 353–374.

P.J. van der Houwen, E. Messina (1998). Splitting methods for second order initial-value problems. *Numerical Algorithms* **18**, 233–258.

P.J. van der Houwen (1999). Parallel methods for nonstiff VIDEs. *J. Integral Equations and Applications* **10**, 503–515.

W.H. Hundsdorfer (1999). Stability of approximate factorization with θ-methods. *BIT* **39**, 473–483.

R. Keppens, G. Töth, M.A. Botchev, A. van der Ploeg (1999). Implicit and semi-implicit schemes: algorithms. *Internat. J. Numer. Methods Fluids* **30**, 335–352.

T. Lachand-Robert, M.A. Peletier (1999). Extremal points of a functional on the set of convex functions. *Procs. Amer. Math. Soc.* **127**, 1723–1727.

D. Lanser, J.G. Verwer (1999). Analysis of operator splitting for advection-diffusion-reaction problems. *J. Comp. Appl. Math.* **111**, 201–216.

J.L. López, N.M. Temme (1999). Uniform approximations of Bernoulli and Euler polynomials in terms of hyperbolic functions. *Stud. in Appl. Math.* **103**, 241–258.

J.L. López, N.M. Temme (1999). Hermite polynomials in asymptotic representations of generalized Bernoulli, Euler, Bessel, and Buchholz polynomials. *J. Math. Anal. Appl.* **239**, 457–477.

J.L. López, N.M. Temme (1999). Approximations of orthogonal polynomials in terms of Hermite polynomials. *Methods and Applications of Analysis* **6**, 131–146.

M.A. Peletier (1999). Non-existence and uniqueness results for fourth-order Hamiltonian systems. *Nonlinearit* **12**, 1555–1570.

L. Schäfer, A. Baumgärtner, U. Ebert (1999). Reptational dynamics of a polymer chain is stable against kinematic disorder. *Eur. Phys. J. B.* **10**, 105–117.

R.J. Schotting, H. Moser, S.M. Hassanizadeh (1999). High-concentration-gradient dispersion in porous media: experiments, analysis and approximations. *Advances in Water Resources Research* **22**, 665–680.

B.P. Sommeijer (1999). The iterative solution of fully implicit discretizations of three-dimensional transport models. *Procs. of the 10$^{\text{th}}$ Parallel CFD Conference*, Taiwan, 1998, 67–74.

F.J. Vermolen, C. Vuik (1999). A vector valued Stefan problem from aluminium industry. *Nieuw Archief voor Wiskunde* **17**, 205–218.

F.J. Vermolen, C. Vuik, S. van der Zwaag (1999). An asymptotic solution for the dissolution of particles in multi-component alloys. T.A. Kowalewski, F. Stella, J. Banaszek, J.S. Szmyd (eds.). *Proceedings Workshop on Phase Change with Convection Modelling and Validation*, June 24–26, Warsaw, 155–159.

J.G. Verwer, E.J. Spee, J.G. Blom, W. Hundsdorfer (1999). A second order Rosenbrock method applied to photochemical dispersion problems. *SIAM J. Sci. Comput.* **20**, 1456–1480.

P.L.J. Zitha, F.J. Vermolen, J. Bruining (1999). Modification of two phase flow properties by adsorbed polymers and gels. *SPE* **54737**, 299–312.

CWI Reports

The following CWI reports were published by members of theme MAS1. See page 59 for the complete titles of the reports.

MAS-R9901	MAS-R9903	MAS-R9904
MAS-R9906	MAS-R9907	MAS-R9908
MAS-R9909	MAS-R9910	MAS-R9911
MAS-R9912	MAS-R9915	MAS-R9918
MAS-R9920	MAS-R9921	MAS-R9923
MAS-R9926	MAS-R9927	MAS-R9928
MAS-R9929	MAS-R9930	MAS-R9932
MAS-R9935		

Industrial Applications – MAS2

In 1999 the number of projects in MAS2 was considerably reduced. The project on Plasma Physics Simulation was incorporated in the project Computational Fluid Dynamics. The project on Discontinuous Dynamical Systems merged with the theme MAS3 and the project Exploratory Research, where convection dominated numerical problems are studied, merged with Computational Fluid Dynamics. Thus, in 1999 the research activities in the theme MAS2 were divided over three subthemes (projects), each of which had its own staff and responsible project leader. The remaining subthemes in MAS2 are:

MAS2.1	Computational Fluid Dynamics (Koren)
MAS2.2	Computational Number Theory and Data Security (Te Riele)
MAS2.3	Numerical Algorithms for Initial-Value Problems (Van der Houwen)

In December it was decided that in 2000 the theme MAS2 will be continued under the name 'Computational Fluid Dynamics'.

Staff

On July 23, our colleague Jaap Noordmans passed away. Jaap has been seriously ill for almost four years. On July 27, he was buried in Garyp, the place of his birth, surrounded by family, friends and colleagues. Jaap has fought till the last moment against his disease and has continued to be committed to his research work. His last research report dates from June 1999. We will continue to remember Jaap as a very fine colleague and friend.

- Ir. E.H. van Brummelen, PhD student
- Drs. S. Cavallar, PhD student
- Dr. J.L.M. van Dorsselaer, postdoc (joint with Mathematical Institute, Utrecht University)
- J. Frank, MSc, PhD student (seconded by Delft University of Technology to CWI)
- Drs. M. Genseberger, PhD student (joint with Mathematical Institute, Utrecht University)
- Drs. E. Havik, PhD student (joint with Korteweg-de Vries Institute for Mathematics, University of Amsterdam)
- Prof. dr. P.W. Hemker, researcher, theme leader
- Prof. dr. P.J. van der Houwen, CWI fellow, project leader
- Drs. J. Kok, researcher
- Dr. ir. B. Koren, researcher, project leader
- P. Langereis, trainee (until November 30)
- Drs. B. Lastdrager, PhD student (joint with MAS1)
- Ir. M. Lewis, PhD student (since October 1)
- Drs. W.M. Lioen, scientific programmer
- Drs. M. Nool, scientific programmer
- Ir. J. Noordmans, PhD student (deceased, July 23)
- Dr. ir. H.J.J. te Riele, researcher, project leader
- Dr. B.P. Sommeijer, researcher
- Dr. F. Sprengel, postdoc (joint with GMD-SCAI, until October 31)
- Dr. J.J.B. de Swart, postdoc (until September 30)
- Prof. dr. ir. P. Wesseling, advisor (Faculty of Mathematics and Informatics, Delft University of Technology)

Scientific Report

MAS2.1

GMD – In the framework of the joint CWI-GMD-project *Sparse Grids and Overlapping Grids in LiSS*, Sprengel proposed some algorithms to solve the system of linear equations arising from the finite difference discretization on sparse grids. For this, use was made of the multilevel structure of the sparse grid space or its full grid subspaces. For a better understanding

of the necessity of strong damping in these algorithms, Hemker and Sprengel investigated the finite difference operators in more detail. Several representations of functions on sparse grids were distinguished and the application of finite difference operators to these representations were described. Comparing the operators on sparse and full grids in hierarchical representation, the reason for the strong damping in the multigrid algorithms was found: the full grid operators are *not* a good approximation to the sparse grid operators. As a result, other multigrid algorithms were proposed. There the operators on the full grids are no longer finite difference operators but Galerkin approximations of the sparse grid operator. In the special case of Poisson-type equations, they can be written in terms of scaled finite difference operators on full grids for the different directions.

MARIN – In the framework of the MARIN-project *Robustness Improvement and Extension of PARNASSOS*, Van Brummelen proposed an extension to Navier-Stokes flow of an iterative method which had been applied successfully to steady free-surface potential flow. The subproblem corresponding to the incompressible Navier-Stokes equations subject to the so-called quasi free-surface condition, was thoroughly analyzed. It was found that the iterative method proposed is indeed suitable for solving steady free-surface Navier-Stokes flow. As a sequel, the iterative method was implemented and numerical experiments were conducted. In this follow-up work, Van Brummelen developed a method for analyzing the properties of discretization schemes for free-surface flow equations. Numerical results were presented for flow over an obstacle in a channel of unit depth.

Multigrid – Noordmans has shown how, under minimal conditions, combination extrapolation can be applied in an adaptive sparse-grid technique. The new technique has been applied to the solution of a two-dimensional singular perturbation problem, described by a convection-diffusion equation and defined on the domain exterior of a circle. Together with Hemker he prepared a paper on the subject.

NCF1 – In the framework of the NCF-project *Parallel, Distributed-Memory Implementation of Existing Sparse-Grid Software for Three-Dimensional Fluid-Flow Computations*, Everaars, Koren and Arbab worked on so-called Manifold-protocols for implementing existing sparse-grid software on a cluster of workstations. The protocols were written, implemented and tested for an air-flow computation around the ONERA-M6 wing, using the Euler equations of gas dynamics.

NCF2 – In the framework of the NCF-project *Parallel Adaptive Mesh Refinement for Computational Magneto-Fluid Dynamics*, Nool worked on the conversion from Fortran77 to Fortran90 of an adaptive mesh refinement code for two-dimensional problems in (magneto)hydrodynamics. The resulting software was suited for the conversion step by the 'LASY' preprocessor, producing software where the number of grid dimensions is given by a parameter. The coupling with the 'Versatile Advection Code' offers a package containing many numerical schemes and visualization tools.

NWO1 – In the framework of the NWO-project *Domain Decomposition Based Preconditioning Techniques for Large Sparse Linear Systems of Equations and Linear Eigenproblems*, Genseberger adapted a preconditioner for the use within the Jacobi-Davidson method. The preconditioner based on domain decomposition already proved to be successful for the solution of ordinary linear systems of equations. In the Jacobi-Davidson method, most of the computational work arises from a correction equation that has to be solved each step. This correction equation depends on the approximate eigenpair computed so far and it involves two projections. Therefore, for the construction of a preconditioner, special care had to be taken. An analysis of the error amplification was performed for a two-dimensional model problem in order to optimize the coupling parameters. For these optimized coupling parameters a faster convergence of the solution process was predicted. Numerical experiments confirmed this.

NWO2 – In the framework of the NWO-project *Sparse Grid Methods for Transport Problems*, Lastdrager, Koren and Verwer applied the sparse-grid combination technique to time-dependent advection problems. Time stepping was performed on a set of semi-coarsened space grids. At given time levels the solutions on the different space grids were combined to obtain the asymptotic convergence of a single, fine uniform grid. Errors were estimated for a two-dimensional, spatially constant coefficient problem. A spatially variable coefficient problem (Molenkamp-Crowley test) was considered to assess the practical merits of the technique.

NWO-EB – In 1999 the NWO-EB project *Reliability and Parallel Computational Efficiency in Scientific Computing* was closed. Over the period January 1, 1996 – July 1, 1999 this was a joint project with KUN (Prof. Axelsson) and a large number of Russian institutes: the Moscow State University (MSU, Prof. N.S. Bakvahlov, Prof. G.M. Kobelkov), the Institute of Numerical Mathematics of the Russian Academy of Sciences (RAS, Prof. Yu.A. Kuznetsov), the Computing Center of RAS, Siberian Branch, Novosibirsk (Prof. V.P. Il'in), the Yerevan State University, Armenia (Prof. Yu. Hakopian), the Steklov Mathematical Institute RAS, St. Petersburg (Prof. L. Kolotilina), and the Institute for Mathematics and Mechanics, RAS Ural Branch, Ekaterinburg (Prof. G.I. Shishkin). During the cooperation a large number of topics have been studied and many workshops have been organized. The project also resulted in a large number of publications and presentations in international conferences. A final report on the work was prepared for NWO in 1999.

For CWI the highlight of the scientific activities in the project was the close cooperation between Hemker and Prof. dr. G.I. Shishkin and his group on the study of the numerical solution of singular perturbation problems. In 1999 a final workshop was held in Moscow at the MSU, May 13–14. Work related to the NWO-EB project was also presented at the EPSICODE'99 Conference, Magdeburg, Germany, September 20–23.

NWO-MPR – In the framework of the NWO-MPR-project *Parallel Computational Magneto-Fluid Dynamics*, Van Dorsselaer investigated how the Jacobi-Davidson method can be used in an efficient way to determine ε-pseudospectra for large sparse matrix problems. After studying the behaviour of this method to small-sized test problems, he started to implement and apply the Jacobi-Davidson code to large problems arising in magneto-hydrodynamics (MHD). This code is based on a code, developed by Nool and Van der Ploeg at CWI, which computes eigenvalues of MHD problems with the Jacobi-Davidson method. Furthermore Van Dorsselaer investigated, together with Hochstenbach and Van der Vorst from Utrecht University, techniques to obtain probabilistic bounds for the extreme eigenvalues of symmetric matrices. These techniques are based on the Lanczos method and use several types of polynomials related to this method, viz. the so-called Lanczos- and Ritz polynomials and Chebyshev polynomials. It turns out that the bounds based on Lanczos polynomials are the sharpest ones.

STW-MARIN – October 1, with the appointment of Lewis, a start was made with the STW-project *Development of a State-of-the-Art Navier-Stokes Solver for Water Flows around Moving Ships*. Lewis began his work with a study of literature on (i) the incompressible Navier-Stokes equations, (ii) free-surface flow computations and (iii) the MARIN-code PARNASSOS. Koren started with the development of a level-set method and an approximate Riemann solver for capturing free-surface water waves. Preliminary results were presented in an invited presentation at a conference in Oxford on the occasion of the 70th birthday of Prof. Godunov.

Overset grids – In this project Havik, Hemker and Hoffmann studied the numerical solution of a singularly perturbed problem, by using the technique of over-set grids. For this purpose, the 'Overture' software library (Lawrence Livermore National Laboratory, USA) was used and contacts with LLNL (Dr. W. Henshaw) were established. The selection of component grids was made on the basis of asymptotic analysis. The behaviour of the solution was studied for a range of small diffusion parameters. Also the possibilities of rotating the grid with the convection direction was considered. A paper on the subject was prepared.

MAS2.2

Computational number theory studies problems from elementary, algebraic and analytic number theory which require the help of fast computers, particularly vector and parallel systems. This helps to enlarge our knowledge, insight and understanding in this field and leads to mathematical and numerical solution techniques for the problems studied. Many problems in this field are extremely suitable for parallelization, and can be used as test-cases for high-performance and parallel computing techniques.

The emergence of public-key cryptography has particularly triggered the study of algorithms for factoring large numbers and primality testing, for computing discrete logarithms, and for the solution of large sparse systems of linear equations over finite fields. These algorithms are the main study objects in this project.

If time and man power permits, problems are being studied for which much knowledge

and experience has been gained at CWI in the past, like the Riemann hypothesis, the Goldbach conjecture, special number-theoretic (aliquot) sequences and cycles (like amicable numbers), continued fractions of algebraic numbers, and the systematic computation of multiplicative number-theoretic functions with help of a generalization of the sieve of Eratosthenes.

For these tasks the group has access to the idle cycles of over 100 SGI and SUN workstations at CWI. The group also has a limited budget for the Cray C90 supercomputer (with 12 CPUs) at SARA.

Scientific collaboration exists with (the groups of) Prof. R.P. Brent (Oxford University Computing Laboratory, Oxford, England), Prof. J.-M. Deshouillers (Univ. Bordeaux 2, France), Prof. M. García (New York, USA), Dr. A.K. Lenstra (Citibank, New York and Parsippany, USA), Dr. P.L. Montgomery (San Rafael, California, USA), J.M. Pedersen (Vejle Business College, Vejle, Denmark), Prof. A. van der Poorten (Macquarie University, Sydney, Australia), Prof. R. Tijdeman (Leiden University), and Prof. H.C. Williams (University of Manitoba, Canada).

(a) *Factorization with the Number Field Sieve (NFS)* (S. Cavallar, W.M. Lioen, P.L. Montgomery, H.J.J. te Riele). In this project the number field sieve and its suitability to factor general numbers is being studied. Firstly, the filter part in the NFS code for reducing the number of relations and compressing the matrix size in the next step of the NFS algorithm was improved. Secondly, a new polynomial search method was developed by P.L. Montgomery and B. Murphy (The Australian National University, Canberra): one of two polynomials is chosen to have a good combination of two properties: being unusually small over its sieving region and having unusually many roots modulo small primes (and prime powers). Thirdly, P.L. Montgomery, in cooperation with Stathis Papaefstathiou of Microsoft Research (Cambridge, UK) developed and started to test a parallel version of his block Lanczos code (for finding linear dependencies in a large sparse bit matrix) for parallel computers like the SGI Origin 2000. Fourthly, optimal sieving parameters for new record size numbers to be factored were looked for.

In this year (1999) three factoring world records were established, one for the Special Number Field Sieve (SNFS): a 211-digit so-called Cunningham number, and two for the General Number Field Sieve (GNFS): a 140-digit and a 155-digit so-called RSA number. The RSA numbers were taken from the *RSA Challenge List*, see `http://www.rsa.com/rsalabs/html/factoring/html`

The factoring world record for SNFS was established on April 8 by the computation of the factors of the 211-digit Cunningham number $N = (10^{211} - 1)/9$ into two primes of 93 and 118 digits, respectively. This achievement also established a record for the largest penultimate prime factor (of 93 digits) ever found. For details see `ftp://ftp.cwi.nl/pub/herman/NFSrecords/SNFS-211` The previous SNFS record was the 186-digit number $32633^{41} - 1$ factored in September 1998: `ftp://ftp.cwi.nl/pub/herman/SNFSrecords/SNFS-186`

The two factoring world records for GNFS were established on February 2 (RSA140), and on August 22 (RSA155), respectively. RSA140, a 140-digit number, turned out to be the product of two primes of 70 digits each; RSA155, a 155-digit number, turned out to consist of two primes of 78 digits each. Both RSA140 and RSA155 are representative for the public keys which are used in the RSA public-key cryptosystem. Written in binary notation, RSA155 is a 512-bit number. RSA–keys of this size protect 95% of today's E-commerce on the Internet —at least outside the USA—and are used in SSL (Secure Socket Layer) handshake protocols and in the PGP (Pretty Good Privacy) public domain software which is used for E-mail protection. A press conference was organized at CWI on August 26 where the factorization of RSA155 was announced, together with its implications for E-commerce and cryptography. Four international experts attended the press conference (A.K. Lenstra, P. Leyland, A.M. Odlyzko, and E. Verheul; see the section 'Visitors' in this report) to comment on the result. The factorization of RSA155 raised much publicity in the Dutch national *and* in the international press, and on radio and television. The table summarizes some technical information about the three factoring world records.

(b) *Extending the Cunningham table* (P.L. Montgomery, S. Cavallar, W.M. Lioen, H.J.J. te Riele). Montgomery and Cavallar continued to factor numbers of the form $a^n \pm 1$ ($13 \leq a < 100$) for the Extended Cunningham table with the help of the ECM, SNFS, and GNFS factoring methods.

number	$10,211-$	RSA140	RSA155
size of the two factors (in decimal digits)	93, 118	70, 70	78, 78
sieving time (in CPU years)	10.9	8.9	35.7
calendar time for sieving (in days)	64	30	110
# workstations and PCs used for sieving	125	125	300
matrix size	4.8M	4.7M	6.7M
row weight	49	32	62
Cray CPU hours for matrix step	121	100	224

Most of the work was carried out on CWI's SGI Origin 2000, and on about 100 SGI and SUN CWI-workstations.

The original and the extended Cunningham tables have been built in in the software package MAGMA, which is being developed by a team at the University of Sydney, headed by John Cannon.

(c) *Computer verification of the Ankeny-Artin-Chowla conjecture* (H.J.J. te Riele). Let p be a prime congruent to 1 modulo 4 and let t, u be rational integers such that $(t + u\sqrt{p})/2$ is the fundamental unit of the real quadratic field $\mathcal{Q}(\sqrt{p})$. The Ankeny-Artin-Chowla conjecture (AAC conjecture) asserts that p will not divide u. This is equivalent to the assertion that p will not divide $B_{(p-1)/2}$, where B_n denotes the n^{th} Bernoulli number. First published in 1952, this conjecture still remains unproved today. Indeed, it appears to be most difficult to prove. In 1988 the AAC conjecture was verified by computer for all $p < 10^9$. In 1998, we verified the AAC conjecture for all primes p up to 10^{11} using a new technique developed by H.C. Williams. Total computing times were 250 and 700 CPU hours on an SGI O2 workstation and on one processor of CWI's SGI Origin 2000, respectively. A report appeared in March (Report MAS-R9905).

(d) *Amicable and related numbers* (H.J.J. te Riele). In 1995, Jan Munch Pedersen of Vejle Business College in Vejle, Denmark, started to create a list of all the known amicable pairs. This list can be accessed through the World Wide Web via `URL http://www.vejlehs.dk/staff/jmp/aliquot/knwnap.htm` The number of pairs in this list now exceeds $530,000$. A survey paper which documents the main developments leading to this explosion of known amicable pairs is (still) in preparation.

MAS 2.3

The extended backward differentiation formulas (EBDF) for solving ordinary differential equations were introduced in the 1980s by J. Cash. These methods are stiffly accurate, and L-stable methods are known to exist up to order 6. Furthermore, recent experience with the Testset for Initial Value Problems shows the EBDF methods to be quite efficient compared to other popular methods in the literature. We have studied a number of possible modifications to these methods which make them feasible for implementation on shared memory parallel computers.

As originally formulated, the EBDF method is a general linear method (GLM) with a lower triangular coefficient matrix A. In the serial case, a desirable property of A is a constant diagonal entry, since this allows reuse of the iteration matrix in all stages. From the parallel point of view, the defective spectrum of A precludes diagonalization, the standard approach to parallelizing GLMs. In our investigations we consider two alternatives: (1) iterating with an approximation to A which *is* diagonalizable, and (2) reformulation of the EBDF methods on a staggered grid such that A does have a complete spectrum.

Tests with these methods using a fixed stepsize code indicate that a reasonable speedup can be obtained in parallel on 3-4 processors.

PhD Theses

J.E. Frank, *Efficient Algorithms for the Numerical Solution of Differential Equations*, TU Delft, 2000.

Knowledge Transfer

P.W. Hemker:

- Capita course at University of Amsterdam Defect Correction and Multigrid Methods (September 16 – November 25).

B. Koren:

- Two courses at TU Delft: Transsone Aerodynamica (April 20 – June 4) and Numerieke

Vliegtuigaerodynamica II
(September 10 – December 17).

P.L. Montgomery and H.J.J. te Riele:

- CWI has entered into a source code license agreement with a German and a French organization to allow them to use the Number Field Sieve factorization code as this was and is being developed by P.L. Montgomery, A.K. Lenstra, M. Elkenbracht-Huizing, S. Cavallar and B. Dodson.
  On a non-commercial basis, the NFS source code has also been made available for research purposes to other cooperating groups.

Organization of Conferences, Workshops, Courses, etc.

P.W. Hemker:

- ACCS Seminar Computational Mathematics, UvA, February 2 (lecturers: W. Schilders, R. Bisseling and H.J.J. te Riele).
- ITW-Symposium 'Computational Science: de derde discipline?' (Lecturers: V. Icke, A. Veldman, G. Stelling, B. Herzberger, R. de Borst and J.G. Verwer).

P.W. Hemker and B. Koren:

- 6th European Multigrid Conference, EMG'99, Ghent, Belgium, September 27–30.

B. Koren:

- NWO-MPR-meeting, CWI, May 4.
- STW-meeting C.H. Venner and D. van Odijck (University of Twente, Faculty of Mechanical Engineering), CWI, September 12.

H.J.J. te Riele:

- Working Group Parallel Computation in Magneto-hydrodynamics and Astrophysics, Meeting on January 12 (at FOM Rijnhuizen, with a contribution by Herman te Riele entitled: *Parallel eigenvalue computation in CMFD: some reflexions*).
- Cryptography – Number Theory Colloquium, Meeting on November 12 at CWI with contributions by Stephan Overbeek (QC Technology BV), entitled: *Cryptography versus Factorisation – How factorisation applies to cryptography* and by Herman te Riele, entitled: *Optimal versus practical choice of parameters in factorisation methods*

Visits to Conferences, Workshops, Colloquia, etc., and Working Visits

- Intercity Colloquium Getaltheorie, various places (Leiden, Utrecht) and dates, S. Cavallar, H.J.J. te Riele.
- NWO-MPR-meeting, FOM-Rijnhuizen, January 12: Van Dorsselaer, Genseberger, Koren, Nool, Te Riele.
- Working visit SKF's European Research Center, Nieuwegein, January 12: Koren.
- ACCS Seminar Computational Mathematics, UvA, Amsterdam, February 2: Hemker.
- Working visit FOM-Rijnhuizen, February 8: Koren (*A fed-back level-set method for moving material-void interfaces*).
- NWO-MPR-meeting, FOM-Rijnhuizen, March 3: Van Dorsselaer (*Some aspects of computing pseudospectra with the Jacobi-Davidson method*), Genseberger, Koren, Nool.
- ITW-Symposium: 'Computational Science: de derde discipline?', Amsterdam, March 19: Hemker.
- Vierendertigste Nederlands Mathematisch Congres, Universiteit Utrecht, April 8–9: Hemker, Te Riele.
- 9th Copper Mountain Conference on Multigrid Methods, Copper Mountain, Colorado, April 11–16: Lastdrager (*The sparse-grid combination technique for a time-dependent advection problem*).
- SciCADE '99, Frazer Island, Australia, August 9–13: Van der Houwen.
- Lectures by Prof. A. Granville, Leiden, April 29 and May 21: Te Riele.
- Conference Orthogonal Polynomials, Approximation and Harmonic Analysis, Ballenstedt, April 22–27: Sprengel (*Interpolation on sparse Gauß-Chebyshev grids in higher dimensions*).
- Working visits MARIN for STW-project, May 3, May 12, September 6: Koren.
- NWO-MPR-meeting, CWI, May 4: Van Dorsselaer, Genseberger (*Alternative correction equations in the Jacobi-Davidson method*), Hemker, Koren, Nool.
- Workshop NWO-EB project Reliability and Parallel Computational Efficiency in Scientific Computing, Moscow State University, May 13–14: Hemker (*Remarks on the solution of partial differential equations on sparse grids*).
- IFIP WG 2.5 Meeting, West Lafayette, Indiana, USA, May 19–20: Hemker.
- Symposium The Numerical Solution of Initial Value Problems, Leiden University, May 21: Van Dorsselaer (*On the computation of pseudospectra with applications to stability analysis*), Te Riele.

- John R. Rice Computational Science Conference, Purdue University, West Lafayette, Indiana, USA, May 21–22: Hemker.
- Working visit CASC (Lawrence Livermore National Laboratory, California, USA, W. Henshaw), May 24–28: Hemker (*Multigrid on 3-dimensional adaptive grids*).
- Working visit GMD-SCAI, Sankt Augustin, May 25: Sprengel (*Multilevel algorithms for sparse grids*).
- Stieltjesmiddag, Leiden, May 31: Te Riele.
- The Mathematics of Public-Key Cryptography, The Fields Institute, Toronto, June 12–17, Stefania Cavallar (*Filter strategies in the Number Field Sieve*), H.J.J. te Riele (*Factorization of RSA–140 using the Number Field Sieve*).
- Foundations of Computational Mathematics 1999, Oxford, July 18–28: Van Dorsselaer (*Computing bounds for extremal eigenvalues of Hermitian Matrices with the Lanczos method*).
- Foundations of Computational Mathematics, Oxford, July 26–28: H.J.J. te Riele (*Progress in factoring large numbers*).
- NWO-MPR-meeting, FOM-Rijnhuizen, September 21: Van Dorsselaer, Genseberger, Nool.
- EPSICODE 99, Schloss Wendgraeben, Magdeburg, Germany, September 20–23: Hemker (*The use of overset grids and adaptive sparse grids to a model convection diffusion problem*), invited paper.
- 6th European Multigrid Conference, Ghent, September 27–30: Hemker, Koren, Lastdrager (*The sparse-grid combination technique applied to time-dependent advection problems*).
- Cryptography Working Group, Utrecht, October 1: Te Riele (*Factorisation of a 512–bits' RSA key: warning or breakthrough?*)
- Colloquium on the occasion of Hoekstra's PhD degree, MARIN, October 6: Van Brummelen, Hemker, Koren, Langereis, Lewis.
- Conferentie van Numeriek Wiskundigen, Woudschoten, October 6–8: Van Brummelen (*Numerical solution of steady free surface Navier-Stokes flow*), Van Dorsselaer, Genseberger, Lastdrager, Lewis, Nool.
- Godunov Methods: Theory and Applications, Oxford, October 18–22: Koren (*A Godunov-type method for capturing free-surface water waves*), invited paper.
- Miniconferentie Gentherapie en Bio-Informatica, UvA, Amsterdam, October 29: Hemker.
- NWO-MPR-meeting, FOM-Rijnhuizen, November 9: Van Dorsselaer, Nool (*Computing probabilistic bounds for extreme eigenvalues of symmetric matrices with the Lanczos method*).
- Working visit RWTH-Aachen, November 9: Koren (*Fitting and capturing of free-surface water waves*).
- Working visit GMD-SCAI, Sankt Augustin, November 29: Hemker.
- Seminar Numerical Analysis, Nijmegen, December 5–7: Hemker (*On the use of an overset grid method and an adaptive MG method for an SPP problem*).
- SARA HPCN Gebruikersdag, CWI, December 16: Van Dorsselaer, Te Riele.
- WIRE–VIE Lezingenavond over Internet: Security, Privacy en het kraken van RSA, Utrecht, December 16: H.J.J. te Riele (*Ontbinden in factoren van een 512-bits RSA beveiligingssleutel: is E-commerce nog wel safe?*)

Memberships of Committees and Other Professional Activities

J.L.M. van Dorsselaer:
- Referee for a journal paper.

M. Genseberger:
- Representative BAU - Union for PhD students of Utrecht University.
- Co-organizer BAU seminar 'Verblijf in het buitenland tijdens en na de promotie', Utrecht University, June 17.

P.W. Hemker:
- Professor of Industrial Mathematics, University of Amsterdam.
- Member Working Group 2.5 on Numerical Software, IFIP.
- Member Numerical Algorithms Group, NAG Inc.
- Member SWON advisory committee.
- Member steering group Amsterdam Centre for Computational Science (ACCS).
- Member Organizing Committee 6th European Multigrid Conference, EMG'99, Ghent, Belgium, September 27–30.
- Member program committee Third International Conference on Finite Difference Methods: Theory and Applications, September 1–4, Palanga, Lithuania.
- Member project committee ISTC-project 'Techniques and software development for the solution of 3-dimensional gasdynamics problems on irregular Lagrangian grids'.
- Referee of papers for various scientific journals and projects.
- Reviewer for *Mathematical Reviews*.

- Member PhD committee M. Hoekstra, TUD, October 7.
- Member PhD committee M.V. Nikolova, KUN, December 7.
- Member PhD committee B.D. Kandhai, UvA, December 16.

J. Kok:
- Secretary organizing committee of the 2000 Woudschoten Conference on Numerical Analysis.

B. Koren:
- Associate professor Computational Fluid Dynamics, Faculty of Aerospace Engineering, Delft University of Technology.
- Co-worker CWI's scientific policy making.
- Editor *CWI Quarterly*.
- Member Organizing Committee 6th European Multigrid Conference, EMG'99, Ghent, Belgium, September 27–30.
- Member STW-committee C.H. Venner and D. van Odijck (University of Twente, Faculty of Mechanical Engineering).
- Referee of papers for various scientific journals.

M. Nool:
- Member SMC Works Council.

H.J.J. te Riele:
- Member of the Board of the *Mathematical Research Institute* onderzoekschool.
- Member of the Program Committee and of the Local Organizing Committee of ANTS4 (Algorithmic Number Theory Symposium IV, Leiden, July 2–7, 2000).
- Editor of *Nieuw Archief voor Wiskunde* (Section Expository Papers).
- Referee of papers for various scientific journals.
- Reviewer for *Mathematical Reviews* and the *Zentralblatt für Mathematik*.
- Chairman CWI-Bibliotheekcommissie.

Visitors

- Dr. I. Shparlinski (Macquarie University, Sydney, Australia), January 14 (Lecture *On the distribution and structure of some non-linear pseudorandom number generators in cryptography and Monte Carlo methods*).
- Dr. B. Murphy (Australian National University, Canberra), January 18–22.
- Dr. A.K. Lenstra (Citibank, Parsippany, USA), January 19–21, June 22, August 26.
- Dr. ir. H.C. Raven (MARIN), March 15.
- Three visitors from VNIIEF (Russian Federal Nuclear Research Institute, Arzamas 16), March 15–17: Dr. V. Rasskazova (*3-D gas dynamics problem solving on irregular grids*), Dr. P. Rasskazov (*Program of 3-D gas dynamics problem outcome visualization*), Dr. V. Motlochov (*Structure of 3-D gas dynamics problem solving program code*).
- Drs. S. Radomirovic (ETH Zürich), March 26–27 (Lecture: *Investigations into span programs with multiplication*).
- Prof. dr. A. van der Poorten (Macquarie University, Sydney, Australia), May 20 (Lecture *Periodic Continued Fractions*).
- Dr. V. Gurariy (Kent State University, Ohio, USA), June 1, (Lecture: *Geometry of Dirichlet sequences and the Riemann density problem*).
- Ir. M.R. Lewis (TU Delft), June 15.
- Dr. N. Neuss (ICA, Stuttgart), June 15–16.
- Dr. J. Fuhrmann (WIAS, Berlin, Germany), June 22.
- Dr. ir. C.W. Oosterlee (GMD-SCAI), July 12.
- Dr. A.M. Odlyzko (AT&T Research, Florham Park, NJ, USA), August 26.
- Dr. P. Leyland (Microsoft Research, Cambridge, UK), August 26.
- Dr. E. Verheul (PriceWaterhouseCoopers N.V., Amsterdam), August 26.
- Prof. dr. B. van Leer (University of Michigan, Ann Arbor), October 1.

Software Developed

P.W. Hemker and E. Havik:
- The data structure BASIS3 was translated into C++ and extended to prepare it for the use with overset grids.

M. Nool:
- JDSEQ: Jacobi-Davidson code with implicit deflation for computing selected eigenvalues of a matrix pair (A, B) with A and B block-tridiagonal. Special application: Magnetohydrodynamics.
- JDPAR: Parallel version of JDSEQ developed for the distributed memory machines Cray T3D and T3E. Parallel preconditioner: DDCR, a block-tridiagonal LU-decomposition, based on a combination of domain decomposition (DD) and cyclic reduction (CR).

Papers in Journals and Proceedings

S. Cavallar, B. Dodson, A.K. Lenstra, P. Leyland, W.M. Lioen, P.L. Montgomery, B. Murphy, H.J.J. te Riele, P. Zimmermann (1999). Factorization of RSA–140 using the Number Field Sieve. Lam Kwok Yan, Eiji Okamoto, Xing Chaoping (eds.). *Advances in Cryptology – Asiacrypt '99*, volume **1716** of *Lecture Notes in Computer Science*, Springer–Verlag, Berlin, 195–207.

J.L.M. van Dorsselaer, C. Lubich (1999). Inertial manifolds of parabolic differential equations under higher-order discretizations. *IMA Journal of Numerical Analysis* **19**, 455–471.

C.T.H. Everaars, B. Koren, F. Arbab (1999). Dynamic process composition and communication patterns in irregularly structured applications. J. Rolim et al. (eds.). *Proceedings of the 10th Symposium on Parallel and Distributed Processing*, *Lecture Notes in Computer Science* **1586**, Springer, Berlin, San Juan, Puerto Rico, 1046–1054.

J.E. Frank, P.J. van der Houwen. Parallel iteration of the extended backward differentiation formulas, CWI Report MAS-R9913, to appear, *IMA J. Numer. Anal.*

J.E. Frank, P.J. van der Houwen. Diagonalizable extended backward differentiation formulas, CWI Report MAS-R9917, to appear, *BIT.*

M. Genseberger, G.L.G. Sleijpen (1999). Alternative correction equations in the Jacobi-Davidson method. *Numerical Linear Algebra with Applications* **6**, 235–253.

P.W. Hemker, G.I. Shishkin, L.P. Shishkina (1999). An ε- uniform defect correction method for a parabolic convection-diffusion problem. O.P. Iliev, M.S. Kaschiev, S.D. Margenov, Bl.H. Sendov, P.S. Vassilevski (eds.). *Proceedings of the Fourth International Conference, NMA'98, Recent Advances in Numerical Methods and Applications* **II**, World Scientific, Sofia, 521–529.

P.W. Hemker, G.I. Shishkin, L.P. Shishkina (1999). The numerical solution of a Neumann problem for parabolic singularly perturbed equations with high-order time accuracy. O.P. Iliev, M.S. Kaschiev, S.D. Margenov, Bl.H. Sendov, P.S. Vassilevski (eds.). *Proceedings of the Fourth International Conference, NMA'98, Recent Advances in Numerical Methods and Applications* **II**, 27–39, World Scientific, Sofia.

P.W. Hemker, G.I. Shishkin, L.P. Shishkina (1999). Parallel methods based on a defect-correction technique for parabolic singularly perturbed problems. L.Vulkov (ed.). *Proceedings of the Workshop on the Analytical and Computational Methods for Convection-Dominated and Singularly Perturbed Problems*, *Analytical and Numerical Methods for Singularly Perturbed Problems*, Nuova Science Publishing House, USA.

P.J. van der Houwen, E. Messina (1999). Parallel Adams methods. *J. Comput. Appl. Math.* **101**, 153–165.

P.J. van der Houwen, E. Messina, J.J.B. de Swart (1999). Parallel Stoermer-Cowell methods for high precision orbit computations. *Appl. Numer. Math.* **31**, 353–374.

B. Koren, A.C.J. Venis (1999). A fed back level-set method for moving material-void interfaces. *Journal of Computational and Applied Mathematics* **101**, 131–152.

B. Koren, A.C.J. Venis, A fed back level-set method for moving material-void interfaces. *Proceedings of the Seventh International Conference on Hyperbolic Problems*, Zürich, 1998. M. Fey, R. Jeltsch (eds.). *International Series of Numerical Mathematics* **130**, Birkhäuser, Basel, 579–588.

M. Nool, A. van der Ploeg (1999). Parallel Jacobi-Davidson for solving generalized eigenvalue problems. J.M.L.M. Palma, J. Dongarra, V. Hernandez (eds.). *Proceedings of the Third International Meeting on Vector and Parallel Processing*, Porto, Portugal. *Lecture Notes in Computer Science* **1573**, Springer-Verlag, Berlin, 58–71.

H. Raven, H. van Brummelen (1999). A new approach to computing steady free-surface viscous flow problems. *Proceedings of the First MARNET-CFD Workshop*, Barcelona.

W. Sickel, F. Sprengel (1999). Some error estimates for periodic interpolation of functions from Besov spaces. W. Haussmann, K. Jetter, M. Reimer (eds.). *Advances in Multivariate Approximation*, *Mathematical Research* **107**, Wiley-VCH, Berlin, 269–288.

W. Sickel, F. Sprengel (1999). Interpolation on sparse grids and tensor products of Nikol'skij-Besov spaces. *Journal of Computational Analysis and Applications* **1**, 261–286.

F. Sprengel (1999). A class of function spaces and interpolation on sparse grids. C.K.

CHUI, L.L. SCHUMAKER (eds.). *Approximation Theory, Computational Aspects* **IX**(2), Vanderbilt University Press, Nashville, 319–326.

CWI Reports

The following CWI reports were published by members of theme MAS2. See page 59 for the complete titles of the reports.

MAS-R9905	MAS-R9906	MAS-R9907
MAS-R9909	MAS-R9913	MAS-R9915
MAS-R9916	MAS-R9917	MAS-R9922
MAS-R9924	MAS-R9925	MAS-R9930
MAS-R9931	MAS-R9933	MAS-R9934

Other Publications

P.W. HEMKER, B.W. VAN DE FLIERT (eds.). (1999). *Proceedings of the Thirty-third European Study Group with Industry*, CWI Syllabus **46**, CWI, Amsterdam.

P. LANGEREIS. *Numerieke simulaties in ISNaS van Navier-Stokes stromingen met een vrije rand*, MSc thesis, University of Amsterdam.

Mathematics of Finance – MAS 3

Staff

- Prof. dr. J.M. Schumacher, pilot leader (until December)
- Drs. M.K. Çamlíbel, PhD student
- Dr. K.O. Dzhaparidze, researcher (0.2)
- Dr. J.K. Hoogland, postdoc
- Dr. C.D.D. Neumann, postdoc
- Dr. M.A. Peletier, researcher (0.2)
- Dr. ir. H.J.J. te Riele, researcher (0.3)
- Dr. A.J. van der Schaft (seconded from Twente Univ., 0.1, until December)
- Drs. J.H. van Zanten, PhD student
- Prof. dr. M.S. Keane, theme leader (0.6, from December)

Scientific Report

This pilot has undergone a number of changes during 1999. The most important was the departure of the pilot leader, Schumacher, who has taken up a full time professorship in Tilburg. He has temporarily been replaced by Keane, who has begun a restructuring of the pilot in December. Also, Te Riele and Peletier have moved to activities elsewhere in CWI, and the research of Van Zanten currently fits better in the PNA3 group, where he will work full time in 2000.

The following is a summary of research activities of MAS3 in 1999; for the activities of Keane, Dzhaparidze and Van Zanten see the report of PNA3.

Research of Schumacher, Çamlíbel and Van der Schaft

Within project MAS3.1 (Mathematics of Finance), Schumacher's main activities were concerned with organization and course preparation. Until September he acted as chairman of FWA, a joint undertaking of CWI and the two Amsterdam universities in the area of mathematical finance. Within project MAS3.2 (Discontinuous Dynamical Systems), Schumacher and Çamlíbel worked together with W.P.M.H. Heemels (TUE) on the development of a solution concept for linear passive systems with state-controlled switches and on a rigorous proof of convergence of a numerical integration method for such systems that does not rely on determination of event times. Van der Schaft and Schumacher completed a book on mixed continuous-discrete dynamical systems (An Introduction to Hybrid Dynamical Systems, Springer). Other work by Schumacher has included joint projects on robust control and system equivalence with M.K.K. Cevik and U. Başer (both of Istanbul Technical University). Schumacher has left the group to become full professor of mathematics at Tilburg University on November 30. Simultaneously, Van der Schaft's secondiment ended. Çamlíbel was transferred to Tilburg University on January 1, 2000.

Research of Hoogland and Neumann

Hoogland and Neumann have been working on the models for pricing of derivatives. This has led to some significant insights into the pricing of complex financial derivatives. A crucial point is the use of symmetries. They provide the means to reduce the complexity of pricing arbitary financial products and show the equivalence of various products which were allways treated separately but turn out to be the equivalent under the appropriate symmetry operations.

The application of scale-invariance in the pricing of financial derivatives turns out to be very fruitful indeed. This invariance is a direct consequence of the fact that prices of tradable ob-

jects can only be expressed relative to each other. To express the price of a tradable in terms of a number one always needs a reference tradable or numeraire. This choice of numeraire should not have any effect on the price of a derivative. In a Black-Scholes world (Wiener-driven prices, complete market, no transaction costs) a PDE is derived which is manifestly invariant. Key ingredient is to express the price of the derivative as a function of the tradable objects, e.g. equity and bonds. Dimensional analysis then shows that this function should be homogeneous of degree 1. The manifest numeraire-invariance leads to a significant simplification of computations. This has been shown for all standard exotic options, such as single/double barriers, lookbacks, and asian options. Some errors in the literature have been found. Also new formulae and relations have been found, such as a formula for arithmetic average strike options and a relation between average strike and average price options.

Hoogland and Neumann have spent significant time on the setup and teaching of FWA courses on Financial Engineering for the financial industry. These courses have been very successful. Many people from financial institutions visited these courses.

Hoogland and Neumann have setup contacts with people from the quantative groups of MeesPierson and Ernst & Young to set up collaborative research. The research with Mees Pierson will be focusing on some problems in pricing of derivatives. The research with Ernst & Young will look at high-frequency data and correlations between various assets.

Research of Peletier

Peletier spent most of his time in this project on seeking mathematical problems that were both interesting for the group and related to his prior knowledge. This search was unsuccessful, and this was one of the reasons for him leaving the group.

Research of Keane

Keane started work in December related to the analysis of tick-by-tick data and deterministic Brownian motion; both topics have been studied by Keane in the past (Tokyo 1992 and Delft 1994/95) and can be of interest for better model fitting. Results will be forthcoming in 2000 and 2001.

Organization of Conferences, Workshops, Courses, etc.

- Organization and delivering of FWA courses Financial Engineering and Financial Time Series by Hoogland, Neumann, Schumacher, Te Riele:
  Jan-Mar (FTS Part II, Schumacher)
  Mar-Apr (FE Part II, Schumacher)
  Nov-Dec (FE Part I, Schumacher)
  Jan-Dec (remainder of FTS and FE, Hoogland and Neumann, with three evenings given by te Riele)
- Meetings of the NWO project 'Financial Derivatives': organized by J.M. Schumacher in cooperation with host institutions. Three meetings took place in 1999 (two at EURANDOM in Eindhoven, one at Twente University).

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

- Project meeting 'Financial Derivatives', EURANDOM (Eindhoven), January 5, Talk by C.D.D. Neumann: *Kelly strategy and derivative pricing.*
- Benelux Meeting on Systems and Control, Houthalen (Belgium), March 3–5, Talk by J.M. Schumacher: *Equalizing control and the Black-Scholes formula.*
- Mathematics colloquium, University of Groningen, April 6, Talk by J.M. Schumacher: *Dynamics and complementarity.*
- Workshop at the occasion of the 60th birthday of Diederich Hinrichsen, Borkum (Germany), April 20–23, Talk by J.M. Schumacher: *Between mathematical programming and system theory: linear complementarity systems.*
- Workshop on Nonlinear Stochastic Models in Finance, EURANDOM, April 26–28, Talk by J.M. Schumacher: *Pricing and hedging in an interval model.*
- Project meeting 'Financial Derivatives', EURANDOM (Eindhoven), June 15, Talk by J.K. Hoogland: *Scale-invariance and contingent claim pricing.*
- Euromech Colloquium 397 'Impacts in Mechanical Systems', Grenoble, June 30–July 2, Talk by J.M. Schumacher: *Complementarity systems.*
- European Control Conference '99, Karslruhe (Germany), August 31–September 3, Talk by M.K. Çamlíbel: *Well-posedness of a class of piecewise linear systems.*
- Workshop at the occasion of the 60th birthday of J.C. Willems, Groningen, September 17–18.

- Workshop on Computational Finance and Insurance, Frankfurt am Main, October 8, J.M. Schumacher.
- Second meeting of EURANDOM project 'Financial Stochastics', EURANDOM, Eindhoven, January 5: J.K. Hoogland, C.D.D. Neumann. Talk by C.D.D. Neumann: *Kelly's strategy and pricing of derivative.*
- Ernst & Young, Amsterdam, February 18: J.K. Hoogland, C.D.D. Neumann. Talk by C.D.D. Neumann: *Kelly's strategy and pricing of derivatives.*
- Third meeting of EURANDOM project 'Financial Stochastics', EURANDOM, Eindhoven, June 15: J.K. Hoogland, C.D.D. Neumann. Talk by J.K. Hoogland: *Scale invariance and contingent claim pricing.*
- Colloquium Financial Mathematics, University of Amsterdam, June 28. Talk by J.K. Hoogland and C.D.D. Neumann: *Scale invariance and contigent claim pricing.*
- Bedrijvendag CWI, October 8. Talk by J.K. Hoogland: *Tulpenbollen, opties en financieel risico.*
- Fourth meeting of EURANDOM project 'Financial Stochastics', EURANDOM, Twente, December 9: J.K. Hoogland, C.D.D. Neumann Talk by C.D.D. Neumann: *Asian variations.*
- Colloquium Financial Mathematics, University of Amsterdam, December 4, Lecture on Deterministic Brownian Motion by M.S. Keane.
- Colloquium Financiële Wiskunde, University of Amsterdam, April 26: H.J.J. te Riele: *Numerieke methoden voor het berekenen van optieprijzen.*

Memberships of Committees and Other Professional Activities

J.M. Schumacher:
- Organizing committee, Workshop on Nonlinear Stochastic Models in Finance, EURANDOM, April 26–28.
- International Program Committee, Euromech Colloquium 397 'Impacts in Mechanical Systems', Grenoble, June 30–July 2.
- Corresponding Editor, SIAM Journal on Control and Optimization.
- Associate Editor, Systems & Control Letters.
- Guest Editor, Automatica special issue on Hybrid Systems, March.
- Member editorial board, CWI Tracts & Syllabi Series.
- Member of the board of the research school Dutch Institute of Systems and Control (DISC).
- Council member, European Union Control Association (EUCA).
- Member, Technical Committee on Linear Systems, International Federation of Automatic Control (IFAC).

J.K. Hoogland:
- Management team FWA Committee for setup of financial mathematics master program University of Amsterdam.

Visitors

- Dr. M. Dacorogna (Olsen Associates, Zürich), February 2–5.
- Prof. L.C.G. Rogers (University of Bath), March 30.
- Prof. M.K.K. Cevik (Istanbul Technical University), September– November.

Papers in Journals and Proceedings

C.D.D. Neumann (1999). The elliptic genus of Calabi-Yau 3- and 4-folds, product formulae and generalized Kac-Moody algebras. *J. Geometry and Physics* **29**(5).

J.K. Hoogland, M. Vellekoop (1999). Opties, kansbomen en geldmachines. *Pythagoras* **38**(6).

R.K. Boel, B. De Schutter, G. Nijsse, J.M. Schumacher, J.H. van Schuppen (1999). Approaches to modelling, analysis and control of hybrid systems. *Journal A* **40**(4), 16–27.

M.K. Çamlíbel, J.M. Schumacher (1999). Well-posedness of a class of piecewise linear systems. *Proc. European Control Conference 1999*, Karlsruhe, Germany.

W.P.M.H. Heemels, J.M. Schumacher, S. Weiland (1999). The rational complementarity problem. *Linear Algebra and its Applications 294*, 93–135.

W.P.M.H. Heemels, J.M. Schumacher, S. Weiland (1999). Applications of complementarity systems. *Proc. European Control Conference 1999*, Karlsruhe, Germany.

Y.J. Lootsma, A.J. van der Schaft, M.K. Çamlíbel (1999). Uniqueness of solutions of relay systems *Automatica* **35**, 467–478.

H. Nijmeijer, J.M. Schumacher (1999). Four decades of mathematical system theory. J.W. Polderman, H.L. Trentelman (eds.). *The Mathematics of Systems and Control: From*

Intelligent Control to Behavioral Systems, Univ. of Groningen, 73–83.

A.D.B. Paice, J.M. Schumacher (1999). Hybrid control of gas compressors. *Proc. European Control Conference 1999*, Karlsruhe, Germany.

J.M. Schumacher, M.H. Vellekoop (1999). Risico's rond EK 2000. *Pythagoras* **38**(6), 4–7.

J.M. Schumacher, M.H. Vellekoop (1999). EK 2000: het zekere uit het onzekere. *Pythagoras* **38**(6), 8–10.

J.M. Schumacher (1999). Re-initialization in discontinuous systems. V.D. Blondel, E.D. Sontag, M. Vidyasagar, J.C. Willems (eds.). *Open Problems in Mathematical Systems and Control Theory*, Springer, London, UK, 203–209.

A.J.T.M. Weeren, J.M. Schumacher, J.C. Engwerda (1999). Strategic behavior and noncooperative hierarchical control. *Journal of Economic Dynamics and Control* **23**, 641–669.

A.J.T.M. Weeren, J.M. Schumacher, J.C. Engwerda (1999). Asymptotic analysis of linear feedback Nash equilibria in nonzero-sum linear-quadratic differential games. *Journal of Optimization Theory and Applications* **101**, 693–722.

CWI Reports

The following CWI reports were published by members of theme MAS3. See page 59 for the complete titles of the reports.

MAS-R9902 MAS-R9914 MAS-R9919

Other publications

Poster. Scaling invariance and contingent claim pricing. *Applications of Physics in Financial, Analysis*, Trinity College Dublin, Ireland.

INFORMATION SYSTEMS

General Overview

The research activities are focussed in this cluster on various aspects of multimedia information systems.

Theme INS1 continues to strengthen the activities of the former database group in the direction of extracting knowledge from large databases and the disclosure of information in multimedia databases. Central to this activity is the development and deployment of the Monet database system. Much of the work in theme INS2 is centered around multimedia applications development and standardization activities for there description and disseminiation. INS3 is focussed on aspects of facial animation, digital libraries, and software for visualization of large graphs. The core of theoretical investigations into new computing paradigms and machines - Quantum Computing - is undertaken in theme INS4.

An important output of the work in this cluster is the development of prototypes for demonstrating and experimenting with solutions. Both senior and junior researchers balance their theoretical work with hands-on experience in developing software solutions. Many of these prototypes are used by affiliated research groups or find their way through partners in (inter)national consortia. The policy regarding their construction is to develop them up to the point that real applications can be built and exercised.

Exploitation of research prototypes, if warranted, is primarily done outside the institute. Therefore, the themes foster transfer of research to its business liaisons, in particular, its older spin-off companies (General Design and Data Distilleries, Oratrix and Eidetica) and through the many externally funded industrial projects. Plans to set-up a new spin off company to exploit the facial animation software are underway.

INS participates in several large national projects (HPCN-IMPACT, ICES, AMIS), Telematics Institute (DMW, DRUID, U-WISH, Mediated Communication), and projects aimed at knowledge transfer (STW-FASE). Such participations are considered a valuable asset in driving frontier and innovative research. We expect to continue this line, balancing the challenges of today's ICT with long-term high-risk undertakings.

The INS senior researchers participate in the National Research Schools (ASCI, SIKS, ILLC, IPA), broadly disseminate their research results in the international scene, and hold faculty positions at the universities. The staff has produced over 70 publications in conferences and proceedings, while electronic dissemination of scientific results remains at unprecedented height.

Staff

- Data Mining and Knowledge Discovery – INS1
  - A.P.J.M. Siebes
  - A.R. van Ballegooij
  - R.E. Blom
  - H.G.P. Bosch
  - P.M.E. De Bra
  - J.R. Castelo
  - A. Eliëns
  - K. van 't Hoff
  - S. Karlsson
  - M.L. Kersten
  - A.J. Knobbe
  - S. Manegold
  - H. Naacke
  - N. Nes
  - J. Pellenkoft
  - A.R. Schmidt
  - Z.R. Struzik
  - A.P. de Vries
  - F. Waas
  - M.A. Windhouwer
- Multimedia and Human-Computer Interaction – INS2
  - H.L. Hardman
  - D.C.A. Bulterman
  - J. Geurts
  - M. Kuzmanovic
  - L.G.L.T. Meertens
  - J.R. van Ossenbruggen
  - S. Pemberton
  - L.W. Rutledge
- Interactive Information Engineering – INS3
  - P.J.W. ten Hagen

- E.H. Blake
- F. Denz
- S. van Dongen
- D.J.N. van Eijck
- A. Ficini
- A.V. Groenink
- M. Hazewinkel
- J. Hendrix
- I. Herman
- A.P.C. Kiers
- A.D.F. Lelièvre
- M.S. Marshall
- G. Melançon
- H. Noot
- Zs. Paál
- M. Pauly
- M.M. de Ruiter
- Zs.M. Ruttkay
- M.H.F. Savenije

- Quantum Computing and Advanced Research Systems – INS4

  - P.M.B. Vitányi
  - A.E. Brouwer
  - H.M. Buhrman
  - W. van Dam
  - D. van Dok
  - H.H. Ehrenburg
  - P.D. Grünwald
  - F.C. Gruau
  - M. van Liempt
  - H. Röhrig
  - B. Terhal
  - J.T. Tromp
  - L. Torenvliet
  - R.M. de Wolf

- Secretary:

  - M.W.A. Hegt

CWI Reports

INS-R9901. J.R. Castelo, A.P.J.M. Siebes. *Scaling Bayesian Network Discovery Through Incremental Recovery.*

INS-R9902. A.R. Schmidt, M.A. Windhouwer, M.L. Kersten. *Indexing Real-World Data using Semi-Structured Documents.*

INS-R9903. I. Herman, D.J. Duke. *Minimal graphics.*

INS-R9904. I. Herman, G. Melançon, M.M. de Ruiter, M. Delest. *Latour - a tree visualisation system.*

INS-R9905. M.L. Kersten, A.P.J.M. Siebes. *An organic database system.*

INS-R9906. F. Waas, J. Pellenkoft. *Probabilistic bottom-up join order selection — breaking the curse of NP-completeness.*

INS-R9907. Zs.M. Ruttkay. *Constraint-based facial animation.*

INS-R9908. A.J. Knobbe, H. Blockeel, A.P.J.M. Siebes, D.M.G. van der Wallen. *Multi-relational data mining.*

INS-R9909. F.C. Gruau, J.T. Tromp. *Cellular gravity.*

INS-R9910. J.S. Karlsson, M.L. Kersten. *Omega-storage: A self organizing multi-attribute storage technique for very large main memories.*

INS-R9911. F. Waas. *Cost distributions in symmetric Euclidean traveling salesman problems – a SUPplement to TSPLIB.*

INS-R9912. S. Manegold, P. Boncz, M.L. Kersten. *Optimizing main-memory join on modern hardware.*

INS-R9913. F. Waas, C.A. Galindo-Legaria. *Counting, enumerating and sampling of execution plans in a cost-based query optimizer.*

INS-R9914. Z.R. Struzik. *Direct multifractal spectrum calculation from the wavelet transform.*

INS-R9915. G. Melançon, I. Herman. *DAG drawing from an information visualization perspective.*

Data Mining and Knowledge Discovery – INS1

Staff

- Prof. dr. A.P.J.M. Siebes, theme leader
- Drs. A.R. van Ballegooij,PhD student, from October 1
- R.E. Blom, intern, from December 1
- Dr. ir. H.G.P. Bosch, post doc, from November 1
- Prof. dr. P.M.E. De Bra, senior researcher, seconded by TUE
- J.R. Castelo, comp.Eng., researcher
- Dr. A. Eliëns, senior researcher, seconded by VU
- K. van 't Hoff, programmer, until December 1
- S. Karlsson, MSc., researcher
- Prof. dr. M.L. Kersten, senior researcher and cluster leader
- Drs. A.J. Knobbe, researcher, seconded by Syllogic b.v.
- S. Manegold, dipl.-Inform., researcher
- Dr. H. Naacke, postdoc, from November 1
- Dr. N. Nes, postdoc
- Dr. ir. J. Pellenkoft, postdoc, from July 1
- A.R. Schmidt, Dipl.-Inform., researcher
- Dr. ir. Z.R. Struzik, postdoc

- Dr. ir. A.P. de Vries, postdoc, from December 16
- F. Waas, dipl.-inform., researcher
- Drs. M.A. Windhouwer, researcher

Scientific Report

Data mining – INS1.1

The data mining subtheme has concerned itself mainly with research along three lines, viz., Bayesian Networks, Wavelets for Time Series Data, and Multi Relational Mining.

For Bayesian Networks, Castelo and Siebes developed and published a divide and conquer strategy for the discovery of such networks from data. Moreover, a survey of the results in the past few years has been published.

In the wavelets stream, Struzik and Siebes carried out further work on the similarity paradigm have been carried out. In particular the Haar wavelet system has been incorporated in the similarity matching methodology. These (published) results are the basis for ongoing work. In particular, the possiblities have been evaluated for the use of the local Hoelder exponent methodology to detect and localise outliers in financial time series with ABN-AMRO.

Moreover, Struzik continued his work on Wavelets as an analysis tool. Collaboration with Boston University lead to a publication in Nature on cardiac signals. This work is continued using the local Hoelder exponent methodology. In collaboration with the AMC, intitial studies have been performed testing this methodology for the determination of hypoxia in fetus. Finally, work has been carried out and published on the direct estimation of multifractal spectra from the local Hoelder exponent methodology.

Knobbe (seconded by Syllogic) and Siebes worked on multi-relational mining. The first results comprising a framework and some initial experiments have been published. Knobbe suffers from a severe case of RSI which has caused serious delays.

Finally, Siebes has worked with Hofmann from the University of Augsburg on visualizing results of data mining sessions. The results of this collaboration will be published in 2000.

Multimedia databases – INS1.2

Pellenkoft was involved as a projectleader in the HPCN Conquer project. This 1 year project was focused on the realization of a multi-query optimizer for data mining applications. In work together with Manegold and Kersten, the validation results on the DDbenchmark showed performance improvements of up to a factor 18. These results will be published in BNCOD'00.

Manegold, Kersten, and Boncz (from Data Distilleries), studied the impact of modern hardware features, especially hierarchical cache-memory systems and super-scalair CPUs, on the performance of databases. The results were published in VLDB'99 and received a best-paper award. An extended version will be published in the VLDB Journal.

Manegold was also involved in the Conquer project. He did reseach on the benefit of Multi-Query Optimization for OLAP and Data Mining applications and implemented a protptypical Multi-Query Optimizer for CWI's high-performance main-memory database kernel Monet. Results of the work will be published in 2000.

Waas was involved in the IMPACT project. Most of 1999 was devoted to research on cost distributions in combinatorial optimization problems, with query optimization as the primary application area. Part of the research were carried out in close collaboration with Microsoft Corp.

Boncz and Kersten presented their work on the Monet database system in a VLDB journal paper focussed on the Monet Interface Language abstraction. This result condense several years of experience in the design and use of alternative database kernels for query dominant environments.

Cellular databases – INS1.3

Windhouwer, Schmidt and Kersten worked on the Acoi system, a part of the Telematics Institute Digital Media Warehouse project. Windhouwer was working on the Acoi system, a part of the DMW project. The concept of feature grammars, the core of the Acoi system, has been further formalized and extended. The toolchain supports the whole traject from defining a feature grammar, populating the database using the generated FDE (Feature Detector Engine) and querying this database using the FQE (Feature Query Engine). As an ongoing case study a web robot tarverses the web and uses a FDE for filling a meta index with features of the multimedia objects it encounters. A web interface for this meta index has been developed and can demonstrate the use of feature grammars.

Furthermore, Schmidt, Kersten and Winhouwer studied opportunities for XML processing in main-memory databases, especially CWI's high-performance main-memory database kernel Monet. Several schemas were evaluated and a mapping was found that performs very favorably. Results of the work were submitted for publication.

Kersten and Pellenkoft were involved in the preparations for the MIA/ICES project. The project started in the summer and Pellenkoft coordinates the CWI contributions of the project. In the MIA project we aim at providing the technology for future digital libraries which require truly multi-media analysis and efficient access to large amounts of multi-media data. Many new post-docs have been hired for this project, and a stream of publications is expected to start in 2000.

Kersten developed a prototype front-end, called the ImageSpotter, to steer the research lines in image storage, indexing and retrieval.

Karlson and Kersten developed the Omega-storage datastructure, a self organizing muli-attribute storage technique for large main- memories. With this task Karlson finished his PhD work on Scalable Distributed Datastructures and accepted a job at IBM San Jose.

Kersten spent a short sabbathical leave (June-August) at Stanford University, where he was able to push forward the functionality of the Feature Query Engine for the Acoi project and realization of the first version of the ImageSpotter. In cooperation with P. Mitra and G. Wiederhold he developed a model for ontology integration, an essential ingredient to enable XML-based information systems to cooperate in a meaningful way.

Finally, K. v't Hoff was responsible for the EU-Mercury project until April 1, whereafter he took a job at CMG.

Organization of Conferences, Workshops, Courses, etc.

Siebes:
- KESO Final review meeting, 12/04, Amsterdam

Kersten:
- IFIP WG2.6 meeting, 25/10, Amsterdam

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

Castelo:
- 10/09 – 19/09 Pavia, Italy, Second European Conference on HSSS. *Model Selection in Bayesian Networks from a Data Mining Viewpoint.*
- 24/09 – 15/10, Toronto, Canada. Workshop on Conditional Independence Structures and Graphical Models & Seminar on Conditional Independence Structures. *Optimizing the Number of Models Considered during Model Selection for Bayesian Networks.*

Karlsson:
- 05/09 – 10/09, Edinburgh, UK, VLDB99.

Kersten:
- 29/04 – 01/05, Edinburgh, UK, VLDB99 PC Meeting.
- 06/06 – 04/09 Stanford University, Stanford, CA, USA. Working Visit.
- 05/09 – 10/09 Edinburgh, UK, VLDB99

Manegold:
- 05/09 – 10/09 Edinburgh, UK, VLDB99. Lecture: *Database Architecture for the new Bottleneck: Memory Access.*

Nes:
- 10/07 – 17/07 Stanford University, Stanford, CA, USA. Working Visit.
- 29/08 – 3/9 Dagstuhl, Germany, Seminar Multimedia Database Support for Digital Libraries.

Pellenkoft:
- 03/06 – 04/06 Noordwijkerhout PAON Course: Research Voorstellen Schrijven.

Schmidt:
- 30/07 – 05/08 Orlando, FL, USA, ISAS99. Lecture: *Feature Grammars.*

Siebes:
- 01/03 – 03/03 Belfast, UK, Workshop High Performance Computing and Data Mining. Lecture: *High Performance Datamining.*
- 25/03 – 26/04 London, UK, IDA99 PC Meeting.
- 12/04 Amsterdam, HPCN99 workshop Data Mining. Lecture: *HPC Data Mining in Keso.*
- 17/05 – 18/05 Paris, France. Working visit Matra Systems.
- 31/05 – 01/06, Antwerp, Belgium. Studiedag Datamining. Lecture: *Financial Data Mining.*
- 09/08 – 11/08 Amsterdam, IDA99.
- 13/09 – 15/09 Edinburgh, UK. OR99. Lecture: *Reject Inference.*

- 04/09 – 10/09 Anapolis, Maryland, USA. EU/US Workshop on Large Scientific Databases. Lecture: *Data Mining on Large Scientific Databases.*
- 15/09 – 18/09 PKDD99 Prague, Czech Republic.
- 20/9 – 25/09 UPC, Barcelona, Spain. Lecture: *Graduate Course Data Mining*
- 09/11 – 12/11, Dosis Meeting, Eurostat, Luxembourg. Lecture: *Keso Final Report*
- 06/12, Universitaire Instelling Antwerpen. Lecture: *A Survey of Data Mining*

Struzik:

- 03/06 – 04/06 Noordwijkerhout PAON Course: Research Voorstellen Schrijven.
- 14/06 – 16/06 Delft, Fractals in Engineering. Lecture:*Local Effective Hoelder Exponent Estimation on the Wavelet Transform Maxima Tree.*
- 27/08 – 03/09, Florence, Italy, DEXA/IWOSS. Lecture: *Measuring Time Series Similarity through Features Revealed with Wavelet Transformations.*
- 04/09 – 14/09 M. Smolochowski Symposion on Statistical Physics, Zakopane, Poland. Lecture: *Determining Local Singular Strength and its Spectrum with the Wavelet Transform.*
- 15/09 – 19/09 PKDD99 Prague. Lecture: *The Haar Wavelet Transform in Time Series Similarity Paradigm*

Waas:

- 27/08 – 03/09, Florence, Italy, DEXA/IWOSS,

Windhouwer:

- 16/05 – 21/05 La Boule, France. EDBT summerschool Acoi: A Feature Database for Multi Media Objects.
- 12/11 – 21/11 Yogyakarta, Indonesia, First International Workshop on Information Integration and Web-based Applications. Lecture: *Acoi: A System for Indexing Multimedia Objects*

Visitors

01/10 – 30/11, Heike Hofmann, Universitaet Augsburg, Germany.

Memberships of Committees and Other Professional Activities

Kersten:

- Editor: *The VLDB Journal* and *Distributed and Parallel Databases*
- Invited Speaker:
  - *Building a Multi-media Index Server*, Stanford University June 30, USA
  - *An organic database system*, Stanford University, July 2, USA
  - *An Impressionist Monet Exhibit*, Microsoft Research, July 8–9, Redmond, USA
  - *An Impressionist Monet Exhibit*, IBM Almaden Research, Augustus 5, San Jose
  - *An Impressionist Monet Exhibit for Multimedia Index Services*, ICSI, Augustus 10, Berkeley
  - *The ACOI project: building a Multi-media Index Server*, IFIP WG 2.6 Meeting, October 26, Amsterdam
  - *My Sister in the Loop: Multi-media challenges*, VNO-NCW, November 25, Den Haag
  - *Large Main-Memory Database Research*, SARA Superdag, December 16, Amsterdam
- Program Commitees:
  - WebNet 99 World Conference on the WWW, Internet & Intranet, 1999, Hawaii
  - Int. Conf. on Data Enginering ICDE, 1999, Australia
  - HICSS-32 workshop on 'Multimedia DBMS and WWW', 1999, Hawaii
  - IEEE Multimedia Systems'99, 1999, Florence
  - Symposium on Large Spatial Databases, 1999, Hong Kong
  - Very Large Databases, 1999, Edinburgh
  - Visual Information SystemsVIS'99 1999 Amsterdam
- Member of the VLDB Endowment Executive Board
- Member of the IFIP WG-2 Databases workinggroup
- CEC Reviewer for the ESPRIT IV projects Jedi, HPRETAIL, and W3I3
- Member of the evaluation panel EU DG-12: Mathematics & Information Science
- Chairman of the non-executive board Data Distilleries
- Member of the non-executive board Consultdata

Siebes:

- Editor: *CWI Quarterly* and *Data Mining and Knowledge Discovery.*
- Program Commitees:
  - Intelligent Data Analysis (IDA) 1999, Amsterdam
  - Knowledge Discovery and Data Mining (KDD) 1999, San Diego

- Principles of Knowledge Discovery and Data Mining (PKDD), 1999, Prague
- SOFSEM, 1999, Milvoy, Czech Republic

- Member of the IDA Council
- Member of the CRISP-DM User Group
- Member of the Board of SIKS

Struzik:

- Invited talk at the 1999 Marian Smoluchowski Symposium on Statistical Physics
- Member of the scientific comitee of the Fractals in Engineering 1999 conference

Papers in Journals and Proceedings

A.T.M. Aerts, P.F.M. Bierhoff, P.M.E. De Bra (1999). WEB-CS: Infrastructure for Web-based Competition. *WebNet*, Honolulu, HA, USA, 69–74.

P.A. Boncz, M.L. Kersten (1999). MIL Primitives for Querying a Fragmented World. *The VLDB Journal* **8**(2).

P.A. Boncz, S. Manegold, M.L. Kersten (1999). Database Architecture Optimized for the New Bottleneck: Memory Access. *Proceedings of the International Conference on Very Large Data Bases (VLDB)*, Edinburgh, UK, 54–65.

P.M.E. De Bra, P. Bruslovsky, J. Eklund, W. Hall, A. Kobsa (1999). Adaptive Hypermedia: Purpose, Methods, and Techniques. *ACM Conference on Hypertext*, Darmstadt, Germany, 199–200.

P.M.E. De Bra, G.J. Houben, H. Wu (1999). AHAM: A Dexter-based Reference Model for Adaptive Hypermedia. *ACM Conference on Hypertext*, Darmstadt, Germany, 147–156.

R. Castelo, A.P.J.M. Siebes (1999). Optimizing the Amount of Models Taken into Consideration During Model Selection in Bayesian Networks. *Workshop on Conditional Independence, Structures, and Graphical Models*, Fields Institute for Mathematical Sciences, Toronto, Canada.

P.Ch. Ivanov, M.G. Rosenblum, L.A. Nunes Amaral, Z.R. Struzik, S. Havlin, A.L. Goldberger, H.E. Stanley (1999). Multifractality in Human Heartbeat Dynamics. *Nature* **399**, 461–465.

A.J. Knobbe, A. Siebes, D.M.G. van der Wallen (1999). Multi Relational Decision Tree Induction. J.M. Zytkow, J. Rauch (eds.). *Principles of Data Mining and Knowledge Discovery*. Springer-Verlag, Prague, Czech Republic.

S. Manegold, F. Waas (1999). Integrating I/O processing and Transparent Parallelism - Toward Comprehensive Query Execution in Parallel Database Systems. A. Dogac, M.T. Ozsu, O. Ulusoy (eds.). *Current Trends in Database Systems*, 130–152. January 1999.

A.R. Schmidt, M.A. Windhouwer, M.L. Kersten (1999). Feature Grammars. *Proceedings of the International Conference on Systems Analysis and Synthesis*, Orlando, FL, USA.

Z.R. Struzik (1999). Local Effective Hölder Exponent Estimation on the Wavelet Transform Maxima Tree. E.L.C. Tricot, M. Dekking, J.L. Véhel (eds.). *Fractals: Theory and Applications in Engineering*, Springer-Verlag, Berlin, New York, USA, 93–112.

Z.R. Struzik, A.P.J.M. Siebes (1999). Measuring Time Series' Similarity through Large Singular Features Revealed with Wavelet Transformation. *Proceedings of the International Workshop on Database and Expert Systems Application*, IEEE Computer Society Press. Florence, Italy, 162–166.

Z.R. Struzik, A.P.J.M. Siebes (1999). The Haar Wavelet Transform in the Time Series Similarity Paradigm. J.M. Zytkow, J. Rauch (eds.). *Principles of Data Mining and Knowledge Discovery*, Springer-Verlag, Prague, Czech Republic, 12–22.

F. Waas (1999). Handling Non-deterministic Data Availability in Parallel Query Execution. *International Workshop on Parallel and Distributed Databases*, IEEE Computer Society Press. Florence, Italy, 61–66.

M.A. Windhouwer, A.R. Schmidt, M.L. Kersten (1999). Acoi: A System for Indexing Multimedia Objects. *International Workshop on Information Integration and Web-based Applications & Services*, Yogyakarta, Indonesia.

CWI Reports

The following CWI reports were written by members of INS1. See page 83 for the complete titles.

INS-R9901	INS-R9902	INS-R9905
INS-R9906	INS-R9908	INS-R9910
INS-R9911	INS-R9912	INS-R9913
INS-R9914		

Multimedia and Human-Computer Interaction – INS2

Staff

- Dr. H.L. Hardman, theme leader
- Dr. D.C.A. Bulterman, external advisor
- Ir. J. Geurts, junior researcher
- M. Kuzmanovic, MA, multimedia artist (May 16–August 16)
- Prof. L.G.L.T. Meertens, researcher (till August 1)
- Drs. J.R. van Ossenbruggen, researcher
- S. Pemberton, researcher
- Dr. L.W. Rutledge, researcher

Scientific Report

The Multimedia and Human-Computer Interaction Theme initiated a new line of research in 1999. This has developed out of previous research on hypermedia document models and authoring systems. The new research direction focuses on the on-demand generation of hypermedia presentations. Successful fund-raising activities at the beginning of the year enabled the start of new projects towards the end of the year (RTIPA, DYNAMO, ToKeN2000).

RTIPA

The scope of this EUREKA ITEA project is to develop and deploy novel IP networks and services, using available technologies in conjunction with standards organisations and forums, such as W3C and ISO. Our group's involvement is to interface these new network services to media intensive and adaptive information applications. The approach is to generate a hypermedia presentation containing the information requested by the user in a format suited to their display device. We cooperate with the Dutch project partners Philips Research, TU Eindhoven and Oratrix Development B.V.

DYNAMO

The main goal of this NWO project is to increase the level of automated adaptation of varying user and system characteristics during the process of creating hypermedia presentations. User adaptation includes such things as the current state of knowledge of the user, the task the user is involved with and characteristics and preferences of the user. Adaptation at the system level includes accounting for the end-user system the presentation will be played on, the network bandwidth between the server generating the source document, the servers supplying the media items and the hardware at the client side. At the end of the year, preliminary work was carried out on the project. The CWI vacancy has been filled and work will commence on the project in February 2000. The work will be carried out in cooperation with TU Eindhoven (also funded by NWO) and Philips Research.

ToKeN2000

The Token2000 project is a multi–disciplinary research project focusing on the fundamental problems of interaction between humans and information systems. The fields involved are cognition and computer science. Key questions in the project are:

- Knowledge discovery. How can the information and knowledge found be processed and enriched?
- Knowledge accessibility. How should the accessibility of information and knowledge be adapted for a user in order to get the best possible knowledge transfer to that user.

The target of the first phase of the project is to realize a prototype system for making the multimedia information of the Rijksmuseum database accessible. This will result in a document generator that will create multimedia presentations based on the preferences of an individual user.

In addition to these projects Van Ossenbruggen and Rutledge contributed heavily to the development of the successor to SMIL 1.0 (Synchronized Multimedia Integration Language) and Pemberton continued chairing the W3C HTML Working Group.

Lynda Hardman led the theme for her first year. The priority was to secure funds for starting up new projects while continuing ongoing research efforts. In addition, recruitment of high-quality new personnel was of paramount importance. The leadership of the theme was interrupted by her absence on maternity leave for the last two months of the year.

Dick Bulterman left CWI at the end of 1998 in order to found Oratrix Development B.V. He continues to have ties with the group in the role of external advisor. In particular, collaborating on work within the W3C SYMM working group

and supporting the use of the GRiNS authoring system within the group's research.

Joost Geurts developed a CORBA-based XML DOM interface to the GRiNS authoring environment. He also worked on research prototypes with Brian Bailey and developed the ToKeN2000 demonstrator.

Maja Kuzmanovic worked for 6 months on a joint project GoTo0 with GMD on multi/hypermedia in virtual reality. This resulted in a storyboard for an interactive narrative which requires stretching the boundaries of current virtual reality technology. Unfortunately, due to GMD resourcing problems, there is currently no demonstration or prototype of Maja's ideas.

Lambert Meertens. After a successful sabbatical leave, he continued his research activities at the Kestrel Institute in the USA.

Jacco van Ossenbruggen coordinated the CWI input to starting up the RTIPA, DYNAMO and ToKeN2000 projects, including supervision of Geurts. He contributed, along with Hardman and Rutledge, to the multimedia/hypermedia courses being given and developed at the VU.

Steven Pemberton continued to chair the W3C HTML Working Group. He is editor-in-chief of the *ACM Interaction journal*. Pemberton's research interests are in the field of user interfaces to electronic documents, currently funded through the UWish project. The vacancy remained unfilled all year because of the shortage of suitable (post-doc) candidates.

Lloyd Rutledge contributed heavily to the research carried out within the group, in particular for the MIA project, producing numerous papers and giving a number of tutorials. In addition to the W3C SYMM working group Rutledge is also an invited expert in the XML Linking working group.

Knowledge Transfer

Lynda Hardman:
- Panel participant, *Digital Libraries*, Imagina, Monte Carlo, January 19.
- *Authoring Hypermedia - It Takes Time* (Tutorial), ACM Hypertext 99, February 22, Darmstadt, Germany.
- *Modelling and Authoring Hypermedia* (Tutorial), IPO, March 2, Eindhoven.
- *Modelling Hypermedia* (Invited lecture), WINS UvA, March 5, Amsterdam.
- *Hypermedia Caput College* (Invited lecture and demo), VU, March 18, Amsterdam.
- *SMIL* (Tutorial with L. Rutledge), WWW8, Toronto, May 11.
- *The Future of SMIL*, Aristote Seminar, Paris, June 10.
- *Multimedia Technology*, (Course), Bunnik, June 22.

Maja Kuzmanovic:
- *Digital Creativity: Topologies of Fortuity*, Medi@terra, Athens, Greece, December 9–12.

Jacco van Ossenbruggen:
- *Interoperability on the World Wide Web*, Open Hypermedia Systems workshop, ACM Hypertext 99, Darmstadt, Germany, February 21.
- *Research directions in processing and modeling Web-documents*, Philips Research Informatica Colloquium, Eindhoven, March 3.
- *Multimedia document abstractions for multi-platform delivery publishing*, SIMOS workshop, Paris, March 29-30.
- *Research directions in processing and modeling Web-documents*, VU, Amsterdam, April 21.
- XML seminar, CWI, June 18.

Lloyd Rutledge:
- *SMIL: The Synchronized Multimedia Integration Language* (Tutorial) given at:
  ACM Hypertext 99, Darmstadt, Germany, February 22,
  WWW8 (with L. Hardman), Toronto, May 11,
  ACM Multimedia 99, Orlando, Florida, November 1.
- *XML Tutorial*, Multimedia Modeling 99, Ottawa, Canada, October 6.

Organization of Conferences, Workshops, Courses, etc.

Lynda Hardman:
- Co-organized (with J. van Ossenbruggen) XML seminar, CWI, June 18.
- Co-chair (with P. De Bra) Informatiewetenschap 99, CWI, November 12.

Jacco van Ossenbruggen:
- Co-organized (with L. Hardman) XML seminar, CWI, June 18.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

Joost Geurts:
- DELOS workshop, Santorini, Greece, July 24–25.

- SIMOS workshop, Santorini, Greece, July 28–29.
- Conferentie Informatiewetenschap, CWI, November 12.

Lynda Hardman:
- INA (Institut National de l' Audiovisuel), Paris, January 20.
- GMD Sankt Augustin, IMK.VE, Febuary 17.
- ACM Hypertext 99, Darmstadt, Febuary 23–25.
- SIMOS workshop, Paris, March 29–30.
- W3C SYMM meeting, CWI, Amsterdam, April 26–27.
- RTIPA/ITEA meeting, Paris, April 28.
- WWW8, Toronto, May 12–13.
- INA, Paris, June 11.

Maja Kuzmanovic:
- Invençao, Sao Paulo, Brazil, August 25–30.
- SEAFair99, Skopje, Macedonia, September 23–30.
- DAC99, Atlanta, Georgia, October 28–31.

Lambert Meertens:
- Kastrel Institute, california.

Jacco van Ossenbruggen:
- ACM Hypertext 99, Darmstadt, February 23–25.
- W3C SYMM meeting, CWI, Amsterdam, April 26–27.
- INA, Paris, June 11.
- RTIPA/ITEA: Paris September 6; Eindhoven September 23; Den Haag, October 7.

Lloyd Rutledge:
- ACM Hypertext 99, Darmstadt, February 23–25.
- W3C SYMM meeting, CWI, Amsterdam, April 26–27.
- DELOS workshop, Santorini, Greece, July 24–25.
- SIMOS workshop, Santorini, Greece, July 28–29.
- W3C SYMM and XML Linking meetings, INRIA, Sophia Antipolis, September 27–28.
- ACM Multimedia 99, October.
- DELOS workshop, Pisa, Italy, November 25–30.

Steven Pemberton:
- De Digitale Stad 5 jaar, January 15
- Innovation exchange workshop, De Waag, February 18
- Four meetings of the W3C HTML Working Group
- CTIT, Enschede, March 22. Talk: *User interfaces and the whole environment.*
- Webgrrls, Amersfoort, 27 March. Talk: *Styling Web Sites.*
- Online Help 99, London, 4 June. Talks: *The New HTML*, *The User Interface of Help.*
- Opennet 99, Bonn, Germany, Nov 16. Talk: *Future Markup Languages.*
- INRIA, Sophia Antipolis, 29 September. Talk: *The Use of Namespaces in XHTML.*

Memberships of Committees and Other Professional Activities

- Member of W3C SYMM Working Group: Dick C.A. Bulterman, Lynda Hardman, Lloyd Rutledge, Jacco van Ossenbruggen.

Dick Bulterman:
- Program committee chair ACM Multimedia 99.
- Program committee chair WWW9.
- Member IW3C2 (WWW conference committee).

Lynda Hardman:
- Program committee ACM Hypertext 99.
- Hypermedia Track chair of WWW9
- Editorial board *New Review of Hypermedia and Multimedia.*
- Committee Vereniging Werkgemeenschap Informatiewetenschap (Information Science).
- Reviewer for ACM Computing Reviews
- Reviewer for conference papers: IEEE ICMCS, H2PTM, ACM Multimedia 99, Webnet 99.
- Reviewer for journal papers ACM *Computing Surveys*; *New Review of Hypermedia and Multimedia*; IEEE *Transactions on Software Engineering.*

Jacco van Ossenbruggen:
- Reviewing activities: WWW9, ACM Hypertext 2000, WebNet 99, ACM Multimedia 99.

Lambert Meertens:
- Professor of Computer Science at Utrecht University (till August 1)

Steven Pemberton:
- Chair of W3C HTML Working Group.
- Conference chair 'HCI in the Netherlands', Utrecht, November 11th
- Member of committee 'Designing Interactive Systems 2000'
- Conference Proceedings 'Human Factors in Computing Systems CHI 99', Associate Editor.
- Editor-in-chief *ACM/interactions.*
- Founding member of SIGCHI.NL.
- SIGCHI.NL Chair for Conferences committee, Chair for international contacts.
- Member ACM/SIGCHI Worldwide Issues WG.
- Founding member and Executive Committee member, Amsterdam New Media Association.

Lloyd Rutledge:

- Member of W3C XLink Working Group.
- Treasurer, ACM Multimedia 99.
- Member, ACM SIGWeb, SIGMM.
- Reviewing activities: ACM Hypertext 2000, WebNet 99, ACM Multimedia 99, ACM Symposium on Applied Computing at SAC '99.

Visitors

- Gwendal Auffret, INA, February 8, July 26.
- Carole Goble, University of Manchester, April 23.
- Brian Bailey, University of Minnesota, May 31 – August 31.
- Frank Nack, GMD-IPSI, June 14.
- Sean Bechhofer, University of Manchester, August 6.
- Jim Davis, CourseNet Systems, October 21 – December 31.

Software Developed

Brian Bailey:
- Prolog/Java prototype of constraint-based hypermedia generation system.

Joost Geurts/Jacco van Ossenbruggen:
- CORBA-based XML DOM interface to the GRiNS authoring environment, ToKeN2000 demonstrator.

Maja Kuzmanovic:
- SMIL demo for WWW8.

Papers in Journals and Proceedings

D.C.A. Bulterman, L. Rutledge, L. Hardman, J. van Ossenbruggen (1999). Supporting Adaptive and Adaptable Hypermedia Presentation Semantics. *The 8th IFIP 2.6 Working Conference on Database Semantics (DS-8): Semantic Issues in Multimedia Systems*, Rotorua, New Zealand, January 5–8.

L. Hardman, J. van Ossenbruggen, L. Rutledge, K.S. Mullender, D.C.A. Bulterman (1999). Do You Have the Time? Composition and Linking in Time-based Hypermedia. *Proceedings of ACM Hypertext 99*, 189–196.

L. Rutledge, L. Hardman, J. van Ossenbruggen, D.C.A. Bulterman (1999). Adaptable Hypermedia with Web Standards and Tools. *Proceedings of The Active Web* – A British HCI Group Day Conference, January 20th, London, UK.

L. Rutledge, J. van Ossenbruggen, L. Hardman, D.C.A. Bulterman (1999). Mix'n'Match: Exchangeable Modules of Hypermedia Style. *Proceedings of ACM Hypertext 99*, 179–188.

L. Rutledge, J. van Ossenbruggen, L. Hardman, D.C.A. Bulterman (1999). Anticipating SMIL 2.0: The Developing Cooperative Infrastructure for Multimedia on the Web. *Proceedings of The Eighth International World Wide Web Conference* (WWW8), May 12–13.

D.C.A. Bulterman, L. Rutledge, L. Hardman, A.J. Jansen, K.S. Mullender (1999). GRiNS: An Authoring Environment for Web Multimedia. *Proceedings of ED-MEDIA 99* – World Conference on Educational Multimedia, Seattle, Washington, USA.

L., Rutledge, L. Hardman, J. van Ossenbruggen (1999). The Use of SMIL: Multimedia Research Currently Applied on a Global Scale. *Proceedings of Multimedia Modeling 99*, (MMM 99), World Scientific, Ottawa, Canada, 1–17.

Other Publications

M. Kuzmanovic (1999). GoTo0. Immersive Storytelling: Hypermedia and VR. *Invençao*, Sao Paulo, Brazil, August 25–30.

M. Kuzmanovic (1999). Alchemy, Mysticism and Shamanism in Projective VR. *SEAFair99*, Skopje, Macedonia, September 23–30.

M. Kuzmanovic (1999). Storytelling in Immersive Virtual Reality. *DAC99*, Atlanta, Georgia, October 28–31.

Steven Pemberton (1999). *Supporting HTML in Xlink*, W3C Note, `http://www.w3c.org/Markup/Group/1999/19990429-Xlink-for-HTML`

L. Rutledge (1999). SMIL–Synchronized Multimedia Integration Language: Moving to the beat. *iX, Magazin für professionelle Informationstechnik* **10**.

L. Rutledge, L. Hardman, J. van Ossenbruggen (1999). Evaluating SMIL: Three User Case Studies. *Proceedings of ACM Multimedia*, Orlando, Florida, USA. Note: Poster Paper

L. Rutledge, B. Bailey, J. van Ossenbruggen, L. Hardman, J. Geurts (1999). Generating Presentation Constraints from Rhetorical Structure. *Conferentie Informatiewetenschap*, November 13, CWI.

Awards

Maja Kuzmanovic:
- *TR100 Best Young Innovators meeting*, Boston Massachussets, November 4.

Interactive Information Engineering – INS3

Staff

- Drs. P.J.W. ten Hagen, theme leader
- Prof. dr. E.H. Blake, visitor, Un. Cape Town (June 1–July 31)
- Ms. F. Denz, trainee, (till April 16)
- Ir. S. van Dongen, PhD student
- Prof. dr. D.J.N. van Eijck, researcher
- A. Ficini, trainee (May 1–August 1)
- Dr. A.V. Groenink, researcher (Eidetica b.v.)
- Prof. dr. M. Hazewinkel, researcher
- Drs. J. Hendrix, project worker (from June 1)
- Dr. I. Herman, researcher
- Ms. ir. A.P.C. Kiers, project worker (from February 16)
- A.D.F. Lelièvre, trainee (from October 11)
- M.S. Marshall BSc., project worker
- G. Melançon, researcher
- Drs. H. Noot, scientific programmer
- Ms. Zs. Paál, visitor (January 18–March 1)
- M. Pauly, MSc., PhD student
- Drs. M.M. de Ruiter, scientific programmer
- Ms. dr. Zs.M. Ruttkay, researcher (STW)
- Drs. M.H.F. Savenije, researcher (till February 1)

Scientific Report

Information Visualisation – INS3.1

Earlier work on visualizing and navigating in trees came to an end in 1999. The resulting system, *Latour*, is in use by Ace b.v., in Amsterdam. The research work concentrated rather on the extension of the general methodology on graph visualization for general graphs, primarily on directed acyclic graphs (DAGs). This included the specification of new types of metrics for DAGs, an investigation, from an information visualization point of view, of DAG layout algorithms and of navigational principles, and an initial work on specialized clustering algorithms for DAGs. In the course of this work the importance of random generation of DAGs was also recognized: they provide a firm basis for the evaluation of various algorithms and methods.

The development of an experimental research environment for graph navigation also began in 1999. Although, initially, it was thought that the code of *Latour* could be reused, a more thorough investigation revealed that the development of a completely new system would be more advantageous. Thus began the development work for the *Royere* system, aimed at general graph visualization.

As a side-product of the investigation on general graph visualization and navigation issues, a large survey has been written and presented as a State of the Art report at the Eurographics'99 conference.

In parallel to the graph visualization and navigation work, issues related to human cognition and their relationships to graphics was also investigated. This resulted in a CWI report (*Minimal Graphics*) as well as a research project proposal which is currently under review by the European Union IST programme.

Applied Logic and Interactive Information Engineering – INS3.2

Van Eijck continued his work on theorem proving for dynamic logic. He published a paper on theorem proving for a variety of dynamic logics, including DPL, in the *Journal of Language and Computation.* A paper on dynamic reasoning without variables (*Incremental Dynamics*) is in press (*Journal of Language and Information*).

Together with his coworker Juan Heguiabehere at ILLC, Van Eijck continued the developement of dynamic logic programming and Dynamo (see `http://www.cwi.nl/~jve/dynamo`). Van Eijck is also working with ILLC colleagues on a new format for Montague Grammar, IMG (Incremental Montague Grammar).

Connections between logic and game theory have been investigated further by Marc Pauly. Specifically, a game-theoretic semantics for various game constructions has been provided, a process equivalence notion has been extended to games, and a modal logic for reasoning about what coalitions of players can achieve in a game has been developed.

Regular contacts are maintained with the spin-off company, Eidetica, that emerged from this group. Van Eijck supervised the work of Frauke Denz, who combined research on lexical tagging with the development of a word tagger for

Eidetica, in the context of a master thesis project for the University of Stuttgart. Official supervisors were Van Eijck, Hans Kamp (University of Stuttgart) and Annius Groenink (Eidetica). In 2000, Frauke Denz will receive her MSc. in computational linguistics. She is now an employee of Eidetica.

Stijn van Dongen researched 'nonnegative matrices' and 'partitioning and graph spectra' in the context of his PhD thesis work, and was engaged in completing his PhD thesis manuscript on 'Graph Clustering by Flow Simulation'.

Report by M. Hazewinkel

A. Research on Hopf algebras and quantum groups. In March 199, Hazewinkel managed to prove an old conjecture of Ditters (1972) on Hopf Algebras. It was published in preprint IC/99/29, Trieste.

B. Research on the mathematical problems of taxonomy. When trying to organize the world literature in a given area of science (key phrases, classification, clustering, taxonomy, etc.) quite a few new mathematical problems arise. Mostly of a combinatorial-algebraic nature, with some computer science additional aspects. Two publications on these matters are mentioned below. Serious dificulties arise because of missing data in various forms. The ideas of identification clouds and weak enriched thesauri introduced in these publications are designed to provide better information retrieval tools in well structured collections like scientific databases. Within the framework of INTAS for cooperation with the ex-Soviet Union a first thesaurus for six parts of mathematics has been created and is available on request (runs on Windows 95 or 98).

Facial Animation – INS3.3

The FASE project completed the first working version of the *CharToon* system. The system has been tried out by several animation artists. As a result improvements were incorporated having to do with the user friendliness and the increase of control for the animator. Also a start was made to incorporate in *CharToon* a repertoire of reusable elements on several levels: for the composition of faces, for the expressions of complete faces, as animation elements, rather than stills, and for the change of viewpoint. By now *CharToon* is a versatile system containing many novel ways of creating animations. In particular the system was adapted for fully exploiting the emerging web-technology. Facial data provided by our partners from TU Delft are now sufficiently accurate that the analysis of facial expressions can lead to a model for a facial expression space, which in turn, can support a 3D facial model. A prototype control system for the emotional behaviour was developed as part of the TI project, called MCCW. This so-called emotion disc is now incorporated in the *CharToon* system. It has been demonstrated that this facility can drive the emotions of avatars in a VRML world. TNO-TM used this facility extensively to perform user test for non-verbal aspects in user interfaces. *CharToon* is now being tested by outside parties in USA and in The Netherlands. The results are encouraging. Many demonstrations have been given this year. *CharToon* was presented at sveral conferences and workshops. The team has started in the autumn with the design of the planned constraint layer that will lead to higher level functionality for *CharToon* users.

Organization of Conferences, Workshops, Courses, etc.

Van Eijck:

- Logic, Representations and Proofs, first year course in mathematical thinking, University of Amsterdam, together with Dr. Kees Doets.
- Reasoning and Computation, ESSLLI Summer School Course, Utrecht, August 9–13, together with Eva Hoogland.
- Formal Forays into Language, graduate course on Logic and Language, University of Utrecht, Spring 1999,
- Computational Semantics, Graduate Course Computer Science, University of Amsterdam, Spring 1999,
- (organizer) Dagstuhl Workshop on Dynamic Semantics, 31 Jan – 3 Feb, together with Michael Kohlhase,
- (organizing chair) Logic Colloquium 1999, Utrecht, August 1–6.
- (organizer) Dutch Graduate School in Logic School Week, December 13–16, at Euclides, Plantage Muidergracht 24, Amsterdam.
- Reasoning and programming, beta-gamma course at University of Amsterdam, Fall 1999, together with Dr. Jan Jaspars.

Hazewinkel:

- Two courses at Utrecht University.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

M. Hazewinkel:

- Abdus Salam ICTP, Trieste, March 19– April 3.
- Nederlands Mathematisch Congress, Utrecht, April 8–9.
- Cooloquium, Math. Inst. University of Bielefeld, April 23.
- Chelyabinsk low dimensional topology conference, Mias, Russia, July 31–August 7.
- ISI meeting on Statistical publishing, Warsaw, August 23–24.
- Limit theorems in probability, Vilnius, August 25–28.
- DMV Tagung, Mainz, September 6–10.
- INTAS Council of Scientists, Brussels, October 19–21.
- Working visit Thesaurus research, Vilnius, Lithuania, November 26–30.
- TRIAL-Solution meeting, Koblenz, December 9–10.
- INTAS council of Scientists, Brussels, December 10–12.
- Colloquium ICTP Trieste, March 29: *The Leibniz-Hopf algebra and its dual.*
- Series of four lectures at the ICTP Trieste, in March : *Interrelations of K-theory and control.*
- Colloquium Dept. Math. Univ. of Bielefeld, April 23: *Quasi-symmetric functions and the Leibniz Hopf algebra.*
- DMV Tagung, September 7, *Mathematics of classification and classification of mathematics*, invited lecture.
- Warsaw ISI meeting, August 23, *Key Phrases and the quality of scientific databases*, invited lecture.
- Chelyabinsk Low dimensional topology conference, August 3, *Quasi-symmetric functions and the Leibniz-Hopf algebra.*
- Chelyabinsk low dimensional topology conference, August 6, *Mixed Yang-Baxter invariants for knots and links.*
- Lecture symposium AS2, *Knots links, braids, and tangles. An introduction.* November 10, Utrecht.

Members of INS3.1:

- May, 8th WWW conference, Toronto, Canada (I. Herman).
- May, Eurographics/IEEE Symposium on Data visualization, Vienna, Austria. (G. Melançon, S.M. Marshall), paper presentation.
- September, Eurographics Conference, Milano, Italy (G. Melançon, S.M. Marshall, I. Herman). Held a STAR report presentation.
- September, Graph Drawing Symposium, Prague, Czech Republic (G. Melançon), paper presentation.
- September, Words, Université de Rouen, France (G. Melançon), paper presentation.
- October, IEEE Visualisation conference, San Francisco, USA (S.M. Marshall, I. Herman).
- November, IHM'99 Workshop, Montpellier, France (Onzièmes journées sur l'ingénierie de l'Interaction Homme-Machine) (G. Melançon), paper presentation.
- March, York, UK, I. Herman (British council cooperation).
- June, November, December Bordeaux, France, S.M. Marshall, G. Melançon, I. Herman, M.M. de Ruiter (van Gogh cooperation).
- October, Stanford University, S.M. Marshall, I. Herman.
- February, Daghstuhl, Germany.
- April, Grenoble, France.
- October, Leiden, I. Herman (TACIT meetings).

Ten Hagen:

- Participated in the IEEE midwinter meeting at TUE, with a lecture about facial animation, Januari 19th.
- Participated in the INFOCARE seminar on human interfaces with a lecture about CharToon. CharToon was also demonstrated at the exhibition, Februari 10.
- Evaluation of ESPRIT project MSC in Rennes (F), on Februari 16.
- Evaluation of the ESPRIT project Open Math in Brussels on April 15 and in Bath (UK) on November 4th.
- Participated at the EUROCASE review meeting for the European IT prize, in Paris on June 21–23, and in Amsterdam on September 6–8.
- Participated in the so-called Mindshare day at the Telematics Institute, with a demonstration of CharToon on September 16th.

Other members of INS3.3:

- Ten Hagen, Noot and Ruttkay participated in the EUROGRAPHICS'99 conference in Milano, with a paper about Facial Animation with CharToon, presented by Zs. Ruttkay, September 6–10.
- Ruttkay participated in the SIGGRAPH99 conference at Los Angeles, USA on August 8–13.
- Ruttkay participated in the ERCIM workshop on constraints in Paphos (GR), with a presentation about Constraints in Facial Animation, on October 25–27.

- Ten Hagen, Ruttkay, Noot, and Kiers organised the Face to Face workshop on Computer Animation in Amsterdam with two presentations and a demonstration of CharToon on March 25th.

Jan van Eijck:

- *Dynamo–A Language for Dynamic Logic Programming*, Dagstuhl Workshop on Dynamic Semantics, February 2.
- *Building Decision Machines with Dynamo*, GRAM, Groningen, February 26.
- *Dynamic Logic Programming*, Aachen-Amsterdam Exchange, Amsterdam, February 19.
- *Dynamo and Non-Monotonic Reasoning*, DGNMR'99, March 26.
- *Computing with Dynamic First Order Logic*, 8th CSLI Workshop on LLLC, Stanford, May 30.
- *Dynamo – a computational version of dynamic FOL.* Amsterdam Coordination Group Colloquium, CWI, November 23.
- *On the Proper Treatment of Context in Natural Language*, Computational Linguistics in the Netherlands (CLIN), Utrecht, December 10.

Marc Pauly:

- *Game Semantics for Game Logic*, Conference on Logic, Game Theory and Social Choice, Oisterwijk, Netherlands, May 16.
- *Game Logic for Game Theorists*, Workshop on Games and Logic, Leipzig, Germany. July 16.
- *Reasoning about the Power of Coalitions*, ILLC Workshop on Logic and Games, Amsterdam, Netherlands, November 20.
- *Modeling Coalitional Power in Modal Logic*, Amsterdam Colloquium, Amsterdam, Netherlands, December 21.
- Research Visit to University of Helsinki, February 10-20: guest of Gabriel Sandu.

Stijn van Dongen:

- *A cluster process for graphs using stochastic matrices*, Seminar Discrete Wiskunde, Eindhoven, February 17.
- *A stochastic uncoupling process with applications to graph clustering*, Seminar Dynamics, Amsterdam, May 5.

Visitors

Guests of Hazewinkel:

- Dr. Peter Malyshev, Kiev, January 20–January 28.
- Dr. Rimas Maliukevicius, Vilnius, April 4–11.
- Prof. dr. Revaz Gamkrelidze, Moscow, April 13.
- Dr. Vytas Statulevicius, Vilnius, April 18–22.
- Dr. Rimas Maliukevicius, Vilnius, April 18–22.
- Dr. Peter Malyshev, Kiev, May 16–23.
- Dr. Laima Pilukaite, Vilnius, May 16–28.
- Dr. Rimas Maliukevicius, Vilnius, June 15–20.
- Dr. Alexander Kazbaras, Vilnius, June 15–20.
- Dr. Kestutis Pilkauskas, Kaunas, June 27–July 14.
- Dr. Peter Malyshev, Kiev, September 26–October 3.

Guests of Herman:

- June, October, Dr. D. Duke, University of York.
- January, G. Eyrolles, I. Dutour, University of Bordeaux (van Gogh cooperation)
- November, D. Auber, University of Bordeaux (van Gogh cooperation).
- November, Dr. Jon May, University of Sheffield; Dr. D. Duke; University of York; Dr. D. Duce, RAL; and P. Barnard, University Hospital, Cambridge (TACIT working meeting).
- October, Prof. A. Ellis, South-Western University, Australia; Jon Bosak, Sun Microsystems, USA; R. Cailleau, CERN, Switzerland; W. Hall, University of Southampton, UK; M. Molroney, Commerce One, Canada; A. Zurco, IRIS, USA; J. Hardin, University of Chicago, USA; B. Hopgood, UK; J.-F. Abramatic, W3C-INRIA, France; Vezza, CNRI, USA, (IW3C2 meeting).

Guests of Van Eijck:

- F. Denz, Stuttgart, October (Supported by University of Stuttgart).

Guests of Ten Hagen:

- Prof. G. de Jager, University of Cape Town on Februari 11.
- Prof. H. Frowein, Dr. B. Elsendoorn and Dr. N. van Son from the institute for the deaf on March 11.
- Prof. E. Blake of University of Capetown (SA), on April 29 and from June 15 to July 15.
- A delegation of NOB headed by J. de Vries and R. Leyendekker visited on May 10.
- K. van Overveld of Philips on December 15.
- R. Koenen of KPN on November 19.
- B. Takacs from Los Angeles, USA on December 17.
- Prof. R. Nakatsu and Dr. N. Tosa of ATR research institute, Kyoto (J) on December 21.

Memberships of Committees and Other Professional Activities

M. Hazewinkel:

- Professor of mathematics (0.2 fte) at Utrecht University.

Refereeing the following items

- Thesis Giovanna Carnovale, Utrecht.
- FWF (Austrian Science Foundation) and three INTAS proposals.

Editorial positions

- Managing Editor book series: Mathematics and Its Applications, Kluwer Academic Publishers, 1977– ...
- Managing Editor journal *Acta Applicandae Mathematicae*, Kluwer Academic Publishers, 1983 ...
- Managing Editor *Handbook of Algebra* in 9 volumes; first volume 1996.
- Associate editor journal *Multi-dimensional system theory*, Kluwer Boston, 1994– ... .
- Co-managing editor series CWI Tracts, Syllabi, Varia, 1983– ...
- Member Steering Committee MTNS 1985– ...
- Liaison member ECMI with the Euromath project.
- Member board CMF (Caribbean Mathematical Foundation).
- Member board WG, 1994–1999.
- President WG, 1996–1999.
- Representative of WG in European Mathematical Society, 1994–1999.
- Chairman Scientific Steering Group ERCIM-INTAS FSU, 1995– ... .
- Manager (co-ordinator) INTAS projects 96–0793 (1997–2000), 96–0741 (1997–2000), 97–0808 (1998–2001), 97–0804 (1999–2001).
- Member Council of Scientists INTAS, Sept. 1999–... .
- Co-organizer KNAW colloquium Computational algebra and systems / control theory to take place November 1–3 2000.

D.J.N. van Eijck:

- Professor of Logical Aspects of Computational Linguistics, University of Utrecht (since December 1990).
- Program committee member of IWCS III (Third International Workshop on Computational Semantics), January 13–15, Tilburg.
- Program committee member of ICoS-1, Inference in Computational Semantics, ILLC, Amsterdam, August 15.
- Member of the European Network in Computational Logic (initiated by the ESPRIT Basic Research Action 'Compulog'), since March 1997.
- Scientific Director of the Dutch Graduate School in Logic (since Spring 1997).
- Member of the International User and Consultation Group for TRINDI.
- Chairman of the local organization of ASL Logic Colloquium (August 1–6).
- Member of the Thesis Defence Committee of Khalil Sima'an, UU (March 31).
- Member of the Thesis Defence Committee of Dirk Heijlen, UU, (June 18).
- Organizer of Workshop on Logic and Games, ILLC, Amsterdam, November 19–20.

Ten Hagen:

- EUROGRAPHICS:
  Fellow of the association
  Member of the Executive Board
  Member of the program committee for Eurographics 2000.
- ISO:
  Member of the subcommittee ISO/IEC JTC1/SC24.
  Member of the SC24/WG8 on Synthetic Environments.
- Member of the Evaluation Group for the European Information Society Technologies Prize.
- IFIP:
  Member of IFIP WG5.2 on Computer Aided Design.
  Member of IFIP WG5.10 on Computer Graphics.
- Member of the advisory subcommitte on mathemetics and computer science of the Dutch Aerospace Laboratory.
- Member of the editorial board of the *Journal Research in Engineering Design.*
- Editor of the Springer Bookseries Symbolic Computation/Computer Graphics.

I. Herman:

- Member of the Eurographics Executive Committee and Executive Board, online information officer for the Association.
- Member of the Eurographics'99 Programme Committee.
- Member of the Editorial Board of the journal Computer Graphics Forum.
- Member of the WWW8 Conference Programme Committee.
- Member of the IW3C2 (International World Wide Web Conference Committee).

- W3C Advisory Committee member on behalf of CWI.
- Member of the Amsterdam New Media Association (ANMA) board.

M. Pauly:

- Assistant teacher of the course 'Logic for AI', University of Amsterdam, Fall 1999.
- Assistant teacher of the course 'Logic and Games', University of Amsterdam, Fall 1998.

PhD Theses

December, G. Melançon defended his Habilitation at the University of Bordeaux I.

Software

- The tree visualization system, *Latour*, has been completed in 1999. Its commercial exploitation is pending, waiting for the decision of an STW project proposal. We began experimentation with the software in order to manage more general graphs. After some experimentation, we decided that a completely new software has to be developed, with much greater configurability and extensibility, to manage general graphs both on the display and navigation aspects. Development for this software began in early 1999, and the software became fully operational for experimentation by October 1999. It is currently used by our group, as well as by our collegues at the Universities of York, UK, and Bordeaux, France.
- An XML, based vocabulary has also been developed for the general description of graphs for visualization purposes; the specification, as well as the core parser for the specification, is operational and will be put into the public domain at the very beginning of 2000.
- A separate software, for the large scale random generation of directed acyclic graphs has also been developed in cooperation with the University of Bordeaux, and has already been extensively used to derive various statistical aspects of DAGs. The software will also be put into public domain in 2000.

Books

D.J. Duke, I. Herman, M.S. Marshall (1999). *PREMO: A Framework for Multimedia Middleware, A Java description of the ISO/IEC Standard*, Lecture Notes in Computer Sciences **1591**, G. Goos, J. Hartmanis (eds.). Springer-Verlag.

Papers in Journals and Proceedings

M. Hazewinkel (1999). Index Theoretical Computer Science Volumes 1–200. *Theor. Comp. Sci* **213/214**, 1–659.

M. Hazewinkel (1999). 35 articles for Encyclopaedia of Mathematics **12**.

M. Hazewinkel (1999). Topologies and metrics on information spaces. *CWI Quarterly* **12**(2), 93–110.

D.A. Duce, D.J. Duke, G. Faconti, I. Herman (1999). The changing face of standardization: a place for formal methods? *Formal Aspects of Computing* **11**(1), 10–20.

I. Herman, M.S. Marshall, G. Melançon, D.J. Duke, M. Delest, J.-P. Domenger (1999). Skeletal Images as Visual Cues in Graph Visualization. E. Gröller, H. Löffelmann, W. Ribarsky (eds.). *Data Visualisation '99, Proceedings of the Joint Eurographics IEEE TCVG Symposium on Visualization*, Vienna, Springer-Verlag, 13–22.

G. Melançon, I. Herman, M. Delest (1999). Indices visuels et métriques combinatoires pour la visualisation de données hiérarchiques. J. Nanard, P. Girard (eds.). *Proceedings of the IHM'99 Workshop (Onzièmes journées sur l'ingénierie de l'Interaction Homme-Machine)*, Montpellier, 166–173.

I. Herman, G. Melançon, M.M. de Ruiter, M. Delest (1999). Latour – a tree visualisation system. *Proceedings of the Symposium on Graph Drawing GD'99*, Springer-Verlag, 392–399.

I. Herman, G. Melançon, S.M. Marshall (1999). Graph Visualisation in Information Visualisation. B. Falcidieno, J. Rossignac (eds.). *Eurographics'99 State-of-the-Art Reports*, Eurographics Publications, Aire-la-Ville, ISSN 1017–4656.

G. Melançon (1999). Lyndon Words and Singular Factor of Sturmian Words. *Theoretical Computer Science* **218**, 41–59.

J. van Eijck (1999). Axiomatising Dynamic Logics for Anaphora. *Journal of Language and Computation* **1**, 103–126.

J. van Eijck (1999). Dynamo with Shift and Reduce. H. Rott, C. Albert, G. Brewka, C. Witteveen (eds.). *DGNMR'99, Proceedings*, ILLC Scientific Publications.

M. Pauly, Modeling Coalitional Power in Modal Logic. P. Dekker (ed.). *Proceedings of the Amsterdam Colloquium*, ILLC Scientific Publications.

Zs. Ruttkay, P. ten Hagen, H. Noot, M. Savenije (1998). Facial Animation by Synthesis of Captured and Artificial Data. *Modelling and Motion Capture techniques for Virtual Environments, Proc. CAPTECH'98*, Geneva, Switzerland, Springer lecture Notes in AI 1998.

Zs. M. Ruttkay (1999). Constrained-based Facial Animation. K.R. Apt (ed.). *Proc. of the ERCIM workshop on Constraints*, Springer Lecture Notes.

P.J.W. ten Hagen, H. Noot, Zs. Ruttkay (1999). CharToon: a System to Animate 2D Cartoon Faces. M.A Albertini et al. (eds.). *Proc. of the Eurographics '99 Conference, short papers and demos*, Eurographics Association .

CWI Reports

The following CWI reports were published by members of theme of INS3. See page 83 for the complete titles of the reports.

INS-R9903 INS-R9904 INS-R9907 INS-R9915

Other Publications

J. van Eijck (1999). Powering Decision Machines with Dynamo. J. Gerbrandy, M. Marx, M. de Rijke, Y. Venema (eds.). *JFAK - Essays Dedicated to Johan van Benthem*, Vossius Press, Amsterdam.

M. Pauly (1999). Game Constructions that are Safe for Bisimulation. J. Gerbrandy, M. Marx, M. de Rijke, Y. Venema (eds.). *JFAK - Essays Dedicated to Johan van Benthem*, Vossius Press, Amsterdam.

M. Pauly (ed.) (1999). *Proceedings of the ILLC Workshop on Logic and Games*, ILLC Technical Report.

Quantum Computing and Advanced Research Systems – INS4

Staff

- Prof. dr. P.M.B. Vitányi, group leader
- Prof. dr. A.E. Brouwer (seconded Univ. Eindhoven)
- Dr. H.M. Buhrman, project leader
- Drs. W. van Dam, junior researcher (PhD student) UvA
- D. van Dok, assistant researcher (undergrad) UvA
- Drs. H.H. Ehrenburg, junior researcher (PhD student)
- Dr. F.C. Gruau, postdoc
- Dr. P.D. Grünwald, researcher (temporary Stanford Univ.)
- M. van Liempt, assistant researcher (undergrad) UvA
- Drs. H. Röhrig, junior researcher (PhD student), NWO-EW
- Dr. B.M. Terhal, junior researcher (PhD student), UvA, until September 1
- Dr. L. Torenvliet (seconded University of Amsterdam)
- Dr. J.T. Tromp, postdoc
- Drs. R.M. de Wolf, junior researcher (PhD student), UvA

Scientific Report

The project works at algorithmic methods and complexity analysis. Specific subjects are quantum computing, quantum communication, and quantum information theory, computational learning, computational linguistics, network algorithms, evolutionary algorithms, formal aspects of AI, structural complexity theory, descriptive complexity and applied complexity theory. Considerations are with respect to both sequential and parallel computation and quantum computing.

Quantum Computing – INS4.1

The research of the group at CWI has a major commitment to establish theoretical and practical principles to develop physical realizations of coherent quantum computers, and to develop theory and applications of reversible unitary algorithms for such machines which improve the capabilities of machines based on classical physics.

Quantum coherent computation is a new field of research that has attracted an increasing number of computer scientists and physicists over the last ten years. In the last years evidence has arisen that the proposed coherent quantum computers may be (and for some tasks are) intrinsically much faster than classical computing

devices, thus making their technological development of great economic interest. Coherent quantum computers have also a theoretical interest, as their study has contributed open problems and may contribute to solving standing open problems in computation theory. Exploring the possibilities of a quantum computer is anticipated to shed new light on aspects of quantummechanics, thus increasing our understanding of quantum phenomena.

The project has no counterpart in The Netherlands. The INS4.3 group at CWI (Algorithms and Complexity) collaborates with the Theoretical Physics Department and the Computer Science and Logic Department of the University of Amsterdam and various major centers abroad: the Quantum Information Group at IBM T.J. Watson Research (C. Bennett), the Quantum Computation Group at the Clarendon Laboratory at Oxford University (A. Ekert), Computer Science Department of the University of Alberta at Calgary, Canada (R. Cleve), Computer Science Department at the University of Chicago (L. Fortnow), and the Computer Science group at Université Paris-Sud Orsay (M. Santha).

Buhrman and *De Wolf* published their lower bound for quantum binary search (square root logarithmic) in the journal *Information Processing Letters*. After the preprint of this result appeared on the quant-ph archive, their result has been improved to optimal (logarithmic) by others (a group from MIT and Ambainis from Berkeley).

De Wolf, together with *A. Ambainis* (UC Berkeley), obtained results on the average-case query complexity of quantum computers that compute total Boolean functions. They exhibited functions where the quantum average-case complexity is exponentially smaller than the classical average-case complexity. This contrasts with the case of worst-case complexity, where at most a polynomial quantum speed-up is possible. The results will appear in the *17th Annual Symposium on Theoretical Aspects of Computer Science* (STACS'2000).

Buhrman and *De Wolf*, together with *R. Cleve* (University of Calgary) and *Ch. Zalka* (Los Alamos), proved complexity bounds for quantum algorithms with very small error probability or even zero-error. In particular, they obtained tight bounds for quantum search under very general circumstances, showed that classical success amplification cannot be improved by quantum computers, obtained almost optimal quantum-classical separations for computing monotone Boolean functions, and established bounds on the quantum complexity of graph properties. The paper appeared in the *40th IEEE Symposium on Foundations of Computer Science* (FOCS'99).

Buhrman and *De Wolf* proved lower bounds for quantum communication complexity, using a novel connection to the number of monomials of polynomials. In particular they showed that the classical log-rank lower bound also holds for the strongest model of quantum communication complexity, where the two parties may exchange qubits and can make use of unlimited prior quantum entanglement. Previously this bound was known only for the model without prior entanglement. They also showed that quantum and classical communication complexity are polynomially related whenever the function f to be computed has the form $f(x, y) = g(x \wedge y)$, for g a symmetric or monotone Boolean function.

Buhrman and *De Wolf* wrote a survey paper about the connections between various complexity measures (block sensitivity, certificate complexity, polynomial degrees) and classical or quantum decision tree complexity.

De Wolf, together with *V. Halava* and *M. Hirvensalo* (University of Turku, Finland), established decidability and undecidability of various special cases of Post's Correspondence Problem, which is one of the best-known undecidable problems in formal language theory. They sharply delineate the boundary between decidability and undecidability: 1-marked PCP is decidable (even in polynomial space) but 2-marked PCP is undecidable. The paper appeared in the *16th Annual Symposium on Theoretical Aspects of Computer Science* (STACS'99), and a final version will appear in the journal *Theoretical Computer Science*.

Buhrman and *Van Dam* initiated research that combines both classical complexity theory with quantum computation. They studied the NP query hierarchy and showed that in this setting the quantum model is more powerful unless the polynomial hierarchy collapses. In addition they show that for the class EXP the speedup is the biggest and can be proven without additional complexity theoretical assumptions. Their paper *Quantum Bounded Query Complexity* appeared in the proceedings of the *14th Annual IEEE Conference on Computational Complexity (CCC99)*.

Buhrman was member of the program committee of the 1999 edition of Algorithms in Quantum Information Processing AQIP'99 and invited

speaker of 2000 edition held in December 1999 in Montréal.

Buhrman obtained (together with *Torenvliet*) a grant from NWO for 1 PhD student and 1 postdoc for 4 years. He is also coordinator of the (in July 1999) approved 5th framework project Quantum Algorithms and Information Processing. There are eight European, three Canadian, and one American participating partners.

Van Dam continued his work on quantum communication. Together with L. Hardy (University of Oxford) he established a separation between classical and quantum communication, using the 'quantum Zeno effect'. He also investigated the close link between nonlocality proofs and the reduction in communication complexity that these inequalities allow. It was shown that with stronger than quantum correlations between remote systems, all distributed decision problems have the same, trivial complexity of one bit.

Together with H. Buhrman, *Van Dam* published an article on the topic of 'bounded quantum query complexity'. This paper suggests that oracles with an underlying structure (like NP or PSPACE-complete problems have) allow a larger quantum reduction in the query complexity than unstructured black-boxes. The 'self-testing' properties of simple quantum gates was studied by *Van Dam,* F. Magniez (Paris), M. Mosca (Waterloo) and M. Santha (Paris). The authors showed how it is sometimes possible to test the correct behaviour of quantum gates without having to assume the reliability of other, prior, quantum mechanical components: self-testing.

Terhal obtained her PhD 'Cum Laude' at the University of Amsterdam on November 3 on the thesis *Quantum Algorithms and Quantum Entanglement*. The research reported consists of two parts: on the one hand the efficient simulation of quantum mechanical systems by quantum computers. In this work the notion of quantum Markov chains for quantum computation was introduced for the first time, and the initial stages of the corresponding theory was developed. In the second part of the thesis new algebraic forms of entanglement where discovered and described, forms that have a partially graph-theoretical characterization and that usher in a new family of positive maps. She received an NWO Talent Award and an IBM Research Postdoc Award.

Vitányi continued work on the quantitative definition of quantum information (quantum Kolmogorov complexity), its properties, and potential applications.

Röhrig worked with Lov Grover, Sanjiv Kapoor, Scott Aaronson, and Ashwin Nayak at Bell Labs on variations of quantum search algorithms. A paper co-authored with Lov Grover is forthcoming.

Machine Learning – INS4.2

Grünwald has obtained several new results concerning the Minimum Description Length (MDL) Principle. In his 1998 thesis, he introduced the concept of 'entropification' as a tool to apply the MDL Principle to classes of non-probabilistic models (e.g. neural networks) combined with general loss functions. In 1999, the preliminary results of the thesis were extended and the proofs greatly simplified. This led to a publication at the 1999 COLT (Computational Learning Theory) Conference. The greatest weakness of the preliminary version of 'entropification' was that it could only be applied to 'symmetric' loss functions. It was impossible to deal with skewed loss functions (e.g. predicting a 1 while the outcome should be 0 is much worse than predicting a 0 while the outcome should be 1). Such skewed loss functions are very important in practical applications. Urged by J. Rissanen and A.P. Dawid, who both saw this as an essential obstacle to further development of 'entropification', Grünwald set out to solve this problem. He succeeded in the second half of 1999; a publication containing the resulting extension of 'entropification' is in preparation.

Grünwald also continued work on the Maximum Entropy (ME) Principle. Together with A.P. Dawid (University College London) a result from Grünwald's thesis was generalized and reinterpreted in game-theoretic terms. This led to a general game-theoretic re-interpretation of the Maximum Entropy Principle (as a game a 'Statistician' plays against 'Nature') and also pointed towards a generalization of the concept of entropy. Grünwald and Dawid defined a 'generalized entropy' which depends on the loss function to be used in the game between Statistician and Nature; if this is the logarithmic loss, then generalized entropy reduces to usual (Shannon) entropy. If it is a different loss function, then different 'entropies' result. One can define a 'generalized maximum entropy principle', which, in turn, turns out to be intimately related to the *Robust Bayes* method in statistics. This connection had not been realized before. Grünwald and Dawid

plan to meet several times in 2000 to finalize their results and summarize them in one or two papers.

Grünwald also continued a different line of work relating to the Maximum Entropy Principle: the distinction between 'risky' and 'safe' applications of ME (introduced in his thesis in 1998) was refined, and it was shown that many of the perceived problems of ME disappear if its application is restricted to 'safe' cases.

Gruau and *Tromp* worked on a problem concerning global behaviour based on local computation in cellular automata: the so-called piling problem.

Vitányi, Tromp continued work (partially with M. Li) treating the mathematical relation between data compression and learning. The relationship between the Bayesian approach and the minimum description length approach was established. This sharpens and clarifies the general modeling principles MDL and MML, abstracted as the ideal MDL principle and defined from Bayes's rule by means of Kolmogorov complexity. The basic condition under which the ideal principle should be applied is encapsulated as the Fundamental Inequality, which in broad terms states that the principle is valid when the data are random, relative to every contemplated hypothesis and also these hypotheses are random relative to the (universal) prior. Basically, the ideal principle states that the prior probability associated with the hypothesis should be given by the algorithmic universal probability, and the sum of the log universal probability of the model plus the log of the probability of the data given the model should be minimized. If one restricts the model class to the finite sets then application of the ideal principle turns into the so-called 'Kolmogorov's minimal sufficient statistic.' In general it was shown that data compression is almost always the best strategy, both in hypothesis identification and prediction. This work is to appear in *IEEE Trans. Information Theory*. *Vitányi* served in several program committees on learning in 1999 (GECCO99, ICML99, 5th ISAIM, COLT01, and was member of IFIP WG 1.2 on data-compression and 1.4 (co-chair) on computational learning.)

Algorithms and Complexity, Advanced Systems Research – INS4.3

Distributed and Network Computing

Buhrman, *F. Franklin* (AT&T, USA), *J. Garay*, *Hoepman*, *Tromp*, and *Vitányi* formulated a new type of search problem called 'mutual search,' where k agents, arbitrarily distributed over n sites, are required to locate one another by posing queries of the form 'Anybody at site i?'. We ask for the least number of queries that is necessary and sufficient. For the case of two agents using deterministic protocols we obtain the following worst-case results: In an oblivious setting (where all pre-planned queries are executed) there is no savings: $n-1$ queries are required and are sufficient. In a nonoblivious setting we can exploit the paradigm of 'no news is also news' to obtain significant savings: in the synchronous case $0.586n$ queries suffice and $0.536n$ queries are required; in the asynchronous case $0.896n$ queries suffice and a fortiori 0.536 queries are required; for $o(\sqrt{n})$ agents using a deterministic protocol less than n queries suffice; there is a simple randomized protocol for two agents with worst-case expected $0.5n$ queries and all randomized protocols require at least $0.25n$ worst-case expected queries. The results are to be published in the *J. Assoc. Comp. Mach.*

Buhrman, Vitányi worked with A. Panconesi (Bologna) on the relation between distributed 'naming' and distributed 'consensus' and improved algorithms for distributed naming. The results indicate that naming is more fundamental than consensus.

Algorithms and Complexity

Vitányi, Buhrman and *Jiang* (McMaster Un., Canada) and *Li* further developed the incompressibility method: an elementary yet powerful proof technique based on Kolmogorov complexity. It was pioneered and developed by Li and Vitányi in a general purpose tool. It is shown that this method is particularly suited to obtain average-case computational complexity lower bounds on algorithms. Such lower bounds have been difficult to obtain in the past by other methods. They give proofs for new results on: space filling curve fitting lower bounds, multidimensional random walks, communication complexity (average-case) and the number of strings of which the complexity exceeds their length. We give new proofs for known results on: boolean matrix multiplication, majority finding, random walks, and communication complexity (worst case). The new proofs are much simpler than the old ones. This work resulted in publications in *Computer Journal*, *Theoretical Computer Science* and in *Intn'l Conf. on Automata, Languages, and Programming* in Prague (Czech Republic) in 1999.

Vitányi and *Jiang* and *Li* investigated the question of a nontrivial general lower bound (or upper bound) on the average complexity of Shellsort (due to D.L. Shell) has been open for about four decades. We present such a lower bound for p-pass Shellsort: the number of data-movements (and comparisons) made by a p-pass Shellsort for any incremental sequence is $\Omega(pn^{1+\frac{1}{p}})$. Using similar arguments, we analyze the average-case complexity of several other sorting algorithms. This work was reported at *Intn'l Conf. on Automata, Languages, and Programming* in Prague (Czech Republic) in 1999, and the final version will appear in *J. Assoc. Comp. Mach.*

Vitányi and *Jiang* (McMaster Un., Canada) and *Li* studied an old problem by Heilbronn. This half a century old problem asks for the least Δ such that n points lying in the unit disc necessarily contain a triangle of area at most Δ. Heilbronn initially conjectured $\Delta = O(1/n^2)$. As a result of concerted mathematical effort it is currently known that there are positive constants c and C such that $c \log n/n^2 \leq \Delta \leq C/n^{1.142-\varepsilon}$ for every constant $\varepsilon > 0$. They resolve Heilbronn's problem in the expected case: If we uniformly at random put n points in the unit disc then the area of the smallest triangle has expectation $\Theta(1/n^3)$ (and the smallest triangle has area $\Theta(1/n^3)$ with probability almost one). The proof uses the incompressibility method based on Kolmogorov complexity. This work was presented at the *Computational Complexity Conference* in Atlanta (USA) in 1999. The Nov. 6 issue of the *New Scientist*, pp. 44–47, carries a feature article by Dana Mackenzie about this work (translated in French in *Courrier International*, December 23, 1999–January 5, 2000, No. 477–478).

Vitányi and *O. Watanabe* (Tokyo Inst. of Technology) studied the mean and variance of the running time of the *monopolist game*: it starts with k players with equal initial capital I/k of the total initial capital of I units. The game is divided into discrete rounds. At every round one of the players wins and receives $k-1$ units from the other players who each lose one unit. The players have equal probabilities $1/k$ of winning a round. If a player has zero capital he is called *bankrupt*. Bankrupt players continue to play but don't pay if they lose and don't receive money if they win: once they have zero capital they continue having zero capital. The game terminates if all but one player has lost all of the money. The surviving player has accumulated all the money and is called a *monopolist*. Clearly, the game is related to a multidimensional random walk and 'ruin' problems in probability theory. However, we were not able to find quantitative trade-offs between probabilities and the values of lower bounds and upper bounds on the number of rounds it takes for the monopolist to emerge. The game is a formalization of a simplified version of a neural network updating rule due to von der Malsburg. This updating rule plays a key role in explaining orientation selectivity in the brain.

Vitányi continued with the theory of time-bounded universal distributions and their applications in 'simple pac-learning' and 'universal average case complexity.'

Vitányi was and is program committee member of Ninth International Conference on Intelligent Systems: Artificial Intelligence Applications for the New Millennium, June 14–17, 2000 The Galt House Hotel Louisville, KY USA; IFIP International Conference on Theoretical Computer Science (IFIP TCS2000) – Exploring New Frontiers of Theoretical Informatics – August 17–19, 2000 Tohoku University, Sendai, Japan; Organizing/Program Committee "Workshop on Complexity and Inference" for the "Computational Information Theory and Coding Year" (2001–2002) at DIMACS at Rutgers University; WADS99 in Canada, ICML99 in Slowak Republic, GECCO99 in USA, SIROCCO'99 in France.

Buhrman and *Torenvliet* studied the NP versus co-NP problem in particular the quality of a possible separation. They extended work from Balcazar and Torenvliet's thesis. They showed that there exists a relativized world where NP contains a a set that is both simple and NP $\cap$ co-NP immune. They show the same thing also holds for co-NP. In addition they are able to extend the results to Π_2^p and show that there is a relativized world where Π_2^p contains a set that is simple and $\Pi_2^p \cap \Sigma_2^p$ immune. The main new tool is the use of Kolmogorov complexity. Their paper *Complicated Complementations* appeared in the proceedings of the *14th Annual IEEE Conference on Computational Complexity (CCC99).*

Buhrman together with *Miltersen, Radhakrishnan*, and *Venkatesh* worked on the static membership problem: Given a set S of at most n keys drawn from a universe of size m, store it, so that queries of the form 'Is x in S?' can be answered quickly. They showed lower and upper bounds for the randomized and deterministic complexity of this problem in the *bitprobe model*.

In particular they show that there exist randomized schemes that store $O(\frac{n}{\varepsilon^2}\log m)$ bits and, using a *single* bitprobe, answers queries correctly with probability more than $1-\varepsilon$. they prove that their schemes are close to optimal by obtaining almost tight lower bounds. Their paper *Are bitvectors optimal* will appear in the proceedings of STOC'2000.

Buhrman together with *Miltersen* and *Laplante* studied a resource bounded version of Kolmogorov complexity, CD^t complexity. They study the problem of language compression. Without time bounds it is well known that for any set D with d elements it holds that for every $x \in$ its Kolmogorov complexity is bounded above by $\log(d)$. Buhrman and Fortnow showed earlier that for polynomial time bound an almost similar statment holds for CD complexity: For all $x \in D^{=n} : \mathrm{CD}^{poly}(x|D^{=n}) \leq 2 * log(d) + O(\log(n))$. The difference lies in the multiplicative constant 2. They now show that this constant 2 is necessary. Furthermore for certain type of random sets they show that the bound holds without the factor of 2. Their results can be found in the paper *New Bounds for the Language Compression Problem*, has been submitted for publication.

Buhrman and *Fortnow* vastly simplify the proof of Andreev, Clementi and Rolim and Andreev, Clementi, Rolim and Trevisan that if there exist quick hitting set generators then P = BPP. They then solve an open problem from Andreev, Clementi, Rolim and Trevisan by showing that there is a relativized world where P = RP $\neq$ BPP.

Buhrman, together with *Fenner, Fortnow* and *van Melkebeek* studied the complexity class $\cap$ SPARSE. They exhibit a relativized world where this class does not have complete sets. It follows immediately that there also is a relativized world where there are no optimal proof systems. They also show a close relation between these issues and the reduction of sparse sets to tally sets. Their paper *Optimal proof systems and sparse sets* will appear in the proceedings of the *17th Annual Symposium on Theoretical Aspects of Computer Science (STACS'2000).*

Brouwer performed research on distance-regular graphs, strongly regular graphs, codes and designs, quantum codes, and similar objects. Furthermore, research on association schemes, on the subspaces of the 759-point near polygon, on on Chevalley groups and buildings of spherical type, on knot theory and related topology, and on cryptographic protocols. He proved a NP-completeness result for a combinatorial problem. Ongoing research in computeralgebra, and computer topics, and Linux.

Tromp improved on recent work of Gary. W. Flake and Eric. B. Baum, who showed the PSPACE-completeness of a simple motion problem involving unidirectional cars. Flake and Baum use cars of sizes both 2 and 3 to construct hard problems. They ventured a claim that both sizes are needed, the problem perhaps becoming easy with size-2 cars only. Tromp's work disproves this claim as he designed alternative constructions achieving the needed functionality with size-2 cars only. A report on this work is forthcoming.

Tromp, Gruau investigated global emergent behaviour of local transition rules in 2-dimensional cellular spaces. The particular problem was 'piling' which has applications in evolutionary cellular coding and also in distributed sorting. This research appeared in preliminary form as CWI report.

Tromp working with *Marcel Crasmaru* (Tokyo Institute of Technology), proved PSPACE-completeness of an aspect of the game of Go. The P-space completeness can be obtained using a very restricted form of Go. Forthcoming in report form.

Organization of Conferences, Workshops, Courses, etc.

- COLORET. European HCM project in the area of Computation, Logic and recursion theory.
- ESPRIT. CWI is partner of the ESPRIT BRA IV NeuroCOLT II Working Group EP 27150 on fundamental understanding of learning and of when and how it can be implemented algorithmically. Particular classes of adaptive systems will also be studied, including neural networks with discrete and continuous activations. *Vitányi* is work area manager of two out of three work areas.

  Partners in the ESPRIT Working Group are CWI, the universities of RWTH Aachen, INRIA, Nancy, France; GMD, Sankt Augustin, Germany; Universitat Pompeu Fabra, Barcelona, Technische Universität Graz, University of Helsinki, Hebrew University, Jeruzalem, Israel; Australian National University, Canberra, Australia; University of Dortmund, Dortmund, Germany; London School of Eco-

nomics, University of London, Ecole Normale Supérieure de Lyon, University of Milan, Université de Mons, Royal Holloway College, University of London. (EuroCOLT finished early 1997, was extended by the ESPRIT Commission to end 1997, and subsequently the follow-up EuroCOLT II was approved comprising a changed set of partners including CWI.)
- *Grünwald* and *Vitányi* organize the 2001 *Computational Learning Theory Conference* in Amsterdam.

Visits to Conferences, Workshops, Colloquia, etc., Working Visits

A.E. Brouwer:
- June 5–10, 2nd Pythagorean Congres, Samos, Greece. Contributed talk.
- July 13–17, Combinatorics and Finite Geometries Congress, Brussels, Belgium. Contributed talk.
- August 4–5, Seidel Congress, Oisterwijk, The Netherlands. Contributed talk.

H. Buhrman:
- Algorithms in Quantum Information Processing in Chicago, USA, January 17–22. Talk: *Quantum Lower Bounds by Polynomials.*
- Visit Lance Fortnow at University of Chicago, USA, January 23–30.
- Short course probabilistic method by Noga Alon in Eindhoven, February 8–12.
- Symposium Theoretical Aspects of Computer Science, Trier, Germany, March 3–6. Talk: *One sided versus two sided error in probabilistic computation.*
- NVTI bijeenkomst Utrecht, March 19. Talk: *Quantum Communication.*
- Visit Thomas Thierauf at University of Ulm, Trier, Germany, March 31– April 2. Talk: *Quantum Communication Complexity.*
- Visit Carl Smith at University of Maryland, Washington, USA, April 28–30. Talk: *Quantum Communication Complexity.*
- FCRC Atlanta USA, May 1–5. Talk: *Complicated Complementations.*
- RAND workshop in Paris, France, May 18–21. Talk: *Quantum Communication Complexity.*
- Visit Miklos Santha, University Paris Sud, Paris, France, June 2–4.
- Quantum workshop Newton Institute Cambridge, UK, July 11–25. Talk: *Quantum Communication Complexity.*
- EU meeting for approved proposals in FET, Brussel, Belgium, September 9.
- Visit Damgård University of Aarhus, Denmark, October 6–11. Talk: *Quantum Algorithms.*
- Workshop on Boolean functions Dagstuhl, Germany, September 31– November 4. Talk: *Lower Bounds for Quantum Communication Complexity.*
- Algorithms and Quantum Information Processing, Montreal, Canada. December 5–12. Talk: *Lower Bounds for Quantum Communication Complexity via Polynomials.*
- Visit Lance Fortnow at NEC, Princeton, USA, December 12–18.

P. Vitányi:
- March 20–28, Dagstuhl Seminar on Learning Theory, Dagstuhl, Germany. Talk: *MDL Induction, Bayesianism, and Kolmogorov complexity.*
- May 1-16, Federated Computer Research Conference, Computational Complexity Conference, ACM Symposium on Theory of Computing, Atlanta, Georgia, USA. Talk: *The Average-case Size of Heilbronn's Triangles.*
- May 18–22, Workshop on Algorithmic Information Theory, Nancy University, Nancy, France. Talk: *The Average-case Time Complexity of Shellsort.*
- July 8–16, International Colloquium on Automata, Languages, and Programming, Prague, Czech Republic. Talk: *The Average-case time complexity of Shellsort.* Talk: *New Applications of the incompressibility method.*
- July 16–25, Quantum Information Processing and Quantum Computing Workshop, Newton Institute, Cambridge, UK. Talk: *Two Approaches to the Quantitative Definition of the Information in a Pure Quantum State.*
- November 9– December 10, Computer Science Department, Tokyo Institute of Technology, O-okayama, Tokyo, Japan (host: Prof. O. Watanabe). (Talk: *A Lower Bound on the Average-case Running Time of Shellsort.*)

J. Tromp:
- Third Workshop on Algorithmic Information Theory (TAI'99), May 20–21, LORIA Nancy, France. Talk: *Kolmogorov Complexity made Concrete.*

P. Grünwald:
- February 4, CSLI Machine Learning Seminar, Stanford University, Stanford, California, USA. Talk: *The MDL Principle for General Model Classes and Error Functions.*

- March 5, SNN (Stichting Neurale Netwerken), Nijmegen, The Netherlands (host: Dr. B. Kappen). Talk: *The MDL Principle and Maximum Entropy.*
- April 12, Day visit to IBM Almaden Research Center, San Jose, California, USA (host: Dr. J. Rissanen). Talk: *The MDL Principle for General Model Classes and Error Functions.*
- During the months of April, May, June and September, 6 more one-day working visits to IBM Almaden took place, all hosted by Dr. J. Rissanen.
- April 28, day visit to EURANDOM, Eindhoven, The Netherlands (host: Prof. R. Gill). Talk: *Safe Statistics.*
- April 30–May 2, visit to University College London, London, UK (host: Prof. A.P. Dawid). Talk: *Safe Statistics.*
- May 28–30, Eighth CSLI Workshop on Logic, Language and Computation, Stanford University, Palo Alto, California, USA. Talk: *Taking the Sting out of Subjective Probability.*
- June 13, visit to SRI International, Menlo Park, California, USA (host: Dr. M. Goldszmidt). Talk: *Safe Statistics.*
- July 6–9, *COLT '99* (The Twelfth Annual Conference on Computational Learning Theory), Santa Cruz, California, USA. Talk: *Viewing All Models As Probabilistic.*
- July 26–29, visit to University of Indiana at Bloomington, Bloomington, Indiana, USA (host: Prof. R. Shiffrin). Talk: *The MDL Principle for 'arbitrary' Model Classes.*
- July 29–August 1, 32nd Annual Meeting of the Society for Mathematical Psychology, Santa Cruz, California, USA. Talk: *The MDL Principle for 'arbitrary' Model Classes.*
- September 7, Berkeley Statistics Seminar, Dept. of Statistics, University of California at Berkeley, USA. Talk: *Safe Statistics.*
- September 9, day visit to the Department of Computer Science of the University of California at Santa Cruz, Santa Cruz, California, USA (host: Prof. M. Warmuth). Talk: *Safe Statistics.*
- September 14, Berkeley AI Seminar, Dept. of Computer Science, University of California at Berkeley, USA. Talk: *Maximum Entropy and the Glasses You Are Looking Through.*
- September 30, day visit to the Department of Computer Science of the University of California at Santa Cruz (host: Prof. M. Warmuth).
- October 5, weekly Nobots colloquium, Stanford University, USA. Talk: *Maximum Entropy and the Glasses You Are Looking Through.*
- December 16, EURANDOM Post-Doc Seminar, EURANDOM Institute for Probability and Statistics, Eindhoven, The Netherlands. Talk: *Safe Statistics.*

H. Röhrig:

- January 17, AQIP'99 conference at De Paul University, Chicago, USA.
- February 8, Mini lecture series by Noga Alon on the probabilistic method at TU Eindhoven, Eindhoven, The Netherlands.
- July 4–December 31, Research stay with Lov Grover, Bell Labs.

B. Terhal:

- September 23–October 1, Physics Department, Cornell University, Ithaca, USA.
- April 15–29, Physics Department, Technion, Israel.
- March '98–April, IBM T.J. Watson Research Center, Yorktown Heights, NY.
- *Quantum Information Theory*, seminar in LASSP Autumn School, Cornell University (September).
- *The Applications of Positive Linear Maps in the Theory of Bipartite Mixed State Entanglement*, workshop on Complexity, Computation and the Physics of Information, Isaac Newton Institute,Cambridge, UK (July).
- *On the problem of equilibration and the computation of correlation functions on a quantum computer*, in Seminar on quantum information theory, Technion, Israel (April).
- *Quantum Information Theory and Computation*, Physics Colloquium, Hunter College, NYC (March).
- *Quantum Information Theory and Computation*, Seminar at Theory Group of Microsoft Research, Microsoft, Seattle (February).
- *On the problem of equilibration and the computation of correlation functions on a quantum computer*, AQIP '99, Chicago (January).
- QIP 2000, Montréal, Canada (December).
- Workshop on Complexity, Computation and the Physics of Information, Isaac Newton Institute,Cambridge (July).
- AQIP '99, Chicago, US (January).

W. van Dam:

- Algorithms and Complexity Group of the Laboratoire de Recherche en Informatique, Université Paris Sud, Orsay, France, April 6–12; working visit.
- 31st ACM Symposium on Theory of Computing, Atlanta, USA, May 1–4.

- 14th Annual IEEE Conference on Computational Complexity, Atlanta, USA, May 4–6. Presentation: *Quantum Bounded Query Complexity.*
- Unisys Users Association Conference, Frontiers in Computing Seminar, Madrid, Spain, May 20. Presentation *Quantum Computing.*
- Quantum Information Workshop, University of Bielefeld, Germany, October 19–20. invited talk: *Superstrong Nonlocality and Communication Complexity.*
- Centre for Quantum Computation, University of Oxford, United Kingdom, November 25–December 1. Talk: *A New Quantum Trick with Quadratic Residues.*

R. de Wolf:

- January 13, General Mathematics Colloquium, University of Amsterdam. Talk: *Quantum Computation and Shor's Factoring Algorithm.*
- March 3–6, STACS'99, Trier, Germany,
- May 20–22, RAND2 Workshop on Randomized Algorithms, Gif-sur-Yvette, France. Talk: *Quantum Complexity in the Black-box Model.*
- July, Cambridge workshop on Complexity, Computation and the Physics of Information, Cambridge, UK. Talk: *Average-case Quantum Query Complexity.*
- October 17–19, IEEE FOCS'99, New York. Talk: *Bounds for Small-error and Zero-error Quantum Algorithms.*
- October 20–29, University of Calgary, Canada. (host: Prof. Richard Cleve) Talk: *Lower Bounds for Quantum Communication Complexity.*
- December 10, CRM workshop on quantum information processing, Université de Montreal, Canada. Talk: *Log-rank Lower Bound for Entanglement-enhanced Quantum Communication Complexity.*

Memberships of Committees and Other Professional Activities

P.M.B. Vitányi:

- Professor of Computer Science, Universiteit van Amsterdam.
- Guest Editor, *J. Computer and System Sciences*, special issue on Computational Learning Theory, 1994–1998.
- Editor *Distributed Computing*, Springer-Verlag, since 1987.
- Editor, *Theory of Computing Systems* (Formerly: *Mathematical Systems Theory*), Springer Verlags, since 1991.
- Editor, *Information Processing Letters*, North-Holland/Elsevier, since 1993/94.
- Editor, *Parallel Processing Letters*, World Scientific Publishers, Singapore, since 1991.
- Editor, *Journal of New Generation Computer Systems*, Akademie-Verlag, Berlin, since 1989.
- Editor, *Frontiers in Computing Systems Research*, Plenum Annual Review Book Series, Plenum Press, since 1988;
- Member of the IFIP Special Interest Working Group on 'Descriptional Complexity' now IFIP WG 1.2, and cochair of IFIP Special Interest Working Group on 'Computational Machine Learning' IFIP WG 1.4.
- Member of the Scientific Board, *Encyclopaedia of Mathematics*, Reidel (updated and annotated translation of the Soviet *Mathematical Encyclopaedia*) since 1987.
- Program Committee, *Ninth International Conference on Intelligent Systems: Artificial Intelligence Applications for the New Millennium*, June 14–17, 2000. The Galt House Hotel Louisville, KY USA.
- Program Committee, *IFIP International Conference on Theoretical Computer Science* (IFIP TCS2000) – Exploring New Frontiers of Theoretical Informatics – August 17–19, 2000, Tohoku University, Sendai, Japan.
- Organizing/Program Committee *Workshop on Complexity and Inference for the Computational Information Theory and Coding Year* (2001-2002) at DIMACS at Rutgers University.
- Program Committee GECCO-99, *Genetic and Evolutionary Computation Conference*, July 14–17, 1999, Orlando, Florida USA, a joint meeting of the *Eighth International Conference on Genetic Algorithms* (ICGA-99) and the *Fourth Annual Genetic Programming Conference* (GP-99).
- Program Committee *ICML-99, the 16th International Machine Learning conference*, Slowakia, 1999.
- Program Committee, *6th bi-annual Workshop on Algorithms and Data Structures*, WADS'99, Vancouver, Canada, 1999.
- Program Committee, *6th International Colloquium on Structural Information and Communication Complexity* (SIROCCO'99), 1999.
- Amsterdam Site Manager of ESPRIT BRA VI NeuroCOLT II Working Group EP 27150: on Fundamental Understanding of Learning and Algorithmic Implementations.

- Member IFIP WG 1.2 on Descriptive Complexity and Applications, since 1991; co-chair of IFIP WG 1.4 on Computational Machine Learning, since 1992.
- Publiciteits commissie van het Wiskundig Genootschap (Publicity Committee Dutch Mathematical Society), since 1989.
- PhD Supervisor of B. Terhal, H.H. Ehrenburg, W. van Dam, R. de Wolf, H. Röhrig, University of Amsterdam. (Terhal received the PhD in 1999.)
- Advisor Monash Key Centre for Computational Data Analysis, Monash University, Clayton Campus, Melbourne, Australia.
- Advisor and evaluator for/of the Japanese Discovery Science Project. The Discovery Science is a three year project from 1998 through 2000 that targets to (1) develop new methods for knowledge discovery, (2) install network environments for knowledge discovery, and (3) establish the Discovery Science as a new area of Computer Science. A systematic research is planned that ranges over philosophy, logic, reasoning, computational learning and system developments.
- Member of the Dutch Robosoccer committee Autonomous Interacting Multiagent Soccer.
- Committee member of the Society for Theoretical Computer Science in the Netherlands (Nederlandse Vereniging voor Theoretische Informatica (NVTI)).
- Dutch Institute for Logic, Language, and Computation (ILLC) (member of the board).
- Dutch Institute for Programming and Algorithmics (IPA) (member).
- Onderzoekschool Logica (OzL) (member).
- Project leader various SION projects in Machine Learning, Multiple Computing Agents, Cryptography and Randomness, Quantum Computing.

A.E. Brouwer:

- Promotor (PhD Advisor) of Rieuwert Blok.
- Member of PhD committees of Ed Voermans, M. Boguslawsky, Petra Heijnen, Stefan Brands, Barbara Terhal.
- Editor of *European J. Combinatorics*.
- Editor of *J. Algebraic Combinatorics*.

H.M. Buhrman:

- Member of the Steering Committee for the Annual Conference on Computational Complexity, since 1998.
- Member of Program committee of AQIP'99.
- Member of Program committee of ICALP'2000.
- Member of Program Committee of MFCS'2001.

P.D. Grünwald:

- ESPRIT BRA VI NeuroCOLT II Working Group EP 27150: on Fundamental Understanding of Learning and Algorithmic Implementations (member).
- The Dutch 'computer science research schools' IPA (Instituut voor Programmatuur en Apparatuur) and OzsL (Onderzoekschool voor Logica); member.

L. Torenvliet: Member of the Board of the NVTI–Dutch Society for Theorical Computer Science.

Books

M. Li, P.M.B. Vitányi (1999). *Description Complexity*, Chinese Science Press, (in Chinese).

Awards

H.M. Buhrman:

- NWO project: Extending Feasible Computing: Quantum Computing. Grant for 1 PhD student and 1 Postdoc for 4 years.
- EU fifth framework project Quantum Algorithms and Information Processing. Coordination and application of the project. The project involves 13 sites in Europe and North America. Budget: 850K Euro.

B.M. Terhal:

- Promotie 'Cum Laude', Fac WINS, Natuurkunde, Universiteit van Amsterdam.
- NWO Talent Award (Fellowship)
- IBM Postdoc Fellowship.

P.M.B. Vitányi:

- First Prize, National Excellence in Science and Technology Books, Peoples Republic of China. (Book awarded: M. Li, P.M.B. Vitányi, *Description Complexity*, China Science Press, 1998/1999 (in Chinese).)

P.D. Grünwald:

- 1999 FoLLI Prize for Outstanding Dissertations in Logic, Language and Computation.

W. van Dam:

- The Wolfson College (University of Oxford) Graduate Award.
- NWO-TALENT Award to continue his research during the academic year 2000/01 at the University of California, Berkeley.

PhD Theses

B.M. Terhal (1999). *Quantum Algorithms and Quantum Entanglement*, University of Amsterdam. (Advisor: P. Vitányi; Co-advisor B. Nienhuis)

Visitors

- November 2–3, Dr. C.H. Bennett, IBM T.J. Watson Research Center, Yorktown Heights, USA.
- June 21–30, Dr. P.B. Miltersen, Computer Science Department, University of Aarhus, and BRICS, Aarhus, Denmark.
- March 10–30, Prof. L. Fortnow, Computer Science Department, University of Chicago, Chicago, USA.
- June 2–10, Dr. L.K. Grover, AT&T–Lucent Technologies, Murray Hill Research Center, New Jersey, USA.
- June 27–July 5, Dr. S. Laplante, Computer Science Department, University of Paris VII, Paris, France.
- June 4–14, Prof. A. Panconesi, Computer Science Department, University of Bologna, Bologna, Italy.
- September 10–20, Prof. C. Smith, Computer Science Department, University of Maryland, College Park, MD, USA.

Papers in Journals and Proceedings

A. Blokhuis, A.E. Brouwer (1999). The universal embedding dimension of the near polygon on the 1-factors of a complete graph. *Designs, Codes and Cryptography* **17**, 299–303.

A. Blokhuis, S. Ball, A.E. Brouwer, L. Storme, T. Szényi (1999). On the number of slopes of the graph of a function defined on a finite field. *JCT* (A) **86**, 187–196.

A.E. Brouwer, J.H. Koolen (1999). The distance-regular graphs of valency four. *J. Alg. Combin.*, 5–24.

A.E. Brouwer, R.M. Wilson, Qing Xiang (1999). Cyclotomy and Strongly Regular Graphs. *J. Alg. Combin.* **10**, 25–28.

A.E. Brouwer (1999). An associative block design $ABD(8,5)$. *SIAM J. Comput.* **28**, 1970–1971.

A.E. Brouwer, R. Pellikaan, E.R. Verheul (1999). Doing more with fewer bits. *Proc. Conf. Efficient Cryptographic Protocols.*

H. Buhrman, R. Cleve, R. de Wolf, C. Zalka (1999). Bounds for Small-Error and Zero-Error Quantum Algorithms. *Proceedings of the 40th Annual Symposium on Foundations of Computer Science (FOCS'99).*

H. Buhrman, W. van Dam (1999). Quantum Bounded Query Complexity. *Proceedings of the 14th Annual IEEE Conference on Computational Complexity (CCC99)*, IEEE Computer Society, 149–157.

H. Buhrman, R. de Wolf (1999). A Lower Bound for Quantum Search of an Ordered List. *Information Processing Letters.*

H. Buhrman, S. Fenner, L. Fortnow, D. van Melkebeek (1999). Optimal Proof Systems and Sparse Sets. *Proceedings* 17^{th} *Symposium on Theoretical Aspects of Computer Science (STACS2000).*

H. Buhrman, L. Torenvliet (1999). Complicated Complementations. *Proceedings of the 14th Annual IEEE Conference on Computational Complexity (CCC99)*, IEEE Computer Society, May 4–6, 227–236.

H. Buhrman, L. Fortnow (1999). Two Queries. *Journal of Computer and System Sciences*, (special issue for the 13^{th} annual conference on Structural Complexity Theory).

H. Buhrman, T. Jiang, M. Li, P. Vitányi (1999). New applications of the incompressibility method. *Proceedings of the International Colloquium on Automata, Languages, and Programming (ICALP99).*

H. Buhrman, L. Fortnow (1999). One-sided Versus Two-sided Randomness. *Proceedings* 16^{th} *Symposium on Theoretical Aspects of Computer Science (STACS99).*

P. Grünwald (1999). Viewing all models as 'Probabilistic'. *Proceedings of the Twelfth Annual Conference on Computational Learning Theory (COLT' 99)*, Santa Cruz, CA, USA.

C.H. Bennett, D.P. DiVincenzo, T. Mor, P.W. Shor, J.A. Smolin, B.M. Terhal (1999). Unextendible product bases and bound entanglement. *Phys. Rev. Lett.* **82**, 5385.

B.M. Terhal, I.L. Chuang, D.P. DiVincenzo, M. Grassl, J.A. Smolin (1999). Simulating quantum operations with mixed environments. *Phys. Rev. A.* **60**, 881.

H. Buhrman, J. Garay, M. Franklin, J. Hoepman, J. Tromp, P. Vitányi (1999). Mutual Search. *J. Assoc. Comp. Mach.* **46**(4), 517–536.

P.M.B. Vitányi (1999). The Erdős graph and the Beast. *Mathematical Intelligencer* **21**(3), 54–55.

T. Jiang, M. Li, P. Vitányi (1999). New applications of the incompressibility method. *The Computer Journal* **42**(4), 287–293.

H. Buhrman, J.H. Hoepman, P.M.B. Vitányi (1999). Space-efficient routing tables for almost all networks and the incompressibility method. *SIAM J. Comput.* **28**(4), 1414–1432.

H. Buhrman, Tao Jiang, Ming Li, Paul Vitányi (1999). New applications of the incompressibility method. *Proceedings ICALP99*, LNCS **1644**, Springer-Verlag, Berlin, Germany, 220–229.

Tao Jiang, Ming Li, Paul Vitányi (1999). Average complexity of Shellsort. *Proc. ICALP99*, LNCS **1644**, Springer-Verlag, Berlin, Germany, 453–462.

Tao Jiang, Ming Li, Paul Vitányi (1999). The expected size of Heilbronn's triangles. *Proc. 14th IEEE Conference on Computational Complexity*, 105–113.

T. Jiang, M. Li, P. Vitányi (1999). Some examples of average-case analysis by the incompressibility method. J. Karhumaki, H. Maurer, G. Paun, G. Rozenberg (eds.). *Jewels are Forever: Contributions on Theoretical Computer Science in Honor of Arto Salomaa*, Springer-Verlag, Berlin, Germany, 250–261.

R. Cleve, W. van Dam, M. Nielsen, A. Tapp (1999). Quantum entanglement and the communication complexity of the inner product function. C.P. Williams (ed.). *Proceedings of the First NASA International Conference on Quantum Computing and Quantum Communications,* LNCS, Volume **1509**, Springer-Verlag, Berlin, Germany, 61–74.

L. Hardy, W. van Dam (1999). Quantum communication using a nonlocal Zeno effect. *Physical Review A* **59**(4), 2635–2640.

H. Buhrman, W. van Dam, P. Høyer, A. Tapp (1999). Multiparty Quantum Communication Complexity. *Physical Review A* **60**(4), 2737–2741.

H. Buhrman, R. Cleve, R. de Wolf, Ch. Zalka (1999). Bounds for small-error and zero-error quantum algorithms. *Proceedings of 40th FOCS*, 358–368. Preprint cs.CC/9904019 on http://xxx.lanl.gov.

H. Buhrman, R. de Wolf (1999). A lower bound for quantum search of an ordered list. *Information Processing Letters* **70**(5), 205–209.

V. Halava, M. Hirvensalo, R. de Wolf (1999). Decidability and undecidability of marked PCP. *Proceedings of 16th Annual Symposium on Theoretical Aspects of Computer Science (STACS'99)* **1563**, LNCS, Springer-Verlag, Berlin, Germany, 210–219. Also available as TUCS Technical Report No.201. Final version to appear in *Theoretical Computer Science A*.

CWI Reports

The following CWI reports were published by members of theme INS4. See page 83 for the complete titles of the reports.

INS-R9909

Other Publications

A.E. Brouwer (1999). Maintains a (frequently cited) database of the best linear codes known today (with email and www interface).

Together with D. Deutsch (University of Oxford), *Van Dam* edited and converted the 1985 article by David Deutsch 'Quantum theory, the Church-Turing principle and the universal quantum computer' into LaTeX-format. This made this historic paper available available to a much wider group of researchers than was previously the case.

APPENDIX
SURVEY OF FTP DOWNLOADS OF CWI REPORTS

Annual downloads

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